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GEOLOGICAL SURVEY OF CANADA
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Edited by
S. Safaie, S. Johnstone, and N.L. Hastings

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RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

June 2022

DRRPathways.ca

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SAGE ON EARTH CONSULTING
UNDERSTANDING RISK AND RESILIENT SOLUTIONS

Editorial + Design uncover

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Published on the unceded, ancestral, and traditional homelands of the xʷməθkʷəy̓əm (Musqueam), Sḵwx̱wú7mesh (Squamish) and səlilwətaɬ (Tsleil-Waututh) Nations, who continue to live on and steward it today.

June 2022

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Forest path: unsplash/James Wheeler

RESILIENCE PATHWAYS

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ABOUT THE RESILIENCE PATHWAYS REPORT

BUILDING A RESILIENT FUTURE FOR BC

This first edition of the Resilience Pathways Report (2022) seeks to better understand disaster and climate risk interactions with socioeconomic development in BC and to identify gaps, challenges, and recommendations for the way forward.

The Resilience Pathways Report is aligned with the Sendai Framework for Disaster Risk Reduction 2015–2030's systemic approach to risk management, with emphasis on the whole of society and collaborations among all actors. More than 70 experts from a wide range of institutions and disciplines have contributed. The articles herein cover a diverse set of topics, organized to allow for comparing and digesting information across hazards, sectors, and risk management issues, and include both findings and recommendations.

Those interested in this report will include practitioners, researchers, policy makers, and decision makers in various fields, who can and are taking action for reducing disaster risk and adapting to climate change impacts in public and private sectors. Considering that the BC Emergency Program Act (EPA, 1996) modernization process is ongoing, we hope that the findings and recommendations of the Resilience Pathways Report will serve as a timely contribution to the new Act and the policies and programs designed for implementation.

The success and value of this report comes from sharing knowledge effectively with a broad audience as well as addressing how we change the approach to disaster and climate risk management from "business as usual" to collaborative and responsive, which will help us build a resilient future for BC.

Resilience Pathways was initiated through the Canadian Safety and Security Program–funded Disaster Risk Reduction Pathways Project, led by Natural Resources Canada. Sage On Earth Consulting designed the initiative and supported the authors throughout the process, including with technical review of the articles. Uncover Editorial and Design undertook editing and design of the report.

The full report, and individual articles, are available at DRRPathways.ca/Report and at www.geoscan.nrcan.gc.ca.

CONTINUING THIS INITIATIVE

This initiative, as a bi-annual endeavour, provides an up-to-date strategic resource on the current issues that need attention from risk management actors and decision makers. It will be an effective mechanism to monitor and evaluate progress over time in implementation of the *Sendai Framework*, Modernized EPA, and *BC Climate Preparedness and Adaptation Strategy*.

The continuation and sustainability of this initiative requires funding, a dedicated editorial team, and leadership support from a provincial or federal governmental or strong non-governmental entity. The editorial team welcomes expressions of interest from any governmental or non-governmental entities interested in hosting the next edition.

PREFACE

The creation of this *Resilience Pathways Report* has convened and connected more than 70 experts to explore the interactions of disaster and climate risk on socioeconomic development in British Columbia. Knowledge and insights from this compilation have direct linkages to national disaster risk reduction and climate change frameworks. The report provides a platform for experts to share their strategic insights on risks, vulnerabilities, capabilities, and opportunities to design pathways to a resilient future.

The strategy and process used to develop the *Resilience Pathways Report* was inspired by and aligned with the Sendai Framework's systemic approach to risk management, including an emphasis on the whole of society's roles and collaborations among all actors. While many of the findings and recommendations have national relevance, the design and development process of the report can be tailored for use in other provinces.

The frequency and costs of disasters have been escalating in BC and across Canada. These continue to increase as the population grows and the climate changes. In addition, experiences from the COVID-19 pandemic, recent wildfires, floods, and the 2021 heatwave have made evident the complexity of disasters and their cascading impacts across the built environment, social systems, and the natural environment. We are also reminded that disasters have disproportionate impacts on the most vulnerable and further exacerbate the existing and systemic inequalities in our society.

There is an urgency to take action to better manage the disaster and climate risks. The report highlights successes, challenges, and gaps and provides recommendations for strategic and proactive approaches to mitigate and adapt to natural hazard risks that take into account the impacts from climate change and the drivers of risk. Many of the recommendations and actions in the report could also be evaluated as options for other areas across the country. The report demonstrates the importance of engaging and empowering actors in all sectors.

This initiative led by NRCan, with support from Defence Research and Development Canada's Canadian Safety and Security Program, points the way toward a more resilient province and country. With the whole-of-society approach, the audience for the report includes practitioners, researchers, policy makers, and decision makers in disaster risk reduction and climate change adaptation. On behalf of NRCan, I commend the editors, authors, and contributors for this informative report.

SONIA TALWAR

Director, Geological Survey of Canada (Pacific)
Natural Resources Canada

Photo: unsplash/James Wheeler

STRATEGIC SUMMARY FOR POLICY MAKERS

June 2022

DRRPathways.ca

RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

STRATEGIC SUMMARY FOR POLICY MAKERS

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THE CONTEXT

URGENT NEED FOR ACTION

In 2015, countries around the globe came together to endorse several major global agreements: the Sustainable Development Goals (SDG2030), the *Paris Agreement* for climate change, and the *Sendai Framework for Disaster Risk Reduction (2015–2030)*.[1] These agreements specifically recognize *resilience* as the unique opportunity to enhance coherence across policies, plans, institutions, goals, indicators, and monitoring systems to move towards a unified objective of ending poverty, protecting the environment, and ensuring that all people enjoy peace and prosperity.

The 2021 heat dome, wildfires, and damaging floods in BC have had devastating impacts and are serious warning signals of the negative impacts of climate change. These events further underscore the reality that there will be more events in the future that exceed historical events with greater magnitude, increased frequency, new locations, different timing, and new complexity. The experience of COVID-19 pandemic impacts and responses has taught us firsthand how disasters are complex events with intertwined and cascading impacts across systems in our society. In the Sixth Assessment Report of Working Group I, the Intergovernmental Panel on Climate Change (IPCC) established that global warming will reach or exceed 1.5°C by the early 2030s—much earlier than previously projected. This makes accelerating action to address climate risks even more urgent.

We must manage risks from natural, biological, and technological hazards, and from climate change, in a comprehensive and collaborative manner across all sectors and at all levels to mitigate disaster risk. Success in this endeavor requires the whole of society to first understand the risks, including the drivers and interdependencies across society, and know their role in collaboratively managing these risks.

THE VALUE OF THE RESILIENCE PATHWAYS REPORT

In 2018, the Province of British Columbia was the first province in Canada to adopt the Sendai Framework. The Province, under the leadership of Emergency Management BC (EMBC), is in the process of modernizing the *Emergency Program Act* (EPA). This process is paying strong attention to the key components and guiding principles[2] of the Sendai Framework, especially as they relate to the shift to disaster risk reduction (DRR) as a holistic approach to manage risk with the goal of preventing new and reducing existing disaster risk and increasing preparedness for response and recovery. In early 2021, BC Ministry of Environment (MoE) released the draft *Climate Preparedness and Adaptation Strategy* and released the Actions for 2022–2025 in June 2022. The Resilience Pathways Report provides findings and recommendations

BOX A: REQUIREMENTS FOR DISASTER (AND CLIMATE) RISK MANAGEMENT BASED ON SENDAI FRAMEWORK GUIDANCE

The Sendai Framework is a very comprehensive document that was developed based on decades of lessons learned from successful and failed policies and projects in disaster risk management across the globe. Below are the key enablers for success in disaster (and climate) risk reduction outlined in the Sendai Framework (Figure 1).

- Legislative or regulatory frameworks that are used to mainstream and integrate disaster risk reduction within and across all sectors.
- Governance mechanisms that are transparent and inclusive for effective and efficient management of disaster risk
- Policy coherence and compliance, notably with the Sustainable Development Goals (SDGs) and the Paris Agreement, between national and local levels.
- Public and private sectors guided with defined roles and responsibilities for the whole of society.
- Clear time frames, targets, and indicators.
- Comprehensive assessment of disaster risk from all hazards.
- Evaluation of technical, financial, and administrative disaster risk management capacity at the local and national levels, used to inform DRR measures.
- Explicit objectives and measures aimed at preventing the creation of risk, reducing existing risk, and strengthening economic, social, health, and environmental resilience.
- Sufficient and stable financial resources dedicated to DRR.
- Mechanisms that build technical and institutional capacities of the actors to be able to implement measures.
- Strengthened mechanisms to follow up with and periodically assess and publicly report on progress.

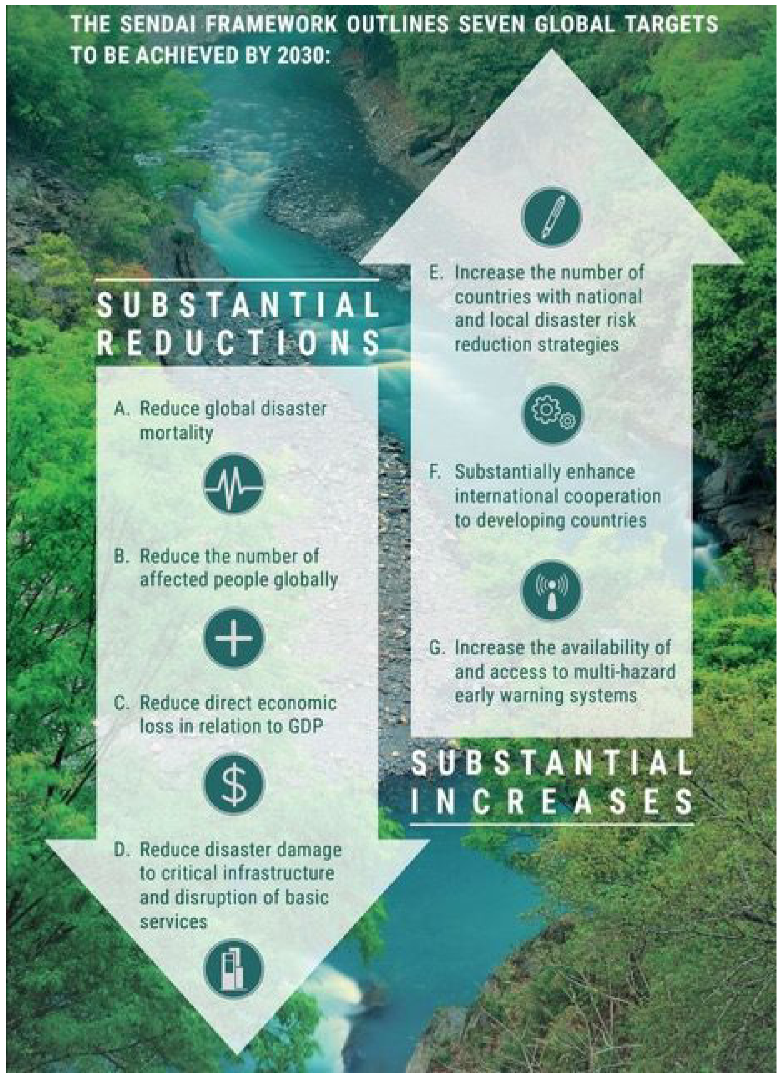

Figure 1: Sendai Framework's Seven Global Targets (Graphic: UNDRR).

that have the potential to influence the policies and programs that will be designed in the near future to implement the Modernized EPA and *Climate Preparedness and Adaptation Strategy*.

The long-term vision for the Resilience Pathways process is to biannually reassess climate-related issues and opportunities and to serve as a strategic resource for decision makers. In addition, this process and ensuing reports offer a mechanism with which to monitor and evaluate progress on implementation of the Sendai Framework, the Modernized EPA, and the *Climate Preparedness and Adaptation Strategy*.

AN OVERVIEW OF HAZARD THREATS AND GROWING RISKS IN BC

BC is exposed to a range of hazards including wildfires, earthquakes, floods, landslides, avalanches, droughts, extreme weather, volcanoes, biological threats, industrial or chemical spills, and cyber-attacks. The population is rapidly growing along with the physical assets that support the lives and economy of BC residents. Disaster risk will transform over time in relation to population growth, land-use change, new construction, building code improvements, and changing social vulnerabilities. Overall risk may increase or decrease, some types of losses may become more prominent, and the location of risk "hot spots" may shift. Development strategies (e.g., compact or sprawled development) used to accommodate the growth can affect how hazard impacts manifest. It is critical to employ long-term measurable targets for risk mitigation efforts and integrate risk management into development strategies, thereby ensuring that disaster and climate risk created from development is not outpacing our capacity to reduce risk and respond to residual risk. In defining the resilience path forward, it is a fundamental necessity to understand the drivers of threat from all hazards, learn the lessons from past inappropriate development, integrate Indigenous Knowledge, and define tolerable levels of risk in regional planning.

PEOPLE

BC, with 9,950 km^2 of land, encompasses ~8% of the total developed area of Canada and is home to more than 5.1 million people, or approximately 13% of the national population. There are ~269,000 Indigenous people living in BC of First Nations, Métis, and Inuit origin. There are 198 distinct First Nations in BC, each with their own unique traditions and history. Most Indigenous people (60%) live in cities, towns, and villages throughout the province, with the remaining living on designated First Nations reserve lands.[3] BC's densely settled metropolitan regions are home to 88% of the province's total population and cover about 48% of BC's land area; 11% lives in rural and remote settings (Figure 2a).

Disasters can have many social impacts, including displacement, disrupted social cohesion, decreased mental health, domestic violence, and disrupted child and youth education and socialization. The social and cultural impacts of disasters are generally not tracked well, poorly understood, and not effectively managed.

> It is critical to employ long-term measurable targets for risk mitigation efforts and integrate risk management into development strategies, thereby ensuring that disaster and climate risk created from development is not outpacing our capacity to reduce risk and respond to residual risk.

The most vulnerable people are disproportionately affected by disasters and climate change impacts, and certain social groups are particularly vulnerable to crises: female-headed households, children, persons with disabilities, displaced persons, sexual and gender minorities, those in poverty, those experiencing racial or social inequality or who are impacted by colonialism and systemic racism, and older people are often affected more strongly by the impacts of events.

The existing social inequities in BC are exacerbated by the impacts of disaster and climate change. The root causes of social vulnerability lie in a combination of geographical location, income level, cultural and social status, gender, access to services, personal agency, and justice.[4] As of 2018, one in nine people[5] in Canada live in poverty. Low-income populations often live in low-cost, vulnerable buildings, and in both urban and rural regions they have fewer resources to allow them to adjust to changing climatic conditions or cope with extreme events.

BUILT ENVIRONMENT

There are ~1.2 million buildings in BC, with an estimated replacement cost of $1.42 trillion.[i] Nearly three quarters of all buildings (74%) are single-family urban and rural residential homes where ~45% of the population lives (2.1 million people). The rest live in multi-storey buildings in higher-density multi-family residential and mixed-use neighbourhoods. Non-residential buildings account for ~41% of the total capital asset value ($587 billion), followed by multi-family buildings (30%; $426 billion) and single-family homes (28%; $404 billion).

Today, the BC Building Code, which is based on the National Building Code of Canada, has provisions for earthquakes but is largely silent on flood and wildfire resistance and resilience measures. Moreover, when it comes to seismic resilience, an overwhelming majority of structures in the existing building stock were designed and constructed using building codes with low levels of seismic provision. For example, in Vancouver, over half of the 90,000 buildings were built prior to 1974 and have no or little seismic resistance, leaving residents and workers vulnerable to disruption, displacement, injury, or loss of life.

People and businesses rely on critical infrastructure (CI) assets and services, such as transportation networks, clean water, sanitation, power, recreation facilities, a vast array of local and provincial services, and far more. There are ten CI sectors as defined by the Government of Canada: energy and utilities, finance, food, transportation, government, information and communication technology, health, water, safety, and manufacturing.[6] Infrastructure demand has outpaced investments for several decades and population growth in the near future will put significant pressure on all CI systems, especially the transportation and trade corridors.[7] Many CI systems are aging and vulnerable to various hazards, especially with the changes in intensities and frequencies of climate hazards. Damage and disruption to CI can have significant health, economic, and social impacts on society.

HOT SPOTS

Areas of considerable, high, and extreme multi-hazard threats across the province (where assets are exposed to damaging hazard events) are presented in Figure 2b. Hotspot areas with a potential for significant levels of damage and socioeconomic disruption are concentrated in the Lower Mainland and Vancouver Island regions and collectively affect more than 90% of the total population (~3.6 million people). Profiles of hazard threat are influenced primarily by potentially catastrophic earthquake and related tsunami events along the active plate margin of western North America, and by the combined effects of flood, landslide, and wildfire events that occur on a more regular basis along river valleys and major transportation corridors throughout BC.

PAST DISASTER TRENDS IN CANADA AND BC

Disasters, especially hydrometeorological events, have been increasing in frequency and cost across Canada and in BC (Figure 3). Since 1970, the Government of Canada has paid out an estimated $8.5 billion dollars in post-disaster assistance through the federal Disaster Financial Assistance Arrangements (DFAA) to assist provinces and territories with response and recovery costs. Of these costs, 97% occurred in the past 25 years, and more than one-third occurred in the past six years alone, which indicates that disasters are increasing in both frequency and cost.

This is mostly due to the growth of population. Canada's population has grown by 80% since 1970 and many of the assets are built on floodplains.

[i] *All values in Canadian dollars.*

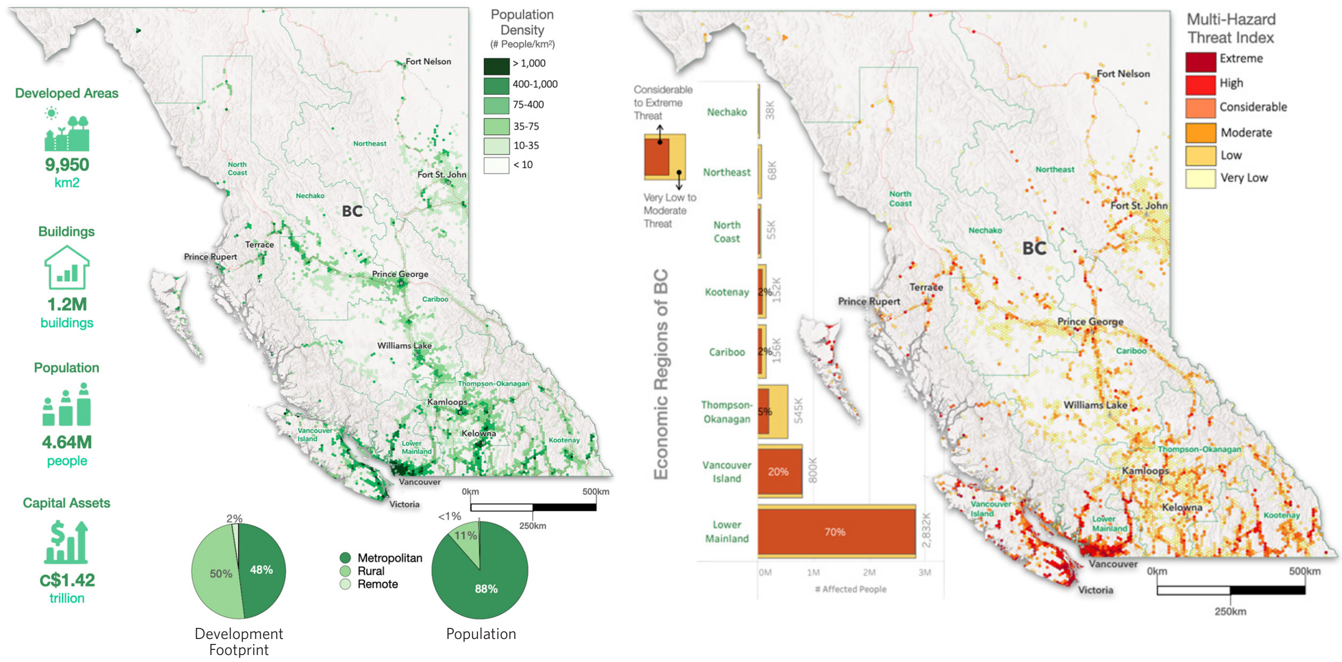

Figure 2: (2.a) Patterns of human settlement; (2.b) regional profiles of physical exposure in BC (Graphic: Murray Journeay).

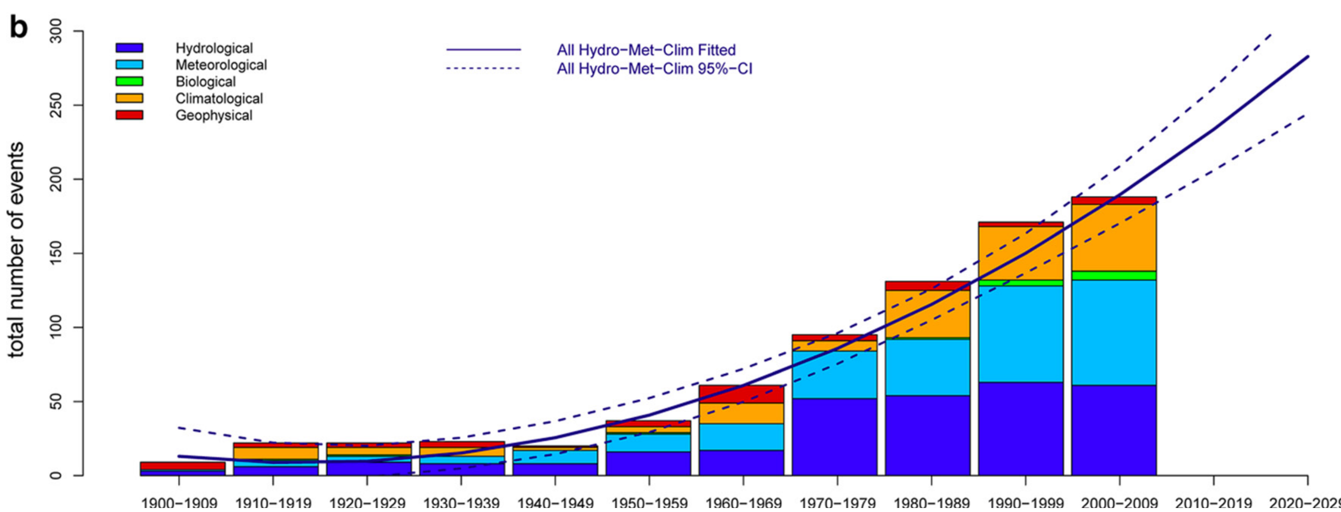

Figure 3: Natural hazard frequency by decade and hazard subgroup in Canada, 1900–2030 (Graphic: Matt Godsoe et al.).[8]

The increase can also be attributed to climate change to some extent. Floods now account for nearly 75% of DFAA events and two-thirds of all DFAA payments. A significant portion of disaster events and losses occur in BC; based on the Canada Disaster Database records of events from 1900 to 2016, 15.8% of the disasters occurred in BC, with 18.7% of fatalities.

An assessment conducted by Natural Resources Canada[9] analysed past trends of population growth and corresponding growth of the exposure to various hazards in BC.[ii] The study looked at population growth in areas that are likely to experience damaging hazard events. The results (Figure 4) show that profiles of flood and tsunami hazard threat in BC have increased at rates of 71% and 73% respectively over a forty-year period and are comparable but lower than overall trends in population growth (76%). Wildfire and landslide hazards have increased at much lower rates (42%–61%, respectively), although approximately 45% of the dwellings in BC are located within 2 km of potentially flammable wildland fuel (this is similar to estimates in Washington and Oregon). Exposure of assets associated with catastrophic earthquake hazards have increased by more than 90% over this same period.

Lower rates of growth for wildfire and landslide hazard threats may be related to the higher growth rates in metropolitan areas. More rapid rates of growth for earthquake threats are attributed to a corresponding increase in the numbers of people moving into densely populated urban centres that are situated in areas exposed to more severe ground shaking hazards. It is anticipated that these trends will likely continue but at slower rates of growth over the next forty years.

FUTURE DISASTER TRENDS IN BC

Climate modelling indicates that climate change will bring extreme temperatures, severe storms, rising sea levels, heavy precipitation, landslides, floods, droughts, wildfires, and other climate-related challenges. The Province completed a *Preliminary Strategic Climate Risk Assessment for British Columbia* in 2019, which evaluated the likelihood of 15 climate risk events that could occur in BC along with their health, social, economic, and environmental consequences. The key findings include:

- The greatest risks to BC are a severe wildfire season, seasonal water shortage, heat waves, ocean acidification, glacier loss, and long-term water shortage.
- Severe riverine floods and severe coastal storm surge risk events

[ii] The study is not a risk assessment; it does not incorporate vulnerabilities nor the probability of hazards. The study geospatially overlays the population or building assets data on hazard intensity information.

Epoch	1975	1990	2000	2015	40-year Growth Rate
Total Population	2,660,621	3,368,910	3,865,314	4,687,192	76%
Earthquake	1,775,932	2,324,388	2,715,764	3,380,124	90%
Tsunami	172,401	217,032	247,168	298,855	73%
Flood	179,464	225,559	256,877	306,406	71%
Wildfire	144,279	170,302	184,108	204,480	42%
Landslide	310,982	382,690	429,410	499,340	61%

Total Population · Earthquake · Tsunami · Flood · Wildfire · Landslide

Figure 4: Correlations between past growth and development over a forty-year period (1975–2015) and corresponding profiles of natural hazard threat in BC (Graphic: Murray Journeay).

Figure 5: Climate projections and impacts in BC for 2050 (Graphic: BC Ministry of Environment).[10]

would have among the highest overall consequences, but their relatively low likelihood reduces their overall risk relative to other events.

- Nearly every risk event scenario would have major province-wide consequences in at least one category.
- The majority of risk events would have "catastrophic" economic consequences.

Figure 5 above outlines climate projections and impacts in BC produced as part of BC's draft *Climate Preparedness and Adaptation Strategy*, which builds on the 2019 climate risk assessment.

BC's population is expected to increase from a total of 5.1 million in 2020 to 6.5 million in 2041 at an average growth rate of 1.4% per year.[11] Past population growth trends (1975–2015) show that the population has nearly doubled in metropolitan regions while growth in rural and remote settlements has increased by a factor of only ~1.3 over this same period of time.[12] As it turns out, many of these larger metropolitan regions are situated in areas that are exposed to significant levels of natural hazard threat along the river basins and coastal zone.

The profile of the population is also changing. As BC's population continues to age, the relative proportion of senior population (age 65 and older) will increase from 19% in 2020 to 25% in 2041. New immigrants are also part of the population growth.

The result of climate change impacts combined with the growth of population and physical assets (buildings and infrastructure) is a substantial increase in disaster and climate risk, unless forward-looking measures are applied—especially related to land-use decisions for where the new assets will be placed.

The result of climate change impacts combined with the growth of population and physical assets (buildings and infrastructure) is a substantial increase in disaster and climate risk, unless forward-looking measures are applied—especially related to land-use decisions for where the new assets will be placed.

POLICY RECOMMENDATIONS

The evaluative approach used in the Resilience Pathways Report is using resilience as the ultimate goal of all actors' efforts. Resilience is defined in the Sendai Framework terminology as "The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform, and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management."[13]

The findings and recommendations that have emerged from the articles of the Resilience Pathways Report 2022 are presented here. The key findings and recommendations are grouped under the four priorities for action of the Sendai Framework for DRR. There are also five overarching themes identified that are applicable to all four priorities for action of the Sendai Framework. To write this section, the authors have drawn on additional research and sources, including conversations with several thought leaders in the field of disaster and climate risk management in BC and Canada. It is important to recognize the significant amount of effort and investment in disaster and climate resilience by all levels of government and non-governmental actors in recent years. The recommendations here are meant to build on the existing mechanisms and use lessons, experiences, and expertise to enhance and scale disaster and climate risk management in BC.

OVERARCHING THEMES: RE-IMAGINE DISASTER AND CLIMATE RISK MANAGEMENT

These five themes are a call to re-imagine the institutional mechanisms, approaches, and processes for protecting what we value for a prosperous life for all people in BC.

THEME 1: Develop strategies that outline the imagined future and are accompanied by action plans with measurable targets, timelines, and accountability.

An important common recommendation, outlined in many of the articles, is the need for developing strategies. In particular, strategies would be useful for: managing different risks at the provincial level; supporting resilience at the local level by embedding it in local development plans and mainstreaming resilience across local government departments; and the many other components of risk management that require a multi-hazard approach, such as community resilience, risk data management, multi-hazard early warning systems, critical infrastructure resilience, etc. Strategies need to provide a clear picture of the goal with mid- to long-term targets that are measurable and supported by mechanisms for tracking. They should be accompanied by action plans that layout timelines, budgets requirements (approved and unmet needs), and accountability for implementation.

It is critical to define measurable targets for risk reduction and resilience based on what we value and our risk tolerance for protecting them. Without targets

BOX B: EXAMPLES OF INDICATORS FOR MEASURING PROGRESS ON ADAPTATION AND CLIMATE RESILIENCE[14]

Protecting and Improving Human Health and Wellbeing

- Percentage of Canadians living on low incomes in climate hazard areas
- Number of culturally appropriate public awareness and education campaigns to promote personal protection from climate change health effects

Supporting Particularly Vulnerable Regions

- Percentage of people in northern, remote, and coastal communities whose access to the land, including country foods and traditional ways of life, is impacted by slow-onset events

Reducing Climate-Related Hazards and Disaster Risks

- Percentage or number of culturally and locally relevant emergency response warning systems focusing on high-risk vulnerable populations

Building Climate Resilience through Infrastructure

- Number of codes and standards reviewed, updated, and developed across the full breadth of climate hazard types and asset types at risk, including Indigenous-specific building programs
- Percentage of total government infrastructure spending directed to building resilience towards locally identified high-priority climate risks (as identified by community climate vulnerability assessments)
- Number of infrastructure owners and operators that have integrated climate resilience into their planning, infrastructure investments, operations, and strategy

Translating Scientific Information and Indigenous Knowledge into Action

- Number of community-based climate-related monitoring and adaptation programs that include Indigenous, local, and scientific knowledge
- Extent of each province and territory covered by adaptation plans incorporating climate risk assessments, designed to be updated every five years

and indicators to monitor progress in implementation, the strategies will remain as conceptual documents. See Box B for few examples of indicators recommended to the government of Canada in 2018 by an expert panel for measuring progress in climate change adaptation and resilience.[15] More work is needed to develop risk-based indicators and use risk models and data for progress in risk reduction.

THEME 2: Shift from reactive to proactive governance and financing.

The current governance mechanism and budgeting for disaster risk management in all hazards is built on emergency response and recovery approaches of the past. As a result, the design of policies, funding, and programs are mostly reactive—including to the most recent disaster events in BC. A more strategic and proactive approach would apply our understanding of hazards and risks alongside climate change impacts, sources and drivers of vulnerabilities, priority objectives, and long-term goals for safety and prosperity. The current and ongoing process of the EPA Modernization, the National Adaptation Strategy,[16] and BC's *Climate Preparedness and Adaptation Strategy*, along with the political and social momentum for managing the climate crisis, triggered by catastrophes in BC in 2021, provide excellent opportunities to shift from reactive to anticipatory governance and financing for reducing disaster and climate risk.

THEME 3: Embrace Indigenous Knowledge and practices because they contain the true principles of sustainability and resilience for everyone.

The decisions of the past have shaped today's realities and the decisions of today are shaping the future. To effectively manage disaster risk exacerbated by climate change, we need to shift from the current approach of seeing the land and natural assets as a resource for extraction and instead choose a path that builds a sustainable relationship with the natural world and resilience of future generations. Indigenous Peoples have been adapting to changing climates and conditions for countless generations, and Indigenous Knowledge is typically founded on direct observation and interaction with the natural world over a long period of time. It is connected to land, water, air, and all life, language, spirituality, values, and sovereignty.

Understanding and embracing Indigenous Knowledge for living in harmony with nature is critical not only for the work that is needed in building the resilience of Indigenous communities but also for the shift that we need to protect BC's people and prosperity for future generations.

THEME 4: Redesign governance mechanisms to merge disaster risk reduction and climate change adaptation, recognizing commonalities particularly between risk mitigation and climate adaptation.

Building the resilience of people, economies, and natural resources to the impacts of slow-onset and extreme weather and climate events is the common ground between climate change adaptation and disaster risk reduction efforts (Figure 6). As we are already experiencing the impacts of climate change, the blurry line between the two fields has now almost disappeared. Weather- and climate-related hazards and their health, social, economic, and environmental impacts are risks common to both efforts. Geological, biological, and technological hazards contribute to disaster risk,[17] though climate change can cause novel biological hazards and extreme climate events, which can lead to cascading technological incidents.

The separation between the two fields is rooted in the origins of where they started and how they advanced. The different origins, with one stemming from national security and civil defence and the other from advocacy by environmental scientists, means that there are two completely separate institutional mechanisms, with separate financing streams, that are leading, coordinating, and implementing DRR and climate change adaptation (CCA) in every country around the world—including Canada. For DRR, Public Safety Canada is the federal lead and Emergency Management BC is the provincial lead. For CCA, Environment and Climate Change Canada is the federal lead and BC Ministry of Environment is the provincial lead.

But CCA and DRR, especially the

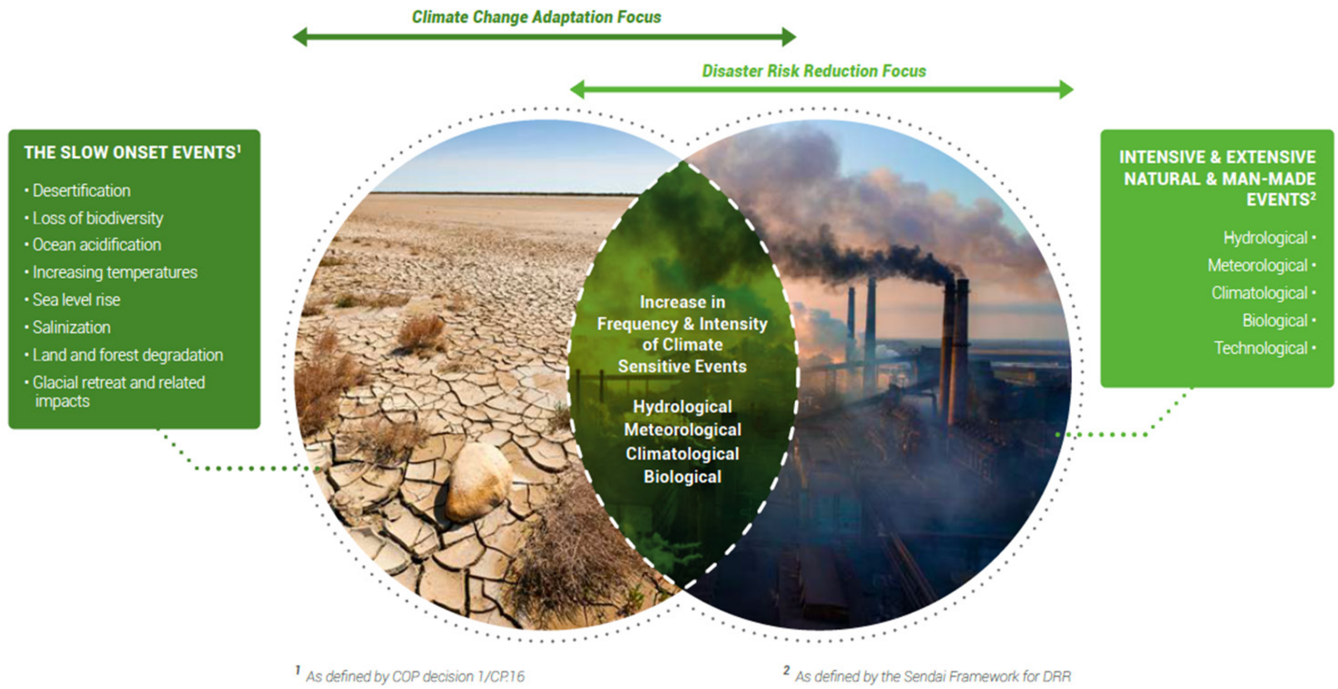

Figure 6: Common and uncommon hazards that are the focus of CCA and DRR (Graphic: UNDRR).[18]

risk mitigation component, face very similar common challenges, require similar approaches in governance, financing, information and data analysis, capacity development, and monitoring. The recommendation is to take steps to merge the common components of DRR and CCA by uncoupling risk mitigation from preparedness, response, and recovery and merge disaster risk mitigation with climate change adaptation.

A committee approach, with strong leadership from senior levels, would allow for shared responsibility for building resilience across departments—engineering, land-use planning, emergency management, climate change adaptation, climate change mitigation, social planning, asset management, and long-range financial planning. The committee approach can be applied at all levels of government.

THEME 5: Design disaster and climate risk management measures that deal with systemic inequalities.

Disasters almost always disproportionately impact the most vulnerable people. The most vulnerable people in Canada are seniors, Indigenous people, low-income residents, those with low literacy levels, transient populations, people with disabilities, medically dependent persons, children and youth, women, new immigrants, and cultural minorities.[19] Our society is only as strong as our most vulnerable. It is critical to ensure disaster and climate risk measures address systemic inequalities within the sphere of their impact.

Existing social inequities in BC are exacerbated by climate change and impacts of disasters. People who experience poverty, racial or social inequality, and who are impacted by colonialism and systemic racism are often more strongly affected by the impacts of a crisis, including the changing climate. Low-income and racialized populations in both urban and rural regions are less likely to be adequately insured and have fewer resources to adjust to changing climatic conditions or respond to extreme events. For example, they may not be able to invest in an air conditioner during a heat wave or repair their home after a flood. They may also have higher rates of adverse health conditions. Indigenous communities are disproportionately impacted by climate change, as they are witnessing the immediate impacts on their territories, traditional foods, medicines, and ways of living.[20]

RECOMMENDATIONS

The following recommendations are organized in alignment with Sendai Framework priorities.

SENDAI FRAMEWORK PRIORITY 1: Understanding Disaster Risk

We need strategies, investments, and methodologies to support all actors with reliable and accessible hazard and risk information that empowers a systemic approach to climate and disaster risk management.

Sendai Framework Priority 1

"Policies and practices for disaster risk management should be based on an understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment. Such knowledge can be leveraged for the purpose of pre-disaster risk assessment, for prevention and mitigation and for the development and implementation of appropriate preparedness and effective response to disasters." [21]

1.1 Develop provincial strategies, supported by guidelines, to produce harmonized hazard and risk information with insights on interdependencies and drivers of risk.

Effective policies and actions for reducing the impacts of hazard events require information on the drivers of risk to target the root causes. Hazard and risk assessments should provide insight into how past decisions and actions have led to the current condition and shed light on the future trends of risk due to climate change, population growth, and physical asset development under the current setting. Such information can support planners for designing strategic and game-changing measures.

Though there has been significant progress in advancing methods and investing in hazard and risk assessments, the level of progress varies significantly across the hazards, and the following challenges are prevalent:

- The coverage is patchy across the province. For example, only a few municipalities with enough capacity have managed to embark on coastal flood risk assessments.
- The outputs are not comparable across municipal boundaries due to variations in methodologies. This is the case with riverine flood risk assessments.
- Risk assessments are conducted in silo and approach the problem without identifying interdependencies. This approach produces results that cannot be used for integrated planning.
- The processes do not always include proper consultations and engagements with the communities, nor do they include Indigenous Knowledge and practices. Many quantitative assessments are only focusing on hazard modelling without insights on exposed assets and potential damage and losses, such as the case of wildfire quantitative assessments.
- The current practice is most often only focused on physical assets and takes a static view of the likelihood and intensity of impacts at the present time.
- Risk assessments are not accompanied by clear communication of the results with actors. Typically, there is no budget allocated for communication of the final results in an engaging and effective way.
- The final datasets are not always accessible to others to use for future projects or for further research.

A provincial strategy for enhancing and harmonizing the quality, format, and availability of information on all key hazards and risks is needed to design the path forward for addressing the gaps and challenges. The strategy would be supported by plans and guidelines to harmonize methodologies and outputs allowing comparison across a region and collaboration and exchange of information within and across sectors and jurisdictions. This would allow risk assessments to be done in small scale but be comparable and complementary to other efforts in a region.

It is important to acknowledge that there are existing professional practice guidelines and standards for some of the hazards, including riverine and coastal flooding and landslides. But not all guidelines cover the end-to-end process that includes required consultations with communities and users, integration of Indigenous Knowledge, insights on the drivers of risk, format of results, data sharing protocols, and final communications.

1.2 Develop a provincial strategy for risk data management and establish a data platform to share the datasets.

Risk data[iii] and information are the valuable outputs of data collection projects and hazard and risk assessments and can be quite a costly endeavor. A common finding and recommendation among many articles of this report is the challenge that practitioners and researchers in both the public and private sector face in accessing data and information from publicly funded hazard and risk assessment projects.

It is important to note the existing and ongoing efforts on open data management in BC. Province of BC introduced its Open Information and Open Data Policy in July 2011, becoming the first province in Canada to publish its data under an open licence.[22] The Province produces and maintains over 1,000 datasets about natural resources, the economy, justice, education, and social programs, which are accessible on BC Data Catalogue free for anyone to use or repurpose under the Open Government Licence - British Columbia.

> A provincial strategy for enhancing and harmonizing the quality, format, and availability of information on all key hazards and risks is needed to design the path forward for addressing the gaps and challenges.

GeoBC creates and manages geospatial information and products to help better manage natural resources in BC. Among GeoBC services is BC's Emergency Management Common Operating Picture portal (BC EM COP) which, since 2018, has been serving the province as the one-stop-shop for emergency GIS information and the primary mechanism to display real-time emergency response data for stakeholders at agencies like EMBC.[23] At the time of writing, BC EM COP is not open to the public and login information is shared with emergency managers, mostly for use during response.

The recommendations for enhancing accessibility of risk data are:

- Develop a strategy for risk data management with a lead provincial entity to manage implementation.

  The recommended risk data management strategy for BC can define the governance mechanism and provide a common approach for sharing and managing risk data. Good governance of risk data would mean effective and efficient production, sharing, and use of risk data in policy and planning for disaster and climate risk management. It would provide regulatory and accountability frameworks, collaboration mechanisms, capacities, and incentives for production and sharing of risk data. Some of the specific areas of focus include:[24]

  - Establishing legislation that requires a risk data management strategy at the provincial level and data sharing among ministries.

  - Building capacity for data management and data sharing approaches and technologies.

  - Creating standards for data collection, formatting, and sharing.

  - Identifying and promoting incentives for industry actors to participate in open data, such as

[iii] *We use "risk data" as a general term inclusive of all types of data involved in the inputs and outputs of hazard and risk assessments.*

BOX C: CHANGE VIA GUIDELINES AND FUNDING PROGRAMS

Guidelines and funding programs can bring the changes that are needed in how risk assessments are conducted. Critical upgrades that we need in the current practice of risk assessments are:

Assessments should include insights on the drivers of risk (diagnostic approach to understanding risk): Designing effective policies and actions for reducing the impacts of natural hazard events requires a holistic and integrated approach to hazard and risk assessments to provide insights on how past decisions and current conditions are the drivers of hazards, the exposure and vulnerability of assets, and the cascading impacts. Such insights, combined with an understanding of how the current trends and projections on climate change, population growth, and development will influence the risk levels in the future, can equip planners for reducing existing disaster and climate risk and mitigating it for future generations. Although it is important to note that current practice in hazard and risk assessment has a static view of the likelihood and intensity of impacts at the present time.

The outputs should match the needs of the target users: Each category of actors may require a different type of risk information depending on the asset and impact type that they are concerned about and the action they need to take. For the same risk type—for example, riverine floods—the land use planner would need a geospatial map of the floodplain with water depth and likelihoods, including the potential variations in time horizon due to climate change. The dike engineer would need to know the water flow values of the 200-year return period flood with climate change consideration. The actor concerned with community emergency planning would need to know the location of shelters in the context of the floodplain and an understanding of the socioeconomic characteristics of the exposed communities, such as knowing who will need evacuation support and where they live or work.

Inclusive consultations with stakeholders and First Nations should start in the early stages of risk assessments: Engagement with various stakeholders and First Nations is critical in a risk assessment not only for gathering relevant information on vulnerabilities, capabilities, needs, existing knowledge, and practices for risk management but also for gaining the trust of users on the quality of the results. It is important to ensure that consultations are inclusive of all stakeholders and First Nations and are designed and facilitated with awareness of the background and culture of each specific group. For example, technical terminology can be very different between emergency managers and planners. Also, scientific risk terminology is foreign to many groups, such as Indigenous communities, community-based institutions, and the general public.

for business development and adding value).

- Creating sustainable funding mechanisms.

- Working with stakeholders, First Nations, and end-users to understand their data needs and help them understand why and how to use risk data and information; this establishes the demand.

- Establishing a governance structure that includes an entity in the leadership position, with established authority and mandate, and a set of protocols for data sharing and collaborations.

- Open dialogues on perceptions versus facts of sensitive data, on data security, and on the value of open data policies.

• Establish a dedicated risk data management platform for hosting the publicly funded risk data produced at provincial, regional, and local levels.

It is important to design such a platform based on the needs of the users in disaster and climate risk management. For example, one of the desired features is to allow the user to browse the data by location. There are many good examples internationally, such as Australian Flood Risk Information Portal.[25]

1.3 Establish a "Disaster and Climate Risk Management Hub" at the provincial level.

Governance of risk information tends to lack the necessary connections across hazard types and between actors. Such fragmentation increases the price tag of each new risk assessment, keeps risk assessments within the scientific community and isolated from policy processes, and impedes the use of risk information in policy design, capability development, and for shaping investments. Alongside recommendations 1.1 and 1.2, a Disaster and Climate Risk Management Hub at the provincial level with a goal of facilitating connection and collaboration between science and policy actors can play a critical role in supporting actors, especially local governments and First Nations. The role of the Hub would include: 1) responding to priority demands of practitioners and policy designers for risk data management and production of relevant risk information, and 2) enabling its use in the design of policies and investments that build resilience in BC communities.

The Hub would tackle the following challenges:

- Making risk data accessible
- Establishing data sharing modalities
- Understanding and using risk information in DRR and CCA
- Coordination and collaboration across projects, hazards, and sectors
- Identifying priorities and common needs for effective disaster and climate risk management across hazards and sectors

A concept note has been developed that outlines the proposed design for an institution that would facilitate connection and collaboration between science and policy actors for the common goal of disaster and climate risk reduction in BC.[26]

1.4 Collect data on what we value and develop methods to analyze.

While there is an obvious need to measure the potential physical impacts of natural hazards, it is also important to understand who is in harm's way, cultural perceptions of risk, socioeconomic vulnerabilities, and potential issues of social inequity that may be associated with the spatial distribution of hazard threats within a given community or region. Addressing systemic risk requires applying metrics that reflect economic as well as environmental and societal wellbeing. When the mechanisms are not collecting the right data, key assets are undervalued in decision making and opportunities are missed for a systemic approach to risk management.

We need to invest in data collection and research and development of analysis methodologies that support the design of DRR programs with an equity focus to address the root causes of vulnerability—not just response solutions for individual characteristics. We also need to invest in collecting comprehensive and harmonized data on environmental assets, cultural assets, and sites of interest to Indigenous communities.

1.5 Invest in advancing science and methods to incorporate climate change into hazard and risk assessments and to interpret the results while managing the uncertainty.

The need for incorporating climate change into hazard and risk assessments and in resulting policies is outlined in this report's articles on wildfires, coastal and riverine floods, avalanches, and landslides as well as few other articles on risk management practice and enablers. For example, the *Preliminary Strategic Climate Risk Assessment for British Columbia* rated severe wildfires as having the highest expected consequences across all climate risk events by 2050. Projections include severe wildfire seasons increasing in frequency with a return period decreasing from one fire in 50 years to one in 10 years. Nevertheless, climate change is not included in current provincial-scale wildfire threat assessments.

The uncertainties in climate-related hazard and risk assessments, which mostly stems from the uncertainty in the climate projection models, pose challenges for decision making in terms of defining the course of action, especially when decisions need to be made on major capital investments with longer life spans. There is a need for guidance and tools to support making decisions in the face of climate uncertainty.

1.6 Conduct a collaborative exercise using a major catastrophic event scenario to help risk owners and actors understand the interdependencies, current capabilities, gaps, and the way forward.

An approach that has proven more effective in facilitating the understanding of potential impacts and gaps in capabilities is to define a disaster scenario with inputs from a wide range of sectors and experts. Such an approach allows use of empirical knowledge in addition to scientific and quantitative models for identifying the complex interdependencies within and among physical, social, and environment systems.

Canada's National Risk Profile, led by Public Safety Canada, is a great example of this approach using scientific evidence, presented as disaster scenarios across the country, and stakeholder and First Nations input to create a forward-looking picture of Canada's disaster risks and capabilities. In the first stage of the National Risk Profile (2021–22), twelve whole-of-society risk assessment sessions were held to better understand national risks and challenges with respect to floods, wildfires and earthquakes. Participants included experts from across all levels of government, academia, Indigenous organizations, and the private sector in order to produce a whole-of-society picture of risks facing Canada.[27] Participants provided perspectives on the level of risk in the five All Hazards Risk Assessment (AHRA) impact categories (people, economy, environment, government, and social function) as well as on critical infrastructure, on Gender-based Analysis Plus considerations, on the risk of a similar event in 2050, and on the risk during a pandemic. Traditional Knowledge and perspectives were also discussed with respect to risks facing Indigenous communities.

Collaborative analysis using a disaster scenario is especially helpful for understanding critical infrastructure interdependencies and vulnerabilities. Scenario development with multi-sectoral participation can be an effective approach in defining and understanding the interdependencies and impacts across CI systems and the vulnerability drivers, and for developing risk management scenarios. An example of such an effort is the HayWired scenario,[28] which anticipates the impacts of a hypothetical magnitude 7.0 earthquake on the Hayward Fault in Northern California. The fault runs along the east side of California's San Francisco Bay and is among the most active and dangerous in the United States because it runs through a densely urbanized and interconnected region. The USGS and its partners in the HayWired Coalition and the HayWired Campaign are working to energize residents and businesses to engage in ongoing and new efforts to prepare the region for such a future earthquake.

SENDAI FRAMEWORK PRIORITY 2: Strengthening Disaster Risk Governance

We need to enhance risk governance mechanisms to provide more clarity on roles and responsibilities of all actors and lead entities, while empowering and incentivizing collaborations for integrated planning.

Sendai Framework Priority 2

"Disaster risk governance at the national, regional and global levels is of great importance for an effective and efficient management of disaster risk. Clear vision, plans, competence, guidance and coordination within and across sectors, as well as participation of relevant stakeholders, are needed. Strengthening disaster risk governance for prevention, mitigation, preparedness, response, recovery and rehabilitation is therefore necessary and fosters collaboration and partnership across mechanisms and institutions for the implementation of instruments relevant to disaster risk reduction and sustainable development." [29]

2.1 At the provincial level, identify and empower a lead entity for each risk to coordinate and empower collaborations among all actors.

Many public entities are actively working on understanding and managing various risk types across BC. While we do have a culture of collaboration and sharing, new forms of collaborations are needed to deal with the complex and growing risks. This includes formal institutional setup as well as the connections and relationships among the individuals who play a role in risk management.

The systemic nature of disaster and climate risk requires many different players to manage each type of risk. But due to a lack of clarity on mandates and commonly agreed methods and approaches, at times there are overlapping activities with outputs that are not comparable or compatible in the same jurisdiction or neighboring jurisdictions. For example, wildfire risk occurs on Crown, Indigenous and private land. It has economic, sociopolitical and ecological dimensions as well as interaction and feedback with other challenges and hazards, including Indigenous land governance, floods and landslides, extreme heat events, and resource industry instability. While no single stakeholder or risk manager can influence all aspects of a hazard, exposure, and vulnerability, collaboration and integration among stakeholders and First Nations is a major challenge; communities and other stakeholders have different incentives, capacities, and barriers to engaging in proactive risk mitigation. Similarly, decision making and resource allocation for landslide risk management is currently spread among many entities, including provincial government agencies, local governments, private companies, and individual professionals. This dispersion has led to inconsistency, duplication of effort, data sharing challenges, and suboptimal resource allocation.

Different organizations need the flexibility to adopt plans, policies, and risk reduction strategies that are suitable to their context and based on resources available. However, issues related to inconsistency, lack of coordination, and disparity in available resources arise due to the absence of leadership.

2.2 Redesign the required professional profiles and human resource planning for disaster risk reduction and climate change adaptation.

We have unrealistic expectations for emergency managers to plan for long-term resilience while concurrently meeting their responsibilities for response and recovery, and this is holding back progress. The approach and understanding of how disasters affect society and how disaster risk should be managed has evolved in recent years; the Sendai Framework marked this transition by clearly calling for a widening of the approach to managing disaster risks (managing the potential impacts before they happen, including planning for dealing with the residual risk), instead of only focusing on managing disasters (managing the impacts once they happen). But this expansion of scope, which requires dramatically different skill sets, has fallen on emergency managers. Currently, emergency managers have to be adaptive and opportunistic in their pursuit of long-term risk reduction while being overworked and fully immersed in response and recovery during the months after disasters.

The systemic nature of disaster and climate risk requires many different players to manage each type of risk. But due to a lack of clarity on mandates and commonly agreed methods and approaches, at times there are overlapping activities with outputs that are not comparable or compatible in the same jurisdiction or neighboring jurisdictions.

To address this, we need stronger leadership, resource commitment, and strategic planning across several different sectors in each level of government. Leadership and resources for climate and disaster resilience should be present in many units, such as asset management, land-use planning, engineering, social development, and environmental preservation units at the local and regional governments. The model of having a resilience officer position that can align and coordinate these efforts is recommended. This model would also enable integrated planning, which has been identified by many of this report's articles as an essential shift for more effective climate and disaster risk management. Another possibility is to implement resilience committees, with clearly defined mandates and leadership from the senior level. Such a committee can be chaired by the resilience officer.

2.3 Share insights and lessons learned through increased guidance, enhanced capacities, and a dedicated mechanism.

Contributors to this report have identified the need for developing further guidance and increasing capacities in a wide range of issues across different levels of government, Indigenous government, stakeholders, and the general public to empower them in playing their role in building resilience.

Common themes of what is needed have emerged from the articles in this report:

- Develop methods for managing climate uncertainties in decision making for long-term asset investments.
- Conduct trainings to build capacities for design and manage engagements and consultations with Indigenous and non-Indigenous governments and communities; capacities are needed in government and the private sector.
- Develop various policies and plans, including integrated disaster and climate resilience plans, alert and evacuation plans, recovery plans, and more.
- Provide media training for reporting during and after disasters, and investigate and report the progress of policy implementation and investments in risk reduction.
- Develop a cross-disciplinary and cross-issue accessible body of knowledge for use by professionals (engineers, planners, architects, others) in understanding and managing various aspects of climate and disaster risk.
- Integrate climate and DRR skills into professional practice areas and provide every professional with ongoing continuing professional development and beyond-introductory climate adaptation and DRR knowledge.
- Explore nature-based solutions for climate change adaptation, disaster risk management, and resilience.
- Incorporate disaster and climate risk management into rezoning and development-related applications.
- Provide open-source access to all disaster and climate risk management projects, research, and strategic planning initiatives that are paid for from public funds.
- Provide policy support for innovative practices that have proven effective in other jurisdictions.

2.4 Upgrade building codes for new and existing buildings to integrate climate change mitigation and adaptation criteria with post-disaster functionality criteria.

Codes and standards have a significant impact on all phases of building and infrastructure life cycles. We must therefore ensure that building codes and standards are updated to reflect expected future climate conditions, the most recent understanding of geohazards, and the expected performance of both new and existing structures. This can be an effective way to increase the resilience of the built environment.

The National Building Code (NBC) is the model building code issued by the National Research Council of Canada. A model building code is one that is developed by a standards organization independent of the jurisdiction responsible for applying and enforcing it. As a model code, the NBC has no legal status until it is adopted by a jurisdiction that regulates construction, which is a provincial responsibility. The City of Vancouver is an exception; it governs the design and construction of buildings through its own Vancouver Building Bylaw. This means the NBC is voluntary and provinces and territories ultimately decide which components of the code to integrate in their jurisdictions.

Building codes in Canada have evolved since the first NBC was released in 1941. Currently, it has provisions for wind, snow, rain, and earthquakes but not for floods.

The earthquake provisions are periodically updated to reflect new scientific knowledge. Earthquake risk tolerance levels have also evolved over time, reflecting a lower tolerance for risk of collapse in modern editions of the NBC. High-importance buildings, such as schools and hospitals, are designed for higher loads and more stringent requirements. The BC Building Code, however, does not set minimum requirements beyond life safety for new buildings, nor contain specific requirements for the earthquake assessment of existing buildings, while an overwhelming majority of structures in the existing building stock were designed and constructed using building codes with low levels of earthquake provisions. Two articles in this report focus on managing earthquake risk and include recommendations for building codes and standards for new and existing buildings.

The recommendations are:

- Upgrade building codes to shift from minimum requirements to protect life safety to desired functionality and recovery performance post-disaster (the requirement that the building will take only five days to achieve functional recovery after a major earthquake).
- Investigate means to incorporate new standards for existing buildings and enforce compliance.

Studies from the United States show above-code design could save $4 per each $1 spent, and private-sector building retrofits could save $4 per $1 spent.[30]

The current national and provincial codes do not integrate any climate change projections. NRC is in the process of using updated climate design values with future climatic changes to incorporate climate resilience in the relevant national codes and standards. This includes provisions for flood-resilient building design. Building codes in BC need to follow suit.

2.5 Support risk mitigation actions by the public by making hazard and risk information available.

For the whole of society to engage with and democratically influence decisions, and to play a role in managing disaster and climate risk, hazard and risk information should be publicly available in understandable and accessible formats.

The *Access to Information Act* of Canada gives people the legal right to obtain information, in any form, that is under the control of a government institution.[31] The general purpose of this act is to make government more open and transparent and to allow citizens to more fully participate in the democratic process of public policy. Hazards, vulnerabilities, and risks can directly affect people's safety and open access to such information can be transformative—increasing the resilience of assets and people—if delivered in a usable format (i.e., without the complex scientific jargon) along with instructions on actions people can take to reduce their own risk.

2.6 Monitor and report on the progress and impacts of risk reduction policies to promote accountability, create incentives, and guide course correction.

The Sendai Framework and accompanying implementation guidelines and tools emphasize the importance of establishing monitoring mechanisms as a key component of accountability in good governance and continuing to enhance policies and programs. Sendai also calls for monitoring trends and patterns in disaster risk, loss, and impacts. A reporting mechanism has been established by UNDRR, in which every country, including Canada, has agreed to report on disaster losses on a yearly basis. Public Safety Canada, which is the national lead for Sendai Framework implementation and reporting, prepared a Readiness Report in 2017 on how prepared Canada is to report on all indicators of the Sendai Framework. Based on the Sendai monitoring platform,[32] Canada has "report in progress" status for 2017, 2018 and 2021. Establishing a provincial program for monitoring disaster risk reduction under the leadership of Public Safety Canada can provide major insights on damage and loss trends, drivers, and impacts of risk reduction measures.

The Canadian Disaster Database (CDD) is the significant source of data on disaster frequency, fatalities, injuries, and evacuations. The CDD includes an interactive geospatial map and database, which contains detailed disaster information on more than 1,000 natural, technological, and conflict events since 1900.[33] But it only covers events that are major on a national scale. To be officially tracked through the CDD, disaster events must meet the following criteria: 10 or more people killed; 100 or more people affected/injured/infected/evacuated/homeless; an appeal for national/international assistance; historical significance; and/or significant damage/interruption of normal processes such that the community affected cannot recover on its own.[34] This means that many events that can be catastrophic for a community or a region do not get included in CDD. Tracking disaster impacts at provincial level could provide very meaningful insights on trends and drivers, but such work would require criteria for local- or regional-scale events and a dedicated team and process.

Another recommendation is to have programs conducting forensic analysis post-disaster to understand how past decisions resulting in human-made and natural alterations of physical, social, and environmental assets relate to disaster impacts and the resilience of the assets. This can provide immense value in designing post-disaster recovery and

BOX D: EVALUATION AND MONITORING OF NATIONAL DISASTER MANAGEMENT PROGRAM

This report contains an article by Public Safety Canada summarizing an evaluation of the National Disaster Management Program (NDMP) at the regional level in BC. This work was complementary to an NDMP evaluation conducted in 2019 at the national level. From 2015 to 2022, the NDMP funded 460 projects across Canada, including 132 in BC, and contributed to an increase of communities that undertook mitigation investments to reduce their vulnerability to floods through four streams of the program: 1. Risk Assessments, 2. Flood Mapping, 3. Mitigation Planning, and 4. Investments in Non-structural and Small-Scale Structural Mitigation Projects.

The evaluation of the NDMP sheds light on successful elements as well as the challenges and recommendations for enhancing the program. A few key findings are presented here:

- The information products, as the outputs of the project, have led to a better understanding of local and regional flood risk, have highlighted major gaps in flood risk management, and have enabled changes in policies and program design.
- No direct quantitative data was collected to determine how the recipient projects have reduced the impacts of disasters in the area or how the value of disaster-related financial liabilities for municipal, provincial, or federal governments (the objective of the NDMP) have been reduced. However, the recipients overwhelmingly stated that their projects contributed to risk reduction and reducing financial liabilities, as these projects triggered policy work and decision making at the municipal level that is effecting changes to future developments and spin-off projects.
- Regional partners spoke to the value of the NDMP in enabling regional cooperation in the development of context-driven tools within local areas and facilitating greater relationship building between municipalities and communities.
- The importance of Indigenous participation and input into the plans was highlighted by many contributors to the evaluation.
- A challenge to procuring the projects in a timely manner was the limited number of consulting firms available to undertake risk mitigation work, which contributed to sometimes lengthy delays, as there can be more projects than technical consultants available.
- The fact that the NMDP is only focused on floods leads to some missed opportunities for designing and investing in mitigation measures that can address multiple types of risk. Public Safety Canada states that this point has been raised in the NDMP's 2019 Evaluation at the national level and the new mitigation programming will consider interplays between hazards to increase resilience in Canadian communities and reduce the overall disaster risk to individuals and their homes.

transferring the knowledge for risk reduction to other communities. Such programs would look into Indigenous Knowledge, historic and existing land-use plans, agricultural and residential development trends, and past risk reduction measures.

2.7 Develop a long-term strategy for critical infrastructure resilience with stronger coordination, harmonized approaches, and accountability.

Infrastructure is critical to the economic capacity and livability of our communities and the viability of our businesses within them. CI is defined as the "processes, systems, facilities, technologies, networks, assets and services essential to the health, safety, security or economic wellbeing of Canadians and the effective functioning of government."[35] Disruptions of CI could result in catastrophic loss of life and injuries, adverse economic effects, and significant harm to public confidence. The Sendai Framework has dedicated Target D to CI resilience. The challenge of securing and maintaining critical infrastructure assets and systems in a complex and fast-changing risk landscape require coordinated approaches between the public sector, private sector, and citizens, which in turn will foster ingenuity, promote adaptability, and ensure collaboration.[36]

Generally, across Canada, municipalities manage nearly 60% and provinces 38% of public infrastructure.[37] In BC, some infrastructure is owned, operated, and maintained by both the public and private sectors. For example, the Canada Line rapid transit system connecting YVR airport, Richmond, and Downtown Vancouver is a public-private partnership built and operated by a private entity. In BC, most electricity is generated and distributed by BC Hydro, which is a provincial Crown corporation, but there are now numerous smaller-scale private power providers selling into the electrical grid. Telecommunications, cable providers, and railways are squarely in the realm of the private sector, although regulated by the public sector, which plays a significant role in the resilience of CI systems and society.

Local governments are essential to identifying and implementing projects that respond to local needs while contributing to regional, provincial, and federal prosperity. However, local governments often lack the resources and expertise to deliver productive and sustainable infrastructure in a cost-effective and timely fashion. Local budgeting processes currently fail to require accounting for future demands for infrastructure upgrades and replacement.

In recent years, all orders of government in Canada have increased their investments in infrastructure.[38] Through the Investing in Canada Plan, launched in 2016, the Government of Canada committed over $180 billion over 12 years for infrastructure, with three objectives: 1) create long-term economic growth to build a stronger middle class; 2) support the resilience of communities and transition to a clean growth economy; and 3) build social inclusion and socioeconomic outcomes for all Canadians. Yet, barriers remain for achieving these objectives. Many communities are struggling with competing financial pressures and aging, failing infrastructure. Government support at all levels is required to renew our infrastructure as well as assist with paying for new and increased regulations and standards.[39]

The main recommendation from the BC Chamber of Commerce is for the provincial government to develop a long-term infrastructure strategy (a strategic investment planning document) for BC, which is coordinated with the long-term strategic planning processes of the province's regional districts. To improve effectiveness in planning, a long-term provincial plan would allow for regional and municipal governments to anticipate the plans in upcoming provincial infrastructure investments and align their budgeting processes and work to federal, provincial, and regional goals.[40]

At the national level, Public Safety Canada has led the development of the *National Strategy for Critical Infrastructure* (2009), addressing three strategic objectives: 1) to build partnerships among federal, provincial and territorial governments and CI sectors, 2) to implement an all-hazards risk management approach, and 3) to advance the timely sharing and protection of information among partners.[41] The strategy will go through a renewal process that will take place over the next three years

(2021–2023)[42] and is an opportunity to shed light on what is working well, what needs to be improved, and what our vision for the future should be as Canada faces an evolving list of risks and threats.

Key points and recommendations from two articles in this report, submitted by Public Safety Canada and BC Hydro on this topic, are:

- The interdependence of CI sectors presents significant risks that can only be better understood and managed through collaboration among governments and CI sectors. A reconfiguration of CI sector networks into networks grouped by function could help to identify interdependencies and related risks as well as facilitate cross-sector information sharing.
- Harmonizing approaches to strengthen the resilience of CI at all levels will enable efforts to facilitate timely and effective prevention, mitigation, preparedness, response, and recovery measures to deal effectively with disruptions.
- The roles and responsibilities are not clearly understood across CI partners, stakeholders, and First Nations. Although different delivery models across regions might be needed to address the specific situation, the cluttered organizational landscape makes it difficult to advance common CI priorities and resilience goals and creates conflicting advice for CI owners and operators.
- Building stronger and more formalized partnerships with academia and think tanks that study issues related to CI security and resilience, infrastructure protection, and digital technology could provide valuable advice to Canada's CI leadership.
- A clear framework that supports results and accountability could help ensure that a focused direction exists, objectives are achieved for public and private sector investments, and efforts to enhance the security and resilience of CI are measurable. Canada currently does not have a national results-based framework in place that effectively measures the collaborative, non-regulatory efforts to achieve CI objectives, as set out in the *National Strategy for Critical Infrastructure* and supporting action plans.
- With climate change impacts, the current practice of using historical data is no longer valid. There is a need for developing event scenarios with future climate data to acknowledge the range of uncertainty from the new realities of climate change, evolving demands on infrastructure, and technology advancement.
- CI systems provide an opportunity to act as the unifying link between levels of government and government entities, the end user, the community, and emergency responders. Strong leadership at CI sectors can enable this role.
- Provincially funded infrastructure has similar requirements as that funded by the federal government—requiring a climate-focused assessment to align investments with acceptable risk.

2.8 Empower stakeholders and First Nations to play their crucial role with expertise, information, and inclusive collaborations.

Non-governmental stakeholders play a crucial role in risk management. They need expert knowledge, data and information, and mechanisms in order to be included in the relevant processes for disaster and climate risk management. This report includes three articles dedicated to the roles of stakeholder groups.

Professional Associations

The influence of professional associations is far reaching, allowing them to play a complementary role to government as a distinct part of civil society. Professional associations govern professional interactions with the social, natural, and built environment, positioning them as leaders and key advisors in disaster and climate risk management.

Professional associations can influence and guide disaster and climate risk management practice through:

SENDAI FRAMEWORK: ROLE OF STAKEHOLDERS

"While States have the overall responsibility for reducing disaster risk, it is a shared responsibility between Governments and relevant stakeholders. In particular, non-State stakeholders play an important role as enablers in providing support to States, in accordance with national policies, laws and regulations, in the implementation of the present Framework at local, national, regional and global levels. Their commitment, goodwill, knowledge, experience and resources will be required."[43]

The stakeholder groups outlined in the Sendai Framework are:

- Business, professional associations and private sector financial institutions
- Media
- Civil society, volunteers, and community-based organizations
- Academia, scientific and research entities

- Professional practice guidelines
- Practice resources
- Continuing education and training
- Collaboration and volunteerism
- Strategic frameworks and knowledge management
- Hazard and risk information

A few key recommendations identified for enhancing the role of professional associations are:

- Develop a collaborative community of practice among professional associations, and between professional associations and Indigenous Peoples.
- Create a shared vocabulary for communicating risk broadly, for cross-disciplinary communication, and for developing a business case for adaptation action; create a process to support development of a shared vocabulary.
- Integrate climate and DRR skills into professional practice areas.
- Provide every professional with ongoing continuing professional development and beyond-introductory climate adaptation and DRR knowledge.

Media

The Canadian media plays an integral role in the resilience of British Columbians. The Government of Canada recognizes that "people need free media to provide them with accurate information and informed analysis to hold governments to account."[44] This has been more vital than ever in recent years following the COVID-19 pandemic and the back-to-back weather disasters of 2021 in BC. Media empowers individuals with clear information for collective action. Canadian media is far reaching, with the ability to connect with most of the population either directly or indirectly through broadcasting, publications, word of mouth, and social media. This holds enormous weight in getting a message of resilience to the public. Media can be a powerful tool for invoking change, including influencing power for more responsive and inclusive governance systems.

The media landscape and the way the public consumes news is constantly changing, so journalists and media platforms must stay agile. Journalists have a responsibility to stay informed about emergency procedures as well as the latest risks to communities, and to navigate the best way to get information to the public. The media also needs an open line of communication to all those involved in risk reduction and resilience, especially as messaging and information changes. However, with the advent of social media and the proliferation of disinformation and misinformation, the core mission of providing facts to the public is even more important.

There is no overarching protocol for the media on how to respond to disaster, at any stage. The media has journalistic guidelines—at both federal and agency levels—but there is no specific protocol to be followed by all agencies. However, individual newsrooms have extensive emergency response protocols, which rely heavily on a list of existing contacts. These include readily available and predetermined experts and officials who can be contacted during breaking news. Developing these relationships ahead of time is key. Often these protocols are created following an event.

Community-based Organizations as Part of Social Infrastructure

In the wake of disasters, survivors emphasize the importance of community-based support systems, including neighbours, grassroots groups, organizations, and businesses that mobilize and deliver aid in response to the failure of basic services. These community-based assets make up networks of social infrastructure (SI) and may include programs and services, physical facilities and spaces, informal networks, deep relationships, knowledge and resourcefulness that support and enable social interaction and hold social purposes. Disasters expose and exacerbate our deepest pre-existing inequities, as impacts are not equally distributed among populations and communities. Networks of SI play a fundamental role in strengthening community resilience by improving equity, reducing disaster risk and vulnerability, and facilitating collective action and essential services through crises, emergency response, and recovery. The sheer number and variety of SI organizations is staggering, and their decentralized locations offer unique opportunities for place-based planning. In BC, there are over 29,000 non-profit organizations that employ 86,000 people and contribute $6.7 billion to the provincial economy.[45]

This report's article on social infrastructure outlines a few key points and recommendations to empower these organizations in playing their crucial role. These are:

- EPA modernization is a great opportunity to acknowledge the role of place-based and embedded SI organizations and their facilities within disaster risk management more prominently.
- SI organizations should be engaged to integrate their capabilities and needs into hazard, risk, and vulnerability assessment (HRVA)

BOX E: TWO STRATEGIES OF CITY OF VANCOUVER LINKING RESILIENCE AND SOCIAL INFRASTRUCTURE

The City of Vancouver has two strategies that directly link resilience and SI. In 2019, the City of Vancouver approved the Resilient Vancouver Strategy, which includes framing as well as several objectives and actions specifically designed to reframe and transform the role of SI in disaster risk and resilience. These objectives include:

- Cultivating community connections, stewardship, and pride through actions like participatory budgeting processes.
- Empowering communities to support each other during crises and recover from disasters through actions like scaling the Resilient Neighbourhoods Program and training community centre staff to support disaster preparedness.
- Strengthening social and cultural assets and services through actions like evaluating the resilience of food assets and meal programs.

City council approved Spaces to Thrive: Vancouver SI Strategy Policy Framework in December 2021. Spaces to Thrive takes a human rights–based approach that emphasizes addressing needs of those most disproportionately impacted by shocks and stresses. Directions within the strategy range from partnerships and capacity building, addressing persistent facility deficits (quality, quantity, and location), prioritizing reconciliation, equity, and resilience in supply, and optimization of the SI ecosystem to improve resilience and adapt to pressures from climate change and disasters.

processes and comprehensive recovery plans. Under the existing *Emergency Program Act* there is no direction to develop HRVA using participatory approaches that engage diverse stakeholders, which is resulting in inconsistent standards, quality, and approaches to assessing risks.

- SI needs funding mechanisms that are comprehensive, recognizing the importance of operational costs, staff, and facilities and physical assets that make the services, programs, and social connections possible and flexible at the time of disasters, as most SIs cannot afford contingency funds.
- SI organizations need to be a part of communication, coordination, and collaboration mechanisms in emergencies. For a lasting and supportive relationship between local authorities and SI, it is necessary for local authorities to ensure clear and effective support for SI across all departments during emergencies (for example, getting permits for temporary facilities in a timely manner).

SENDAI FRAMEWORK PRIORITY 3: Investing in Disaster Risk Reduction for Resilience

Provincial and federal funds drive the design of policies, projects, and actions at the local level. We need funding mechanisms that are strategic while empowering the implementation of priority actions designed at the local level and facilitating collaborations at the regional level.

Sendai Framework Priority 3

"Public and private investment in disaster risk prevention and reduction through structural and non-structural measures are essential to enhance the economic, social, health and cultural resilience of persons, communities, countries and their assets, as well as the environment. These can be drivers of innovation, growth and job creation. Such measures are cost-effective and instrumental to save lives, prevent and reduce losses and ensure effective recovery and rehabilitation." [46]

BOX F: BC BUDGET 2021

In BC's 2021 budget, the allocation for managing disaster and climate risk is significantly higher than in past years, although the increase is mostly driven by preparation for response and recovery from 2021 events. The budget allocates $1.5 billion in funding to rebuild from last year's floods and wildfires. More than $600 million in operating and capital funding is targeted for continuing the response to climate-related disasters, for local government and First Nations disaster and recovery projects, and to begin to implement the Climate Preparedness and Adaptation Strategy, which will do the following:

- Expand climate monitoring networks.
- Lead climate resilience initiatives with local and Indigenous governments.
- Develop an extreme heat response framework.
- Expand the River Forecast Centre and provincial floodplain mapping program.
- Build data collection and expertise to better understand how to mitigate climate risks.

There is also $210 million to help local governments and First Nations plan for and reduce disaster risk, including through the FireSmart program, the Community Emergency Preparedness Fund, and Indigenous-led emergency management priorities.

BOX G: DISASTER FINANCIAL ASSISTANCE ARRANGEMENTS (DFAA)

In the event of a large-scale natural disaster, the Government of Canada provides financial assistance to provincial and territorial governments through the Disaster Financial Assistance Arrangements (DFAA), administered by Public Safety Canada. Since 1970, the Government of Canada has paid out an estimated $8.5 billion dollars in post-disaster assistance with the costs of response and in returning infrastructure and personal property to pre-disaster condition. Of these costs, 97% occurred in the past 25 years, and more than one-third occurred in the past six years alone.48

When response and recovery costs exceed what individual provinces or territories could reasonably be expected to bear on their own, assistance is paid through the DFAA to the province or territory—not directly to affected individuals, small businesses or communities. DFAA funds are disbursed based on a cost-sharing setup with the provinces and territories. As of January 2022, the threshold for BC is at $17,743,766 (disaster costs higher than this value are eligible for cost sharing through DFAA).

Under DFAA, repairs that are eligible for reimbursement through insurance are not eligible for cost sharing. At the provincial level, BC Disaster Financial Assistance also doesn't cover insurable losses, which includes damages caused by wildfires, earthquakes, snow loads, and wind storms.49 This is despite the fact that insurance is unaffordable to some.

3.1 Prioritize investing in risk reduction to reduce the cost of future disasters.

The increases in federal and provincial budgets for disaster and climate risk management in recent years is good news but they are still heavily focused on disaster preparedness and response instead of mitigating the risk. In the past few decades there has been an increase in federal and provincial budgets to fund emergency response and recovery as well as climate and disaster risk management, though it is noteworthy that decisions for most funding programs have been in response to major events and are still very much focused on preparedness, response, and recovery instead of reducing existing risk.

Existing analyses suggest that the costs of preparedness and mitigation are several times lower than the savings these measures create. For example, flood mitigation spending is a particularly sound investment: one Canadian analysis reported that every $1 spent on reducing residential basement flood risks led to $11 in savings and found that the implementation of the tools and guidelines, established by Canada's Climate-Resilient Buildings and Core Public Infrastructure initiative, could yield annual benefits of $4.7 billion. A recent study in the United States estimated that investment in mitigation has a 13:1 average benefit-to-cost ratio.[47]

3.2 Design funding programs based on risk information and the intention to shape a harmonized and strategic risk management approach across the province.

Local governments have a political mandate to protect citizens, yet they often lack the financial resources to undertake disaster and climate mitigation projects. The lack of operating budget (staff salaries) and base funding for planning, combined with the reality of response and recovery processes, leaves little time for an emergency management team to work on proactive and strategic risk management. Response and recovery activities may require many days where staff work at the activated Emergency Operations Centre; on average, the EOC in the Kootenay region is activated 100 days per year.

With minimal base funding at local governments, the grants from federal and provincial governments are the main funding source for risk mitigation, especially for the large engineering design and construction projects and to pay the required long-term operation and maintenance costs. In the current ecosystem of disaster and climate risk management in BC, local governments are opportunistic rather than strategic as they end up designing their risk mitigation efforts based on the available provincial and federal funding programs versus their own risk-informed and objective-based risk management plans.

> Local governments have a political mandate to protect citizens, yet they often lack the financial resources to undertake disaster and climate mitigation projects. . . . [They] end up designing their risk mitigation efforts based on the available provincial and federal funding programs versus their own risk-informed and objective-based risk management plans.

Local governments compete for funding of capital costs from a variety of provincial and federal grants, but the grants can take years to secure and are without a guarantee of success. They often have a maximum value that is insufficient and unrelated to the cost of reducing risk to a tolerable level. The biggest challenge is the lack fund continuity to support long-term planning.

With this context, this report recommends enhancing the design of funding programs, employing the following considerations:

- Design funding programs based on organized consultations on vulnerabilities, risks, capabilities, and needs at the local level. While there are some committees and working groups created through various programs that allow communication with local-level representatives, at the moment there is no organized and systematic mechanism for inputs from local and Indigenous governments on priority needs for funding.
- Have wider and more flexible scope to empower local authorities with the strategic and priority actions that they have identified based on their risks and capabilities.
- Accommodate regional projects, as many local governments don't have the resources to apply and implement risk mitigation projects, and also because some risks are cross-boundary and can be managed more effectively at the regional level.
- Encourage multi-hazard approaches, as many actions such as inspection, monitoring, warning, evacuation and response plans, social resilience building, and even structural upgrades can be cost-effective ways of reducing risk for several types of hazard scenarios.
- Provide longer-term operational grants for social infrastructure organizations and technical institutions to maintain their core programs and services and conduct long-term planning.
- Support long-term plans and continuity of different phases of risk management. The short-term schedules don't allow adequate research and engagement of the stakeholders and the uncertainty for continuation of funds for capital projects lowers the incentives for proactive risk management.

3.3 Organize the information about the funding programs for disaster and climate risk management.

Every one of the funding programs at the federal or provincial level has its own webpage, which gets updated as needed with new information on the details of the program. Many regional and local practitioners have a hard time staying up to date on the new funding programs or updates to existing programs, as it would require checking various sites or be on numerous mailing lists, if they exist. Developing a simple platform to host links to all available federal and provincial funding programs with one newsletter for updates would facilitate information sharing with local practitioners immensely. A great example of such a platform that has recently been developed is www.indigenousclimatehub.ca/funding, which has a page dedicated to available funding sources.

SENDAI FRAMEWORK PRIORITY 4: Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation, and reconstruction

Emergency response and recovery processes need enhancement with effective early warning systems, and collaboration mechanisms, response and recovery plans that are developed pre-disaster.

Sendai Framework Priority 4

"The steady growth of disaster risk, including the increase of people and assets exposure, combined with the lessons learned from past disasters, indicates the need to further strengthen disaster preparedness for response, take action in anticipation of events, integrate disaster risk reduction in response preparedness and ensure that capacities are in place for effective response and recovery at all levels. Empowering women and persons with disabilities to publicly lead and promote gender equitable and universally accessible response, recovery, rehabilitation and reconstruction approaches is key. Disasters have demonstrated that the recovery, rehabilitation and reconstruction phase, which needs to be prepared ahead of a disaster, is a critical opportunity to "Build Back Better", including through integrating disaster risk reduction into development measures, making nations and communities resilient to disasters." [50]

4.1 Establish a task force for enhancing and managing multi-hazard impact-based forecasting and early warning systems.

Forecasting and early warning and alerting systems are vital tools for saving lives in disasters. As the economic and social impacts of disasters are increasing, further refinements to accuracy and accessibility are needed.

There is currently no comprehensive strategy or plan for early multi-hazard forecasting, warning systems, and alerting in BC that would provide clarity on roles and responsibilities of various entities and collaborations among them in the design and implementation of each component for various hazards and the connections between each of the four components (Box H).

1. **Disaster risk knowledge**
   Enhancing the quality and availability of hazard and risk information across the province, as mentioned in earlier sections of this document, would directly support the early warning system.

2. **Detection, monitoring, analysis, and forecasting of the hazards and possible consequences**

There has been progress with numerous recent initiatives in monitoring systems of various hazards. Examples are the federal government investment of $4.9 million over five years (2019–2024) for Environment and Climate Change Canada to improve Canada's ability to predict coastal floods and to develop early warning systems (not yet operational).

There is currently no comprehensive strategy or plan for early multi-hazard forecasting, warning systems, and alerting in BC that would provide clarity on roles and responsibilities of various entities and collaborations among them in the design and implementation of each component for various hazards and the connections between each of the four components.

NRCan is developing a national Earthquake Early Warning System (EEW) with federal, provincial, Indigenous, and other partners and in collaboration with the United States Geological Survey. The national EEW network is focused on the west coast of BC and in the densely populated regions of eastern Ontario and southern Quebec; this national EEW system is slated to be operational in 2024.

Lack of long-term financial support for maintaining operation and improving technology is the main challenge for many of the existing monitoring and forecasting systems, such as the BC Storm Surge Forecasting System (a joint program between the BC Ministry of Environment and Fisheries and Oceans Canada), and avalanche warning services (mostly run by Avalanche Canada, which is a non-governmental and non-profit organization, and Parks Canada). The monitoring system for volcanoes is far less advanced than other hazards. There is a need for enhancing predictive services to integrate climate projections into forecasting landslides, debris flows, droughts, water scarcity, and wildfires.

3. **Communication and dissemination of warnings**
Canada has a National Public Alerting System (NPAS) that provides emergency management organizations across the country with the capability to rapidly warn the public of imminent or unfolding hazards to life. The NPAS is a collaborative initiative between federal, provincial, and territorial (FPT) governments and complements existing public alerting systems and tools in a number of FPT jurisdictions.

The BC government is expanding the use of push notifications to cellular phones during emergencies to also include floods and wildfires. The Alert Ready system was previously used only for tsunami warnings, Amber Alerts, and very rare police

BOX H: FOUR COMPONENTS OF IMPACT-BASED FORECASTING AND EARLY WARNING SYSTEMS

Early warning systems consists of four components. All of these components are critical and the design and implementation of each requires a wide range of technical, legislative, governance, accountability, operational and capacity development, organizational partnership (including with the private sector and volunteer organizations), community engagement, and public communications.

1. Disaster risk knowledge
Having an understanding of the possible impacts of events provides the basis for forecasting impacts and can significantly improve the quality and effectiveness of response and evacuation planning in an early warning system as it can shape the evacuation and response plans as well as the content of public messages.

2. Detection, monitoring, analysis, and forecasting of the hazards and possible consequences
The detection, monitoring, analysis, and forecasting of hazards and possible consequences is essential to generating accurate warnings in a timely fashion that allow sufficient time for the affected communities and authorities to enact their disaster management plans, including evacuations. Early warning systems must have scientifically sound and reliable technology that allows for the monitoring and detection of hazards in real time or near real time, and a forecasting and warning system that is operational 24 hours a day, 365 days a year. The system must be staffed and monitored by qualified people and have a multi-hazard focus.

3. Communication and dissemination of warnings
It is critical that early warning systems provide timely, clear, and concise warning messages containing simple, useful, and actionable information on risk and impact. This is key to enabling the necessary preparedness and response measures that will help safeguard lives and livelihoods by individuals, communities, and organizations.

4. Preparedness and response capabilities
For an early warning system to ultimately be effective, the general public (and particularly vulnerable populations) should be aware of the risks they face, understand what different warnings mean, and be clear on what actions they should take to protect themselves and their property.

incidents, but the alert system was not used in November 2021 during the atmospheric river and following floods. All other hazards (avalanche, volcano, landslides) should also get connected to NPAS. Until May 2022, the Alert Ready system was not accessible to local governments, yet the duty to warn residents of hazards and risks has been the responsibility of the local authority for many years, as stated in provincial legislation: *Local Authority Emergency Management Regulation* describes the duty to "establish procedures by which those persons who may be harmed or who may suffer loss are notified of an emergency or impending disaster."[51] In order to meet this legislated requirement, local governments procured private notification services, all of which require some form of user subscription, which results in woefully inadequate subscription rates (less than 10% in most jurisdictions). Due to Canadian Radio-television and Telecommunications Commission (CRTC) regulations, local authorities do not have access to push notification technology and so were reliant on national and provincial governments for that service. The recent move to allow local authorities the ability to request push notifications via Alert Ready is welcome.

4. **Preparedness and response capabilities**
   There are challenges observed in evacuations mostly because evacuation plans are not in place or the population is not well educated in how to respond to an evacuation notice. Emergency preparedness education and outreach campaigns are key components in ensuring that residents are ready to effectively act on risk information, warnings, and instructions. Residents need to know the answer to "What now?" when they receive a notification through the Public Alerting System.

4.2 Develop standardization and guidelines in recovery processes.

It is important to note that this edition of the Resilience Pathways Report does not include dedicated articles on emergency response nor recovery planning. A few key points have been raised through interviews, which are presented here. EMBC has published the fourth edition of *Recovery Guide for Local Authorities and First Nations* in February 2022. Some of the following points may already be reflected in the updated guide.

Physical Recovery

The accurate and efficient assessment of the damage caused to buildings and critical infrastructure in an area hit by a disaster (earthquake, tsunami, fire, flood, etc.) is essential for prioritizing recovery resources and actions. Rapid damage assessment guidelines, training, and tools have been developed by BC Housing for residential buildings. Further work is needed for infrastructure damage assessment protocols and prioritization tools. Greater government and private sector cooperation and communication is required before, during, and after the disaster. This was evident in October 2018 when an explosion and fire in a natural gas pipeline northeast of Prince George led to natural gas shortages throughout BC. A working group was established, facilitated by Integrated Partnership for Regional Emergency Management (IPREM), to ensure clarity in roles and responsibilities in recovery and improve communication between Fortis and local governments. This collaborative work would best be facilitated before an emergency and applies across all CI sectors.

Delays in development planning and building permit processes during disaster recovery are exacerbated by reduced staff capacity and applicants under financial and emotional stress. Local government planning departments could consider disaster scenarios and create tools and resources to expedite the implementation of official community plans (OCPs) as part of proactive recovery planning. Hazards and risks should be considered early in the process of developing OCPs. Most importantly, the community impacted by the disaster must be consulted in a meaningful way throughout the recovery process. This consultation should be facilitated by both engagement and planning professionals and should be an eligible cost under Disaster Financial Assistance.

Social Recovery

Social recovery planning committees are one forum available to work collaboratively before a disaster with SI organizations, BC Housing, Ministry of Social Development and Poverty Reduction, and Ministry of Health. These same agencies can then come together during disaster recovery as an "Unmet Needs Committee" to assist residents to fill the gaps of recovery assistance for longer term.

Economic Recovery

While Disaster Financial Assistance is important, it does not go far enough nor is it accessible quickly enough to meet the initial recovery needs of a community post-disaster. Some local governments can access reserve or emergency funds to implement immediate, high-priority actions.

Insurance provides the best financial resilience. Yet, vulnerable populations tend not to be adequately insured because insurance is expensive. In rural areas compared to urban areas in BC, there are more property owners that do not have mortgages and are therefore not required to have insurance.

When more people buy insurance, society tends to be more resilient, prompting it to bounce back faster after a catastrophic loss than in places where fewer people purchase coverage. Only 60% of homeowners in the BC Lower Mainland have earthquake insurance, leaving a large protection gap. Linear assets (sewer, water lines) tend to not be insurable.

GAPS IN THE FIRST EDITION OF RESILIENCE PATHWAYS REPORT

While this first edition of the Resilience Pathways Report covers a wide range of topics and issues in its articles, there are some important issues that were not covered sufficiently, and future editions can bring experts together to analyse and share insights on these topics:

- Emergency response and recovery planning is fundamental work for managing impacts of residual risk and requires risk-informed planning pre-disaster. Guidance and support in the form of resources and capacity development is needed in developing response plans and recovery plans. While many emergency managers were engaged at early stages and interested to contribute to this report, none of them could afford the time as they were all fully occupied with the various disaster events of 2021.
- The role of the private sector in disaster and climate risk management needs to be recognized and better understood as the backbone of the economy and provider of many services to society. The private sector also has deep expertise and resources in areas that are required for disaster and climate risk management.

  Issues of critical importance to be explored include:

  - The status, gaps, and needs in enterprise risk management and business continuity for small and medium businesses.
  - Understanding and managing disaster and climate financial risks in pension funds.
  - Leveraging public-private partnerships in establishing forecasting and alerting systems.
- Land-use planning is one of the most effective tools in avoiding the creation of new risk and building long-term resilience. Urban and land-use planning practices are still allowing extensive development in hazard-prone areas. While it might not be possible to completely avoid building in hazard zones, we need updates in land-use planning legislations and enforcement mechanisms to prioritize resilience of the society over financial benefits or the cost of change in status quo approaches.
- Nature-based solutions are an effective approach to manage disaster and climate risk that also protect, sustainably manage, and restore natural ecosystems. While its value has been recognized, there are limited expertise, guidance, and resources available to local governments for designing and implementing nature-based solutions.

- Specific hazards such as tsunami, urban floods, drought, extreme windstorms, extreme weather (cold and heat waves, snowstorms, and frosts), chemical and industrial accidents, biological hazards and cyber-attacks.
- Insurance and other financial risk management mechanisms are critical in managing the financial impacts of residual risk and there are many recent efforts to enhance insurance availability and protection for Canadians (for example, Public Safety Canada–led task force on flood insurance and relocation).
- Understanding the risk and resilience in telecommunication, water and sanitation, and transportation critical infrastructure.

CONCLUDING REMARKS

With the growing trends of disaster and climate risk due to population growth, climate change, and aging infrastructure, "business as usual" in risk management can have devastating social, environmental, and economic costs. There is great need for innovative, informed, and collaborative planning at all levels to support climate and disaster risk management that is integrated in a wide range of policies and actions, including development planning, across different sectors.

The authors and collaborators who prepared the articles of the Resilience Pathways Report 2022 have provided insights on challenges and recommendations for the paths forward based on scientific evidence and experiences on the ground. Each article is accessible independently and provides detailed information on the challenges and recommendations related to its respective topic. The common trends from all articles were identified and synthesized for developing this Strategic Summary for Policy Makers.

The Resilience Pathways Report provides a mechanism and platform for a wide range of stakeholders to collaborate and share their valuable insights on gaps and priority actions for building our resilience. Sustainability and success of this initiative requires funding, a dedicated editorial team, and leadership support from a provincial or federal government entity. This initiative, as a bi-annual endeavour, provides an up-to-date strategic resource on the current issues that need attention from risk management actors and decision makers. It will be an effective mechanism to monitor and evaluate progress over time in implementation of the Sendai Framework, Modernized EPA, and *BC Climate Preparedness and Adaptation Strategy*.

The continuation and sustainability of this initiative requires funding, a dedicated editorial team, and leadership support from a provincial or federal governmental or strong non-governmental entity. The editorial team welcomes expressions of interest from any governmental or non-governmental entities interested in hosting the next edition.

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1.1 HAZARD OVERVIEW: A PROFILE OF NATURAL HAZARD THREAT FOR BC

June 2022

DRRPathways.ca

RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 1 Understanding and Managing Climate and Disaster Risk: Hazard Threat*. To read all articles in the report, see DRRPathways.ca.

The Resilience Pathways Report is a project of Natural Resources Canada.

1.1 HAZARD OVERVIEW: A PROFILE OF NATURAL HAZARD THREAT FOR BC

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INTRODUCTION

Natural hazard threat occurs in areas of the built environment where earth system processes have a potential to cause loss of life, injuries, property damage, and/or socioeconomic disruption. The severity of threat varies from place to place based on the physical susceptibilities of people and critical assets to natural hazard processes, and on intrinsic social vulnerabilities that may limit the capacities of certain population groups to anticipate, withstand, and respond to the negative impacts of future disaster events. As communities continue to expand and densify in response to the pressures of urban growth, so too do corresponding trends in natural hazard threat.

Adoption of the UN's *Sendai Framework for Disaster Risk Reduction 2015–2030* in Canada has shed light on the critical role that disaster risk information can have in promoting community resilience and sustainable development strategies at local and regional scales.[1] Nonetheless, there remain significant challenges in establishing the evidence, incentives, and resources that are required to incorporate disaster risk information into the broader context of planning and policy development. For many communities, the challenge is in sourcing the necessary information, knowledge, and insights needed to develop integrated disaster risk reduction strategies that are robust enough to meet the requirements of sustainable community development—where regulatory requirements for public safety and the security of public assets must be balanced against competing demands for economic growth, social equity, and environmental integrity. For others, there are political challenges in considering investments in longer-term risk reduction measures that threaten to draw scarce resources away from what appear to be more immediate public policy concerns.[2, 3]

While our understanding of natural hazard processes has increased significantly over the last few decades, the ability to assess likely impacts and consequences of future disaster events (i.e., risk) is often limited by access to an equally comprehensive understanding of who and what are situated in harm's way and the underlying physical and social determinants of risk at a given location. Public Safety Canada and Defence Research and Development Canada have embarked on a multi-year project to address these challenges by increasing our understanding of natural hazard impacts and by enhancing capacities that will be needed to transform this knowledge into actionable strategies for disaster risk reduction.[4, 5] Initial stages of the National Risk Profile (NRP) are focused primarily on the negative impacts of flood, wildfire, and earthquake hazards in Canada.

Natural Resources Canada contributes to the broader mandate of increasing disaster resilience at the community level through fundamental research on natural hazard processes (e.g., earthquakes, tsunamis, volcanic eruptions, floods, landslides, space weather, wildfire) and through the development of analytic methods that are used to assess both current levels of threat and the potential for disaster risk reduction through proactive investments in mitigation, adaptation, and emergency planning. The following sections summarize highlights of a national assessment of natural hazard threat in Canada[6, 7] with a focus on the underlying physical and social determinants of risk that are specific to BC. Model outputs are accessible through an open-science data platform (OpenDRR) designed to support disaster resilience planning in Canada.[8]

THE BUILT ENVIRONMENT

BC encompasses ~8% of the total developed area of Canada (9,950 km^2) and is home to more than 4.6 million people, or approximately 13% of the national population. There are ~269,000 Indigenous people living in BC, of whom ~64% are First Nations, 33% are Métis, and 0.6% are Inuit. Most Indigenous people (60%; 161,400 people) live in cities, towns, and villages throughout the province, and the remaining 40% (107,600 people) live on designated First Nations reserve lands.[9]

The share of people living in these higher-density population centres is estimated to have nearly doubled over a forty-year period (1975–2015) while growth in rural and remote settlements has increased by a factor of only ~1.3 over this same period.

Regional patterns of human settlement in BC are controlled primarily by a rugged western coastline, steep mountainous terrain throughout much of the interior region of the province, and a limited supply of privately owned land for residential and commercial development (see Figure 1). Settled areas in rural and remote settings represent more than half of all developed lands in BC (52%; ~5,200 km^2) and account for more than 11% of the total population (~537,000 people). More densely settled metropolitan regions encompass a smaller overall development footprint (48%; ~4,800 km^2), yet account for more than 88% of the total population (~4.1 million people). The share of people living in these higher-density population centres is estimated to have nearly doubled over a forty-year period (1975–2015) while growth in rural and remote settlements has increased by a factor of only ~1.3 over this same period.[10, 11] As it turns out, many of these larger metropolitan regions are situated in areas that are exposed to significant levels of natural hazard threat (Figure 2).

There are ~1.2 million buildings in BC, with an estimated replacement cost of $1.42 trillion.[i] Nearly three quarters of all buildings (74%; ~881,000 structures) are single-family urban and rural residential homes, with the remainder being represented by multi-story buildings in higher-density multi-family residential neighbourhoods (~17%; 202,000 structures) and mixed-use neighbourhoods (~9%; 112,000 structures). More than half of the population in BC lives in multi-family buildings of various types (54%; 2.5 million people) with ~45% in single-family homes (2.1 million people) and ~1% in mixed-use commercial and industrial buildings. Although representing a relatively small proportion of the total building stock, non-residential buildings account for ~41% of the total capital asset value ($587 billion), followed by multi-family buildings (30%; $426 billion) and single-family homes (28%; $404 billion). The number and types of buildings at a given location provide important insights on *where* the impacts of future hazard events are likely to be the greatest, and also provide a framework for assessing both *who* and *what* will be most affected for different locations within a particular community or region.

[i] *All values in Canadian dollars.*

Developed Areas

9,950
km2

Buildings

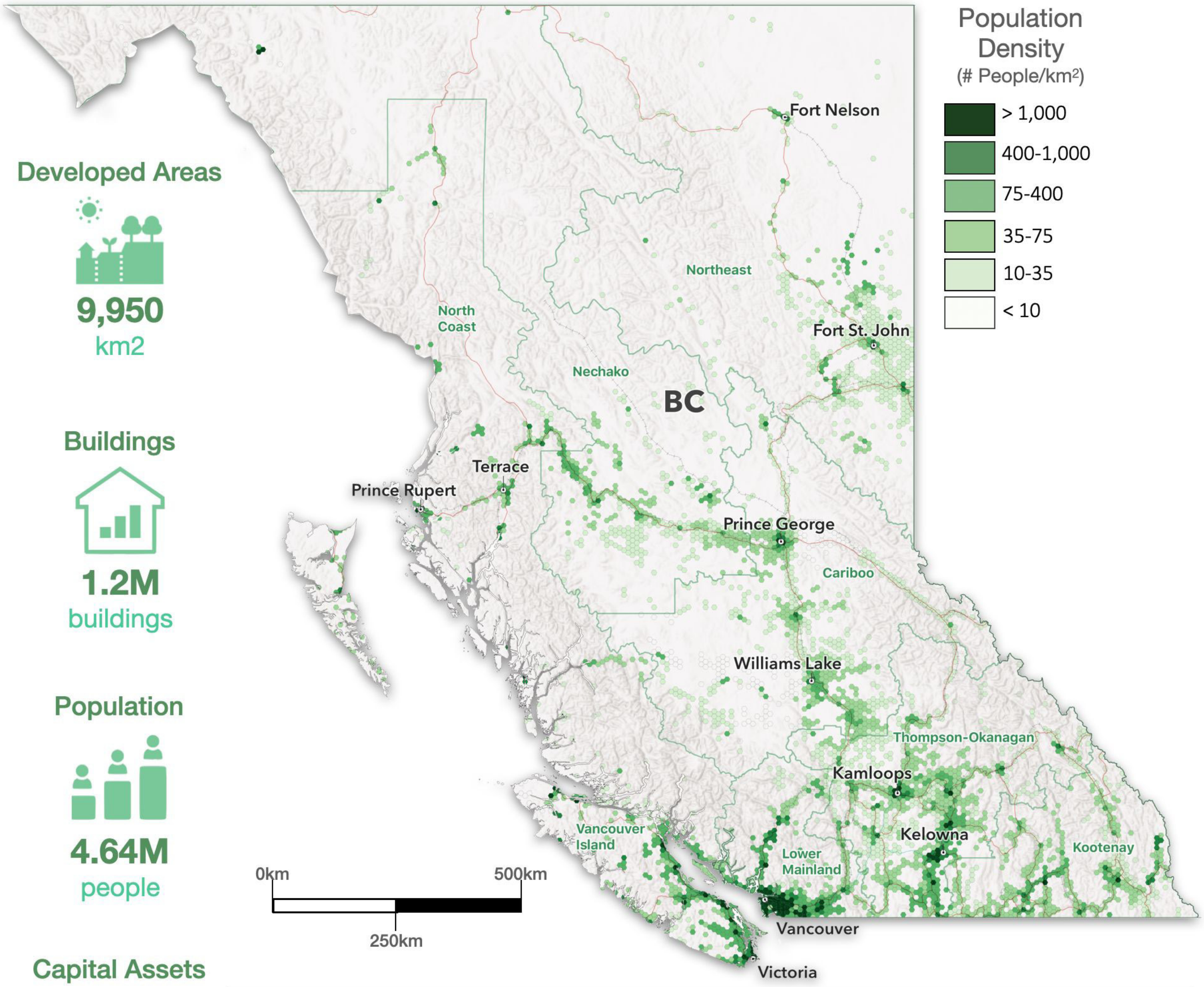
1.2M
buildings

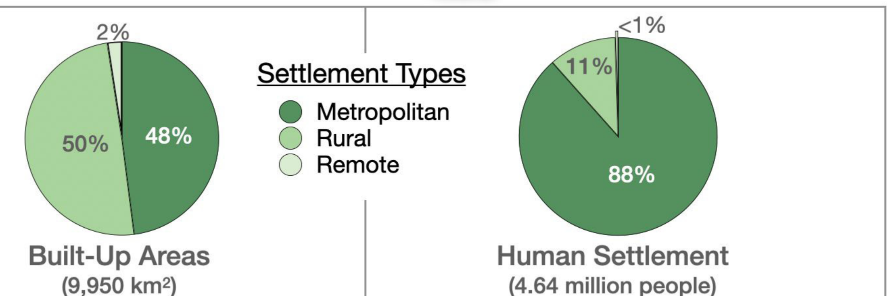
Population

4.64M
people

Capital Assets

C$1.42
trillion





Economic Regions	Built-Up Areas: Metropolitan	Built-Up Areas: Rural	Built-Up Areas: Remote	Human Settlement: Metropolitan	Human Settlement: Rural	Human Settlement: Remote
Lower Mainland	1,876	333	18	2,765K	64K	2K
Vancouver Island	997	703	37	681K	114K	5K
Thompson-Okanagan	792	1,184	38	422K	121K	3K
Cariboo	731	539	9	128K	27K	1K
Kootenay	183	840	12	45K	106K	1K
Northeast	155	841	6	41K	26K	1K
North Coast	42	130	27	28K	22K	5K
Nechako		364	95		34K	4K

Figure 1: Patterns of human settlement and regional profiles of physical exposure in BC (Graphic: Murray Journeay).

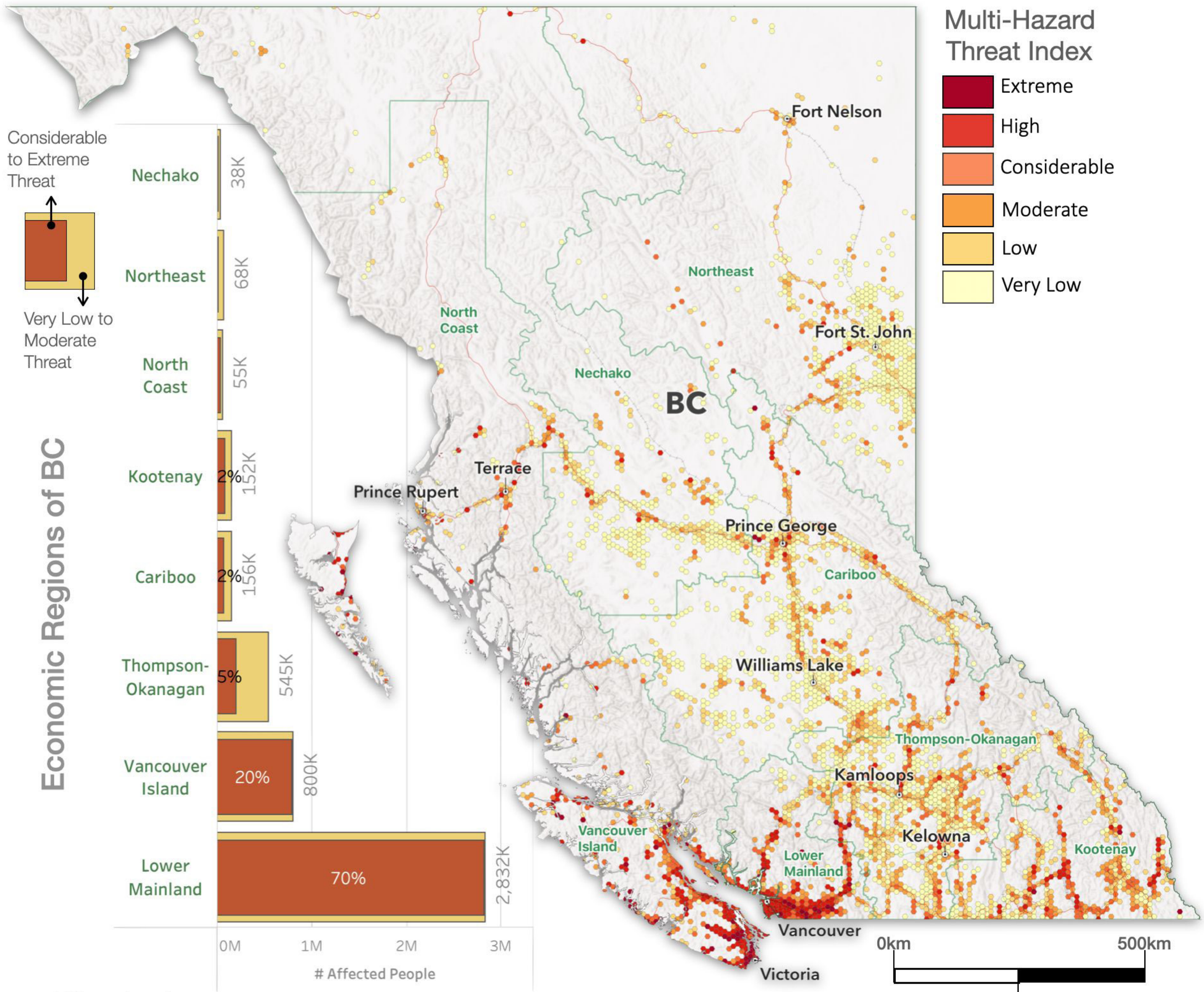
Figure 2: Metropolitan areas around the province are exposed to various natural hazard threats (Photo: iStock / Sen Yang).

PHYSICAL SUSCEPTIBILITY TO NATURAL HAZARDS

Our analysis of physical susceptibility to natural hazards in BC (Figure 3) is based on available open-source hazard assessment information. These include probabilistic models that predict spatial patterns and intensity levels for earthquake, tsunami, and flood events that are likely to occur over a ~500-year period,[12-15] and stochastic models that assess wildfire hazard intensity and the potential for landslides based on seasonal weather and land cover conditions.[16, 17] The analysis of physical susceptibility considers both the overall exposure of people and critical assets to each of these hazards and the potential for negative impacts based on empirical damage scales that relate the overall resistance of buildings and other engineered structures to measured hazard intensity levels at a given location. Damage scales include the Modified Mercalli Index for earthquakes,[18, 19] generalized depth-damage functions for riverine floods,[20] and the Wildland Urban Interface (WUI) fire hazard index.[21]

Hazard footprints for each of these perils are intersected with built-up areas of human settlement to assess mean hazard intensity, and the corresponding number of people, buildings, and value of financial assets that are susceptible to corresponding levels of damage (i.e., very low, low, moderate, considerable, high, and extreme). The combined hazard threat for all perils at a given location is evaluated by multiplying an aggregate hazard intensity score by the number of people who are likely to be affected over a 24-hour period. As shown in Figure 3, areas of considerable, high, and/or extreme levels of physical susceptibility to natural hazards are concentrated primarily along southwest coastal regions of the Lower Mainland and southern Vancouver Island; interior mountain valley sections of the Thompson-Okanagan, Kootenay, Cariboo, and Nechako regions; and North Coast regions of BC. Collectively, these areas of more severe physical susceptibility affect more than 90% of the total population in BC (~4.2 million people). Regional hazard threat profiles are controlled primarily by extensive ground shaking and coastal inundation hazards associated with earthquake and related tsunami events along the active plate margin of western North America, and by the combined effects of more localized flood, landslide, and wildfire events that occur on a more regular basis along river valleys and major transportation corridors throughout BC.

By intersecting hazard footprints with historic patterns of human settlement derived from national census data we are also able to measure escalating trends in physical susceptibility related to rapidly evolving patterns of growth and urban development that have occurred since 1975.[22] As shown in Figure 4, regional profiles of flood and tsunami hazard threat in BC have increased at rates of 71% and 73% respectively over a forty-year period and are comparable but lower than overall trends in population growth (76%). Wildfire and landslide hazards have increased at much lower rates (42% and 61%, respectively), while those associated with catastrophic



Physical Susceptibility

		Earthquake		Tsunami		Flood		Wildfire		Landslide	
Susceptibility Threshold		>3.9%g	**>18%g**	>25%	**>50%**	>30 cm	**> 1m**	>500 kW/m2	**> 2,000 kW/m2**	Index Value >2	**Index Value > 3**
People	**4,645,786**	3,675,618	3,380,000	432,319	319,559	1,168,143	295,029	393,606	165,355	1,286,620	376,922
	% of Total	79%	**72.8%**	9.3%	**6.9%**	25.1%	**6.4%**	8.5%	**3.6%**	27.7%	**8.1%**
Buildings	**1,195,098**	840,054	743,706	97,315	68,615	339,939	96,644	141,829	58,198	453,486	139,370
	% of Total	70%	**62.2%**	8.1%	**5.7%**	28.4%	**8.1%**	11.9%	**4.9%**	37.9%	**11.7%**
Assets (m $CAD)	**$1,416,507**	1,073,629	977,155	158,996	119,365	366,691	102,843	129,885	52,721	414,801	117,237
	% of Total	76%	**69.0%**	11.2%	**8.4%**	25.9%	**7.3%**	9.2%	**3.7%**	29.3%	**8.3%**

Figure 3: Physical susceptibility to natural hazard threats in BC (Graphic: Murray Journeay).

Historical Profile of Physical Susceptibility to Natural Hazards in BC

Epoch	1975	1990	2000	2015	40-year Growth Rate
Total Population	**2,660,621**	**3,368,910**	**3,865,314**	**4,687,192**	**76%**
Earthquake	1,775,932	2,324,388	2,715,764	3,380,124	**90%**
Tsunami	172,401	217,032	247,168	298,855	**73%**
Flood	179,464	225,559	256,877	306,406	**71%**
Wildfire	144,279	170,302	184,108	204,480	**42%**
Landslide	310,982	382,690	429,410	499,340	**61%**

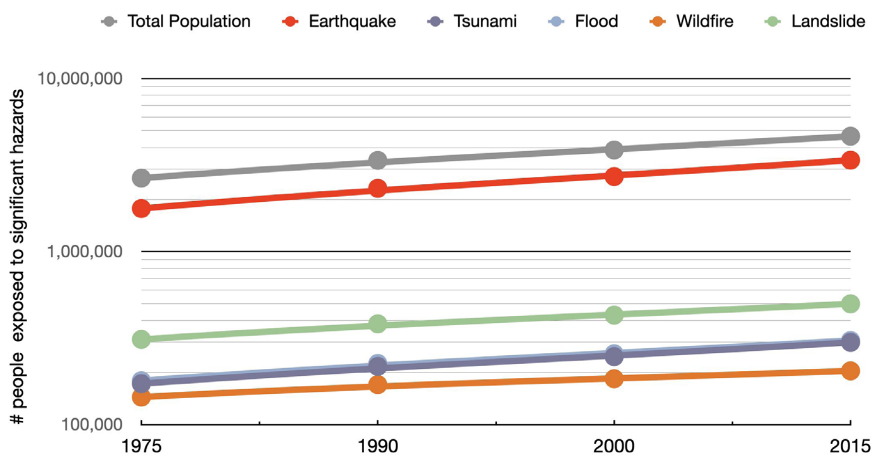


Figure 4: Correlations between growth and development over a forty-year period (1975–2015) and corresponding profiles of natural hazard threat in BC (Graphic: Murray Journeay).

earthquake hazards have increased by more than 90% over this same period. Lower rates of growth for wildfire and landslide hazard threats may be related to the relocation of people from rural and remote communities into more densely settled metropolitan regions. More rapid rates of growth for earthquake threats are attributed to a corresponding increase in the numbers of people moving into densely populated urban centres that are situated in areas exposed to more severe ground shaking hazards. Based on population projections by Statistics Canada, it is anticipated that these trends will likely continue over the next forty years.[23]

SOCIAL VULNERABILITY

Certain population groups often bear a disproportionate share of the physical impacts and related socioeconomic consequences when a disaster strikes. Those most affected by underlying social, economic, and political factors that increase levels of social vulnerability include lower-income households, recent immigrants, racially marginalized populations, and other groups whose rights and needs are not always fully considered in the context of community planning or disaster risk management.[24-28] Understanding the patterns and underlying causes of social vulnerability within a given community or region is an important step in identifying and prioritizing actions that can be taken in advance to reduce levels of disparity and to improve the overall prospects of disaster resilience.

Certain population groups often bear a disproportionate share of the physical impacts and related socioeconomic consequences when a disaster strikes. Those most affected . . . include lower-income households, recent immigrants, racially marginalized populations, and other groups whose rights and needs are not always fully considered in the context of community planning or disaster risk management.

Our assessment of social equity in BC is based on theoretical principles established by the Hazards of Place model,[29, 30] which highlights spatial interactions between social, economic, and physical dimensions of vulnerability that exist within a given community or region. System interactions are evaluated using a blend of statistical analysis and geospatial modelling to assess how patterns of vulnerability vary from one place to another as a function of:

1) social inequities that are intrinsic to a particular community or region; 2) levels of physical exposure and susceptibility to natural hazards that are controlled by geographic setting; and 3) human adjustment behaviors that have the potential to either amplify or lessen the outcomes of disaster events over time.

Profiles of social vulnerability are evaluated using a hierarchical framework of composite indices that measure both absolute levels of disparity for specific settlement types at a given location and the relative contributions of underlying socioeconomic factors that are known to influence the capacities of community members to withstand, cope with, and recover from disaster events. These include characteristics of family structure, housing conditions, the capacity of individuals to make decisions that will affect their own wellbeing, and the financial resources needed to weather both the physical impacts and downstream economic consequences of a disaster event. Fundamental patterns of social vulnerability are assessed by tallying the number of instances where indicators at a given location exceed values that are typical for a corresponding settlement type (mean + 1sd). Relative degrees of social vulnerability (low, moderate, considerable, high, and extreme) are evaluated by categorizing the distribution of threshold exceedance scores into statistically significant groupings. Levels of integrated hazard threat are then assessed by multiplying social vulnerability indices (SVI) by multi-hazard threat scores at a given location. Results of our assessment are summarized in Figure 5.

Mean threshold scores in BC are equivalent to or exceed national average values across all dimensions of social vulnerability for each of the major settlement types in Canada. Although levels of disparity are highly variable from place to place, results of our assessment show that people living in densely settled multi-family residential and mixed-use neighbourhoods in BC are more likely to experience higher levels of social inequity compared with those living in single-family neighbourhoods. Those most affected include: 1) recent immigrants and newcomers from other parts of the country living neighbourhoods with high levels of housing insecurity; 2) lower-income families and individuals from diverse ethnic and cultural backgrounds with limited access to resources and social support networks; and 3) those living in areas with higher concentrations of unaffordable and/or insecure rental housing.

There are also significant disparities between people living on designated First Nations reserve lands and those living in equivalent settlement types governed under provincial jurisdiction. Differences in mean levels of vulnerability are relatively small in the major urban centres of southwestern BC but increase in rural and remote settings where measures of vulnerability for Indigenous communities exceed those of the general population by a factor of between 1.3 and 1.9. Contributing influences include overcrowded housing, higher than average levels of unstable employment, and additional financial stresses related to higher shelter costs and reduced capacities for household maintenance by homeowners who are either younger than 25 years or older than 65 years.

DISASTERS BY DESIGN

Disasters are the predictable outcome of ongoing growth and development in areas where both physical systems of the built environment and the complex network of interconnected social, economic, and political systems that define the essential fabric of cities, towns, and rural communities are periodically overwhelmed by the forces associated with natural hazard events.[31, 32] If disasters are predictable, why is it that the most vulnerable members of society continue to be situated in areas that are both more susceptible to the physical impacts of future disaster events and disproportionally affected by land governance decisions that limit their capacity to weather the downstream socioeconomic consequences? May and Deyle[33] suggest the answer to this thorny question may lie at the intersection of a central conflict in public policy agendas where "common good" goals of public safety, economic security, social equity, and environmental justice are systematically overshadowed by the more immediate concerns of promoting growth and maximizing

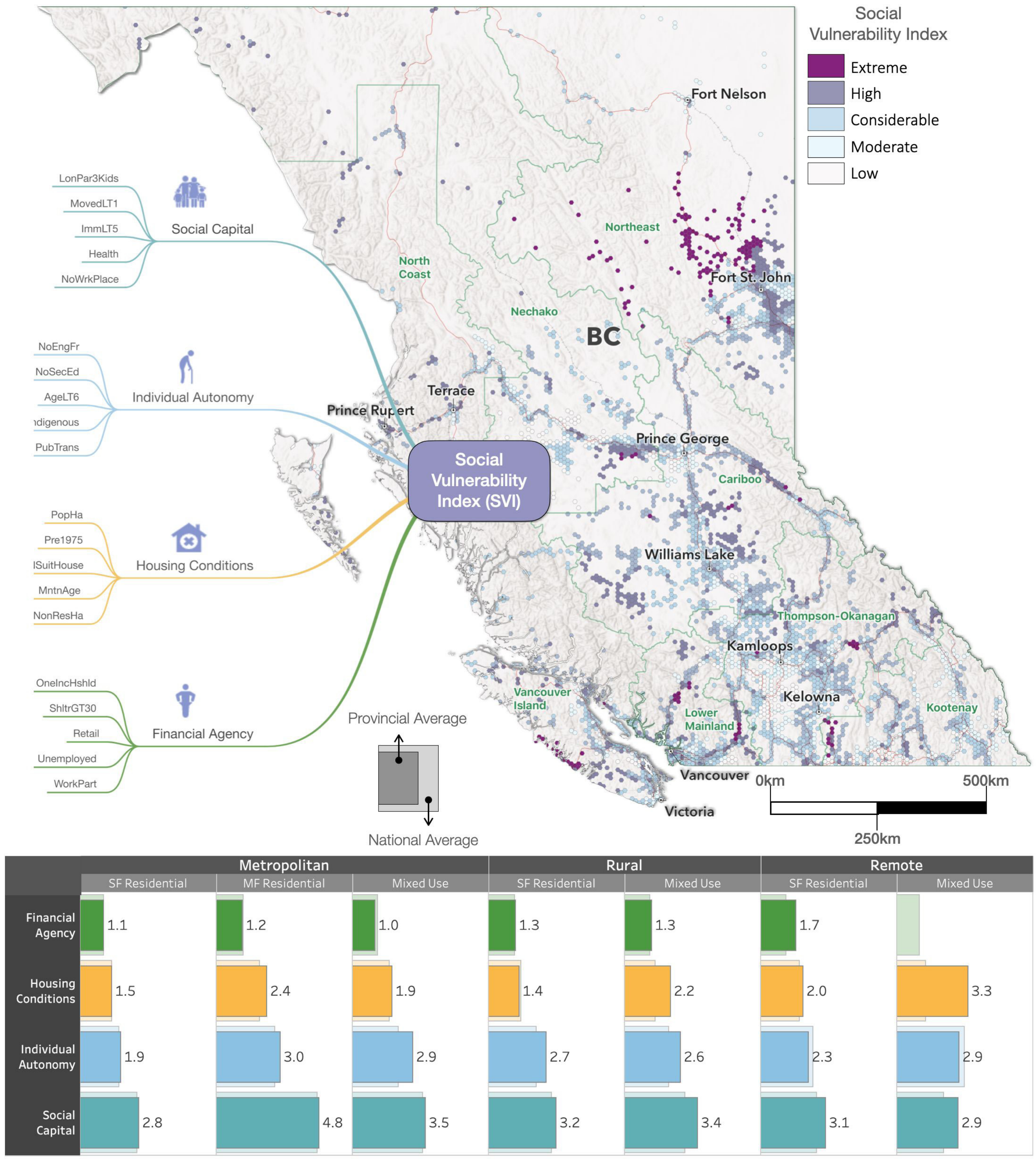


Figure 5: Regional disparities in social equity and corresponding profiles of social vulnerability in BC (Graphic: Murray Journeay).

the shorter-term economic benefits of developing privately owned lands at the community level.

> [There is a] central conflict in public policy agendas where "common good" goals of public safety, economic security, social equity, and environmental justice are systematically overshadowed by the more immediate concerns of promoting growth and maximizing the shorter-term economic benefits of developing privately owned lands at the community level.

While there is an obvious need to measure the potential physical impacts of natural hazards and how they vary from one location to another to help guide strategic investments in disaster risk reduction, it is equally important to understand who is in harm's way, cultural perceptions of risk, and potential issues of social inequity that may be associated with the spatial distribution of hazard threats within a given community or region. The integration of social and physical dimensions of hazard threat provides important insights on who is likely to bear the greatest burden of risk following a disaster event, the underlying causal factors that systematically disadvantage the most vulnerable in our communities, and strategic opportunities for increasing capacities for functional recovery at the neighbourhood level.

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Photo: Wayne Ball

1.2 SNOW AVALANCHES

June 2022

DRRPathways.ca

RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 1 Understanding and Managing Climate and Disaster Risk: Hazard Threat*. To read all articles in the report, see DRRPathways.ca.

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1.2 SNOW AVALANCHES

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ABOUT SNOW AVALANCHES

DESCRIPTION

Snow avalanches[i] are rapid, gravity-driven mass movements of snow that start on slopes of sufficient steepness (Figure 1). Large avalanches can encompass more than 10,000 tonnes of snow and run for kilometres with speeds up to 200 km/h and impact pressures on the order of 1,000 kPa.[1]

Avalanche release is determined by complex interactions between terrain, the sequence of weather events that produced the local snowpack, current weather conditions, and the triggering mechanism. The most fundamental and constant indicators for assessing whether a slope with sufficient snow cover has the potential to release avalanches are slope incline and forest density. Avalanches typically require relatively open slopes steeper than 25 degrees to start and accelerate, but the most common slope angles are between 30 degrees and 45 degrees. Once released, large avalanches travel downslope along the avalanche track until they reach the runout zone where the terrain is consistently less than 15 degrees steep. It is in this area where the avalanche debris decelerates and is deposited. However, the exact runout distance of an avalanche depends on the total amount of snow released and the specific terrain characteristics of the entire path. While avalanches typically do not release on densely forested slopes, they can run into forested terrain and destroy mature timber. This means that most mountainous terrain in BC with sufficient snowfall is either capable of producing avalanches or potentially threatened by avalanches from above. In addition to natural avalanche terrain, human-made structures such as roofs, dam faces, and steep cutbanks are also able to produce avalanches.

People and assets located in avalanche paths can be damaged or destroyed by avalanches. Examples of threatened assets include occupied structures, transportation infrastructure including vehicles and occupants, critical energy or communication infrastructure, and natural resources and associated development infrastructure. In addition to these direct impacts, avalanches can also have secondary impacts. Examples include transportation or production delays as well as financial, legal, and reputational impacts. Short- and long-term psychological impacts from avalanche accidents have been documented but are not routinely monitored.[2,3]

[i] *All mentions of the term "avalanches" in this article refer to snow avalanches.*

Figure 1: An explosive controlled avalanche at the Galore Creek Project located in northwestern British Columbia, Canada (Photo: Wayne Ball).

AVALANCHE THREAT AND PAST EVENTS

There has been a distinct evolution in the nature of avalanche accidents in BC.[4] Prior to about 1970, avalanche accidents primarily involved transportation infrastructure, resource industries, or buildings. Examples of some of the most noteworthy accidents during that period include the railway accident on Rogers Pass on March 4, 1910 (58 railway workers killed), the Granduc Mine accident on February 18, 1965 (26 mine workers killed), and the North Route Café accident on Highway 16 west of Terrace on January 22, 1974 (seven stranded motorists killed).[5] All of these accidents occurred during major winter storms that resulted in widespread avalanche activity. They caused substantial property damage and killed individuals who involuntarily and possibly unknowingly exposed themselves to the hazard.

Since 1970, the majority of avalanche fatalities have involved winter backcountry recreationists who voluntarily exposed themselves and accidentally triggered avalanches while travelling in mountainous terrain. The shift from industrial to recreational accidents was due to a combination of improved avalanche risk management in non-recreational settings (i.e., highways, railways, mines, developments, etc.) as well as the growing popularity of winter backcountry recreation. Most of these post-1970 accidents resulted in single or double fatalities, but larger, multi-casualty accidents have also occurred (e.g., Canadian Mountain Holidays Bay Street with nine fatalities on March 13, 1991; Connaught Creek with seven fatalities on February 1, 2003; Harvey Pass with eight fatalities on December 28, 2008).[6] Since 1981, 95% of the 458 avalanche fatalities in Canada involved backcountry recreationists, and 72% of these individuals perished in BC. At the time of this writing, an average of ten individuals are killed in avalanches in Canada every year and eight of them typically occur in BC.

DRIVERS OF RISK

The main anthropogenic driver of recent changes in avalanche risk is increased exposure to avalanche hazard. While there are no systematic observations of more people in uncontrolled (backcountry) terrain, indirect indicators (e.g., sales of backcountry recreation equipment) show that the popularity of winter backcountry recreation has increased tremendously over the last decades,[7] as have traffic volumes on mountain roads and highways. Natural resource extraction and associated infrastructure developments are also pushing further into mountainous terrain, and wildfires and construction activities such as deforestation, slope or rock cuts, or the construction of dam faces can create new avalanche terrain. At the same time, avalanche risk has been mitigated through improved avalanche planning, expanded public safety programs and resources, advances in avalanche safety and rescue equipment, tightened worker safety regulations and land-use policies, continued development and enrollment in training programs for recreationists and avalanche professionals, and advancements in understanding and forecasting of avalanche hazard.

UNDERSTANDING RISK

WHAT SOURCES HELP US UNDERSTAND HAZARD AND RISK

Avalanche risk is the probability or chance of harm resulting from interactions between avalanche hazard and specific assets, and it is determined by the exposure of those assets and their vulnerability to the hazard.[8] To describe how avalanche hazard and risk are assessed, it is best to distinguish between long-term avalanche planning and short-term operational avalanche forecasting as they use distinct techniques and information sources. However, in both contexts, the risk assessment process consists of identification, analysis, and evaluation.

AVALANCHE PLANNING

Avalanche planning aims to assess the long-term potential for avalanches to impact a specific asset at a defined location. After confirming that the location of interest is threatened by avalanches based on a basic terrain and snow supply analysis, the risk analysis process starts with estimating the local return periods for avalanches and their destructive potential. Methods for determining long-term avalanche hazard include analysis of historic avalanche records and identification of vegetation damage through analysis of air photos and satellite imagery as well as field surveys including tree-ring analysis.[ii] This direct evidence is complemented with the output from numerical avalanche models, which estimate the maximum runout distance and simulate the flow characteristics of potential avalanches. Estimates of frequency and magnitude are then combined with estimates of the exposure and vulnerability of the assets to determine the risk level.

OPERATIONAL AVALANCHE FORECASTING

Operational avalanche forecasting is used in situations where permanent protection from avalanches is either impractical (e.g., for mobile assets such as backcountry users) or economically not meaningful (e.g., too expensive for the given exposure, such as on roads with low traffic volume), or it is used to manage residual risk after suitable long-term mitigation has been applied.[9] In these cases, the focus is on assessing the current (e.g., daily) level of avalanche hazard to direct and implement short-term mitigation measures, such as temporary closures or the use of explosives to proactively trigger avalanches before or when they become threatening. Avalanche forecasters assess the nature and severity of the current hazard conditions based on a qualitative synthesis of available weather, snowpack and avalanche observations, and their knowledge of the local terrain. Forecasters address the natural uncertainty associated with observations with targeted sampling and by assimilating evidence incrementally over time. While deductive methods are used to analyze some data, the assessment process is dominated by inductive and abductive logic and uses experience-based heuristics. The Conceptual Model of Avalanche Hazard (Figure 2) describes the essence of the qualitative forecasting process as a

[ii] Tree-ring analyses aim to estimate return periods for destructive avalanches by estimating the age of growing trees and the age of trees that were felled by avalanches as well as identifying and dating damage to trees inflicted by avalanches (e.g., scaring, tilting, decapitation).

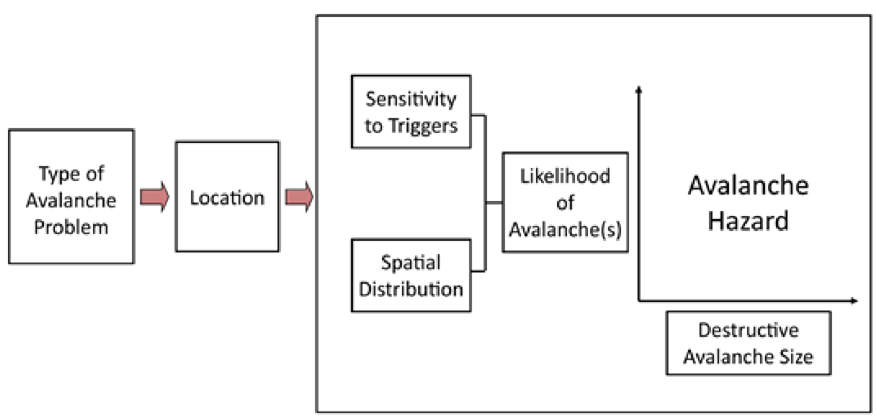

Figure 2: Conceptual Model of Avalanche Hazard used for day-to-day operational avalanche forecasting. Avalanche hazard is often represented as a range of values for both likelihood of avalanche and destructive size, representing variability and uncertainty.

systematic workflow that answers four sequential questions: 1) What type of avalanche problem exists? 2) Where are these problems located in the terrain? 3) How likely is it that avalanches will occur? and 4) How big will these avalanches be?[10]

Operational avalanche forecasting programs are common in BC and exist in many different contexts. Examples include mountain highway passes and railway lines, mine and construction sites with associated access roads, winter backcountry recreation operations, and ski areas. In most circumstances, the avalanche risk is assessed and managed in situ by a team of avalanche safety professionals who collect detailed weather, snowpack and avalanche observations to assess the local conditions throughout the winter season. To ensure a high degree of awareness about developing conditions, avalanche safety operations in BC share their observations and assessments via InfoEx, a private and confidential information exchange managed by the Canadian Avalanche Association. In addition, avalanche forecasting programs utilize remote automated weather stations and mountain weather forecasts. Numerical snowpack models that simulate the evolution of the seasonal snow cover can be used as an additional information source in areas that are otherwise data sparse.

PUBLIC AVALANCHE WARNING SERVICES

Public avalanche warning services are special types of avalanche forecasting programs that inform the general public about current avalanche conditions and help self-directed winter recreationists make informed decisions about when and where to travel in the backcountry. Agencies involved in public avalanche safety in BC include Avalanche Canada, a non-government, not-for-profit organization dedicated to public avalanche safety, and Parks Canada. Together, these agencies publish daily avalanche hazard forecast bulletins for approximately twenty regions that range in size from roughly 1,000 km^2 to more than 50,000 km^2. While smaller forecast regions are field-based, where forecasters go into the field to collect their own observations for writing the forecast (e.g., Glacier National Park), the programs for larger forecast regions are typically office-based, where forecasters primarily rely on observations collected and shared by others (e.g., InfoEx, Mountain Information Network, dedicated field teams) and the conditions are assessed remotely. This is currently the approach for most Avalanche Canada forecast regions.

While Avalanche Canada maintains an avalanche incident database that is searchable by the public, it does not have an official mandate to investigate avalanche accidents. However, Avalanche Canada and the Canadian Avalanche Association assist the BC Coroners Service to ensure it has the necessary avalanche expertise when investigating fatal avalanche accidents. Since there is no legal requirement to report or investigate non-fatal avalanche accidents, the available avalanche accident information primarily focuses on fatalities for which reliable records exist. While these reports provide insightful case studies, the lack of dependable exposure information (i.e., the number of recreationists who use the backcountry every winter) prevents the calculation of meaningful accident rates. An exception is the mechanized skiing industry, where the number of skier days has been recorded systematically since the 1970s.[11] Information on other impacts of avalanches (e.g., property damage, economic impact of road closures) is currently not collected systematically.

CURRENT PRACTICE IN HAZARD AND RISK ASSESSMENT

Since the early 1980s, the Canadian Avalanche Association has published guidelines and standards that have shaped how avalanche hazard and risk is assessed and mitigated in BC. The most recent editions of these documents include *Technical Aspects of Snow Avalanche Risk Management – Resources and Guidelines for Avalanche Practitioners in Canada* (TASARM)[12] and *Observation Guidelines and Recording Standards for Weather, Snowpack and Avalanches* (OGRS).[13] The TASARM document provides a comprehensive overview of best practices in the technical aspects of snow avalanche hazard and risk assessment and mitigation and suggests guidelines for acceptable risk and typical assessment processes and mitigation options. The risk management concepts presented in TASARM are firmly grounded in the International Organization for Standardization risk management standard known as *ISO 31000 Risk Management — Principles and Guidelines*.[14] The OGRS document describes the terminology, techniques, and data codes for making and recording avalanche, snowpack, and mountain weather observations. This long history of standard documents has resulted in a high degree of harmonization in the data collection procedures and hazard and risk assessment practices and has been crucial for the industry-wide exchange of avalanche safety information in Canada.

Figure 3: Canyon and truck (Photo: Mark Austin).

REDUCING RISK

PRACTICE AND CAPABILITIES

Avalanche risk mitigation (or risk acceptance) decisions are always based on a risk evaluation where the assessed risk level is compared against risk acceptance levels. These evaluations and the resulting avalanche risk reduction practice, policy, and capabilities depend heavily on context. Most approaches focus on managing exposure to the existing hazard, while approaches that modify the hazard (e.g., avalanche control) or decrease the vulnerability of assets (e.g., avalanche rescue training and equipment) are typically of secondary importance.

INVOLUNTARY RISK EXPOSURE

Actions taken to reduce risk to facilities, infrastructure, and individuals who involuntary expose themselves to avalanche risk are typically a combination of long-term planning and short-term operational avalanche risk management. While regulatory standards for worker and public safety are well defined (see Table 1), risk acceptance benchmarks for non-human assets are context dependent and typically defined by the risk owner based on a mitigation cost-benefit analysis that aims to reduce the residual risk to "as low as reasonably practical" (ALARP). Location planning (i.e., considering avalanche hazard when evaluating location options) is often the first step taken to reduce risk to fixed facilities or infrastructure. Avalanche hazard zoning, with associated bylaws and access policies, is typically used to restrict development of occupied structures in avalanche areas. If relocation is not an option, then engineered avalanche protection is considered. Currently, avalanche hazard zoning in BC is conducted on a case-by-case basis for new developments with updated hazard zone mapping, using modern methods for some communities with existing zoning (e.g., Stewart and Fernie).

This long history of standard documents has resulted in a high degree of harmonization in the data collection procedures and hazard and risk assessment practices and has been crucial for the industry-wide exchange of avalanche safety information in Canada.

If these protection measures cannot reduce the risk to an acceptable level or are economically not feasible, seasonal closures are considered except in situations where long closures are unacceptable (e.g., highways, ski areas, active work sites). In these circumstances, avalanche professionals will use short-term risk reduction actions (e.g., temporarily restricting access to exposed areas during periods of elevated hazard) based on operational avalanche forecasting. In industrial situations where the threat from avalanches is infrequent and relatively low, risk reduction actions have also been based on regional hazard assessments published in public avalanche bulletins. Risk management at work sites typically includes avalanche safety training and rescue equipment for workers with ongoing avalanche hazard assessment by an avalanche professional. If deemed cost-effective, artificial avalanche triggering (e.g., explosive avalanche control) can be used to proactively reduce the hazard and minimize closure times.

VOLUNTARY RISK EXPOSURE

While the responsibility for the risk assessment and mitigation actions in the above contexts resides with avalanche professionals and ultimately the risk owner, avalanche risk management practices for self-directed backcountry recreation depends on the initiative and self-reliance of the involved public.[15] Key components of backcountry avalanche safety include recreational avalanche safety training, detailed trip planning, route finding, group management, and avalanche rescue equipment (e.g., avalanche transceivers, probes, shovels, air bags) as a last resort. Most actions taken to reduce risk are short-term measures that are applied on a day-to-day basis. This includes using up-to-date avalanche condition information when planning trips, continuously monitoring conditions when in the field, choosing terrain that matches risk tolerances, and following safe travel practices (e.g., spreading out and only exposing one person at a time).

INFRASTRUCTURE, TECHNOLOGY, AND TOOLS

Existing infrastructure, technology and tools that support the management of avalanche risk in all contexts include information exchange platforms such as Canadian Avalanche Association's InfoEx (avalanche professionals only), Association of Canadian Mountain Guides' Mountain Conditions Report (information from avalanche professionals that is publicly available), and Avalanche Canada's Mountain Information Network (public information) where avalanche professionals and recreationists can share information about current avalanche conditions. In addition, several networks of remote automated weather stations provide real-time weather data that are used extensively by professional avalanche forecasters and self-directed recreationists for assessing current avalanche conditions, and historical weather data from these networks are used by avalanche consultants and researchers for climate characterizations.

EVOLUTION OF PRACTICE

The evolution of avalanche safety practices in BC and Canada has largely been driven by practice reviews and recommendations following fatal accidents. The standard for avalanche safety on highways, for example, was shaped considerably by the North Route Café accident on Highway 16 in 1974, which resulted in the formation of the BC Ministry of Transportation and Infrastructure's Avalanche Program and associated regulations for occupied structures, as well as the *Five Mountain Parks Highway Avalanche Study* commissioned by Parks Canada in 1993.[16] The recommendations in a BC Coroners Service report that examined a fatal heli-skiing avalanche accident that killed seven skiers in 1979 were the initial impetus for creation of InfoEx.[17]

> The evolution of avalanche safety practices in BC and Canada has largely been driven by practice reviews and recommendations following fatal accidents.

In terms of public avalanche safety, the *Parks Canada Backcountry Avalanche Risk Review*[18] that examined the 2003 Connaught Creek avalanche accident where seven high school students were killed, led to the establishment of a national centre for public avalanche safety, now known as Avalanche Canada, as well as the development of new public backcountry avalanche safety tools such as the Avalanche Terrain Exposure Scale[19] and the Avaluator.[20] Similarly, BC Coroner Service responded to the record number of mountain snowmobiling fatalities in 2009 with a rare death review panel, whose recommendations[21] provided a roadmap for enhancing public avalanche safety initiatives in BC and mobilized increased funding from local, provincial, and federal sources.

Table 1 lists general or specific organizations involved in avalanche risk management with any associated legal mandates and current roles and key programs.

CLIMATE IMPACTS

Due to the tight link between weather and avalanche hazard, it is reasonable to expect that climate change will have a substantial impact on the nature of avalanche activity in BC. Direct research on the effect of climate change on avalanche hazard in BC is limited,[24, 25] but snow science principles and research from other mountain regions[26] offer valuable insight. At lower elevations close to the freezing level, we expect that rising temperatures will result in a substantially reduced and eventually disappearing snowpack. While this will cause avalanche initiation to ultimately cease at these elevations in the long term, we might see a higher prevalence of wet snow avalanches during the transition period and the occasional winters with sufficient snow. Furthermore, avalanches can start above and threaten areas below with little or no snow on the ground

Table 1: Organizations involved in avalanche risk management

Organization	Type of Organization	Legal Mandate	Role	Key Programs
Employers operating in avalanche terrain	Private businesses, government agencies	Occupational Health and Safety Regulations 4.1.1 and 4.1.2[22]; BC Mines Health, Safety and Reclamation Code (Section 3.3.6)[23]	Ensure safety of workers in avalanche terrain	Avalanche safety plan
Public highways (BC Ministry of Transportation and Infrastructure, Parks Canada)	Government agencies	BC Transportation Act National Parks Highway Traffic Regulations	Provide an acceptable level of safety for all highway users, including workers. Minimize avalanche related delays or closures reliability.	Avalanche protection infrastructure, avalanche forecasting program, artificial triggering of avalanches, temporary closures
Municipal government	Government agencies	Zoning bylaws	Ensure safety of occupants	Restrictions for development of occupied structures in avalanche hazard zones
Commercial recreation operators (e.g., ski resorts, backcountry guiding operators, individual guides)	Private businesses	Body of case law that clarifies the application of common legal concepts (e.g., Occupier's Liability Act, Family Law Act) as they relate to insurance, practice standards, etc.	Ensure the expected duty of care for paying guests	Avalanche forecasting program, artificial triggering of avalanches, terrain selection, and temporary closures

Organization	Type of Organization	Legal Mandate	Role	Key Programs
Canadian Avalanche Association	Practitioner associations		Set industry standards; train and regulate avalanche safety workers	Professional avalanche education programs, guidelines, and standards documents; InfoEx; supports research and development in avalanche safety
Other industry associations (Helicat Canada, Canada West Ski Area Association, Association of Canadian Mountain Guides, Canadian Ski Guide Association, Engineers and Geoscientists BC)	Practitioner associations		Set industry standards; train and accredit members	Guidelines and standard documents, member accreditation
Public avalanche warning services (Avalanche Canada, Parks Canada)	Not-for-profit, government agency	National Parks Act	Support safety of self-directed backcountry recreation	Public avalanche bulletins, curriculum for recreational avalanche safety training, public avalanche awareness initiatives
Search and Rescue organizations (Emergency Management BC, Search and Rescue Association of BC, Parks Canada)	Government agency, not-for-profit	National Parks Act Emergency Program Act BC Emergency Program Management Regulation, Schedule II Good Samaritan Act	Ensure capacity for ground SAR in the province and within national parks	24-7/365 on-call availability of trained professional and volunteer rescue programs
Avalanche safety consulting companies	Private businesses		Support companies and agencies operating in avalanche terrain with avalanche safety expertise	Avalanche planning and operational avalanche forecasting services
Avalanche awareness course providers (e.g., mountaineering schools, guides)	Private businesses and individuals		Teach avalanche safety skills to recreationists	Delivery of Avalanche Canada curriculum
Research programs (e.g., Simon Fraser University Avalanche Research Program)	Academic institutions, private businesses, not-for-profits		Support development of new knowledge and innovative tools	Research programs, academic education

(i.e., there can be an av hazard in areas with no snow). At higher elevations where snow remains abundant, changes in avalanche hazard will primarily be determined by how climate change will affect the intensity and sequence of winter weather events that determine the nature and severity of avalanche conditions.

Since long-term avalanche risk management planning relies heavily on historical weather, snowpack, and avalanche occurrence data, climate change adds considerable uncertainty to predicting future avalanche hazard characteristics, such as long-term frequency and magnitude relationships and extreme runout extent. To account for this increased uncertainty, avalanche professionals typically use a factor of safety when planning avalanche risk mitigation measures.[27] Since day-to-day operational avalanche forecasting decisions are based on the weather and not long-term climate trends, climate change is not expected to overly affect existing risk management approaches. However, higher year-to-year variability in conditions will result in more unusual winters that make judgements informed by previous experiences less reliable. Furthermore, more common extreme weather events may result in more frequent extreme avalanche cycles that have the potential to overwhelm the existing mitigation practices and emergency response plans.[28]

GAPS

While we judge the level of understanding of avalanche risk in BC to be relatively high, there are several gaps in the available information and knowledge that prevent the risk from avalanches in BC from being managed more effectively.

Since avalanche hazard is spatially and temporally highly variable, one of the most significant limiting factors for accurate and timely avalanche forecasts is the general sparsity of high-quality weather, snowpack, and avalanche observations across much of BC's mountain ranges. While the use of numerical snowpack models can partially address the lack of direct observations, these simulations rely on accurate weather forecasts.[29] Possible approaches for addressing this issue include developing better precipitation forecasts, expanding the existing network of high-elevation weather observation sites, and providing ongoing support for research on how to best use snowpack modelling and advance satellite-based remote detection of avalanche deposits.[30, 31]

Another significant limiting factor for using existing avalanche planning practices to their full potential is the lack of high-resolution, publicly available terrain and forest cover datasets. Existing research highlights that digital elevation models and landcover information with a spatial resolution of at least 10 m is necessary to reliably identify potential release zones using GIS algorithms[32, 33] and accurately model the runout of extreme avalanches. In addition, the lack of mountain range–specific calibrations for numerical avalanche dynamic models further limits their effective use in BC. Addressing this data gap would allow for more detailed and widespread avalanche terrain mapping across all types of avalanche risk management contexts. This includes the computation of impact-based hazard maps for land-use planning and the use of automated algorithms to generate avalanche terrain exposure maps for recreationists.

> A significant limiting factor for using existing avalanche planning practices to their full potential is the lack of high-resolution, publicly available terrain and forest cover datasets.

With respect to public avalanche forecasting, the large size of many forecast areas naturally limits the precision and amount of detail that can be included in avalanche bulletins. Hence, having the resources to decrease the size of forecast regions or temporarily adjust their boundaries would allow bulletins to be more specific. However, avalanche bulletins describing the existing hazard conditions need to be complemented with terrain guidance products to provide recreationists with tangible advice on what type of terrain choices are appropriate under different types of hazard conditions.[34] To design these types of products in an informed way, a better understanding of the desires, needs, existing capabilities, and expectations of the increasingly diverse backcountry community is required. While there have been several exploratory research projects on this topic,[35, 36] more work is needed to better understand the users and design a more inclusive and integrated avalanche awareness education system. And while the lack of accurate information on trends in backcountry recreationists prevent the calculation of accident rates, a meaningful collection of backcountry use numbers across BC is challenging and likely extremely costly.[37]

Though the lack of well-grounded understanding of the effect of climate change on future avalanche conditions adds substantial uncertainty to existing practices and thresholds, we perceive a more significant climate change vulnerability: the lack of coordinated disaster planning for large-scale avalanche cycles (i.e., intense avalanche activity across substantial parts of BC for multiple days in a row) coming from the more frequent occurrence of extreme weather. Large-scale avalanche cycles would result in widespread avalanche activity running beyond historic paths, multi-day closures of every transportation corridor in the province, disruption of critical power transmission lines, and communities isolated for extended periods of time.[38] Targeted interagency disaster planning is necessary for responding to such a disaster in a meaningful way.

OPPORTUNITY

RECOMMENDATIONS

Avalanche safety in BC has largely been a success story, yet there are many opportunities to improve the system. While the gaps described in the previous section primarily relate to information and knowledge challenges, the recommendations listed in Table 2 target higher-level systems improvements.

Table 2: Recommendations

Recommendation	Description of Impact	Priority Level	Capabilities Needed
1. Improve disaster planning for critical infrastructure.	Emergency preparedness for extreme avalanche events.	Critical	Contingency planning and interagency coordination.
2. Establish long-term funding to safeguard existing avalanche safety systems.	Reliability of critical avalanche information.	Critical	Reliable financial support for Avalanche Canada and Canadian Avalanche Association's InfoEx.
3. Create a mechanism for land-use planners to determine when it is necessary to consult an avalanche hazard mapper.	Avalanche hazards are not overlooked in future developments.	Necessary	Updated Canadian Avalanche Association's Land Managers Guide; planners informed about avalanche hazards.
4. Identify existing developments that are exposed to avalanche hazard.	Avalanche hazards are not overlooked in existing developments.	Necessary	Desktop and field-based province-wide study to retroactively identify existing occupied structures exposed to avalanche hazard.
5. Expand public avalanche bulletin regions to areas not currently covered.	Critical avalanche safety information provides for more areas used by recreationists.	Necessary	Increased financial support for Avalanche Canada.

Recommendation	Description of Impact	Priority Level	Capabilities Needed
6. Decrease the size of the regions for the public bulletins.	Reduces uncertainty in avalanche forecasts due to inherent spatial variability.	Necessary	Increased financial support for Avalanche Canada.
7. Design a robust strategy for evaluating and improving the effectiveness of public avalanche safety products.	More effective public avalanche safety products and services.	Necessary	Increased financial support for Avalanche Canada and research programs.
8. Improve the understanding of the needs and perspectives of the increasingly diverse community of backcountry users.	Critical for the design of effective public avalanche safety products that serve all users.	Necessary	Increased financial support for transdisciplinary avalanche safety research.
9. Create systems and tools that increase forecast accuracy based on available snowpack and weather information.	More effective public avalanche safety products and services.	Necessary	Better and more data to support the forecast so that products can be targeted more effectively.
10. Further develop computerized snowpack modelling and terrain mapping.	A warning system that integrates weather models, terrain maps, and snowpack modelling to predict significant avalanche events farther in advance.	Necessary	Better terrain datasets coupled with more support for computerized terrain mapping and snowpack modelling.
11. Investigate capital projects (e.g., Remote Avalanche Control Systems and avalanche detection networks) to help protect transportation corridors and other critical infrastructure.	Highway and infrastructure closure times are shortened, which reduces economic risks.	Necessary	Further investment in avalanche protection for transportation corridors and other critical infrastructure.

THE CHALLENGE

While the avalanche risk management safety systems in BC are well regarded around the world, it is important to point out that they suffer from a fundamental economic vulnerability that many decision makers might not be aware of. Avalanche Canada's public avalanche bulletins and, by extension, InfoEx have been critical components of the WorkSafe BC–legislated avalanche safety plans of many businesses and government agencies. The provision of this critical information by not-for-profits differs considerably from approaches taken for managing other natural hazards, such as where government agencies play a more central role in the collection and interpretation of the hazard information and the dissemination of warning messages. Relying exclusively on not-for-profits and private businesses for the provision of these essential services for local economies comes with substantial societal risks.

To enhance BC's resilience to natural hazards, it is important that avalanche risk management strategies are considered at the same level as other natural hazards and included in the planning process for the economic development of the province. The first step to addressing this challenge is to raise awareness about the seriousness of avalanche hazard in BC and the vulnerability of the current safety systems. Once this awareness is established, key stakeholders should collaboratively investigate feasible long-term models to safeguard existing avalanche safety systems. Integrating avalanche risk management into a broader geohazard strategy might offer a promising pathway for improving the sustainability of the existing safety system and strengthening BC's avalanche risk resilience.

> To enhance BC's resilience to natural hazards, it is important that avalanche risk management strategies are considered at the same level as other natural hazards and included in the planning process for the economic development of the province.

RESOURCES

1. Technical guidelines for planning and operational avalanche risk assessment and mitigation:

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2. A book outlining field and desktop methods for planning-level avalanche risk assessment and mapping:

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1.3 LANDSLIDES

June 2022

DRRPathways.ca

RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 1 Understanding and Managing Climate and Disaster Risk: Hazard Threat*. To read all articles in the report, see DRRPathways.ca.

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1.3 LANDSLIDES

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ABOUT LANDSLIDES

DESCRIPTION

Landslides are the downward movement of soil, rock, or other earth material under the influence of gravity.[1] In BC, these hazards are most common in mountain areas but also can occur in river valleys, lakes, fjords, off the coastline, or in terrain modified by human development (Figure 1). Thousands of landslides occur each year in BC, although most are small and located in remote areas.

Landslides occur when the factors that destabilize a slope overcome those that hold it in place. Complex interactions between slope topography, geologic conditions, vegetation, and human development create the conditions where landslides might arise, while triggers are external factors that can cause landslides to release.[2]

In BC, most historical landslides have been triggered by an increase in the supply of water to slopes.[3] This is typically due to rainfall or snowmelt, but can also be from anthropogenic causes, like irrigation.[4] Other common landslide triggers include freeze-thaw cycles,[5] terrain modifications from land or resource development,[6] or river erosion.[7] A less commonly occurring trigger of landslides in BC is earthquake. While these events are relatively infrequent, they could cause widespread slope failures. In the past century, no earthquake has triggered multiple landslides near a population centre in BC; however, recent events around the world indicate that impacts could be significant.[8,9]

Landslides can be classified as fast moving or slow moving.[10] Common fast-moving landslides in BC include debris flows, debris avalanches, rockslides, and rockfalls; these mainly cause impacts in runout zones and can cause life loss and secondary hazards like tsunami waves or landslide dams.[11,12] Common slow-moving landslides include earthflows and earthslides;[13] these cause progressive ground deformation that can lead to high economic loss due to long-term maintenance costs. Both fast and slow landslides cause economic loss from property destruction, infrastructure damage, and road and utility service disruption.

Climate change is anticipated to increase the frequency of landslides across much of BC.[14,15,16] These changes will mainly be driven by more frequent and intense weather systems, such as the atmospheric

[i] *The recommendations provided are solely the opinion of the authors and not the contributors or their organizations. The contributors provided very helpful insights and feedback to develop content in the article, but ultimately the authors developed the content and recommendations based on their understanding and opinion.*

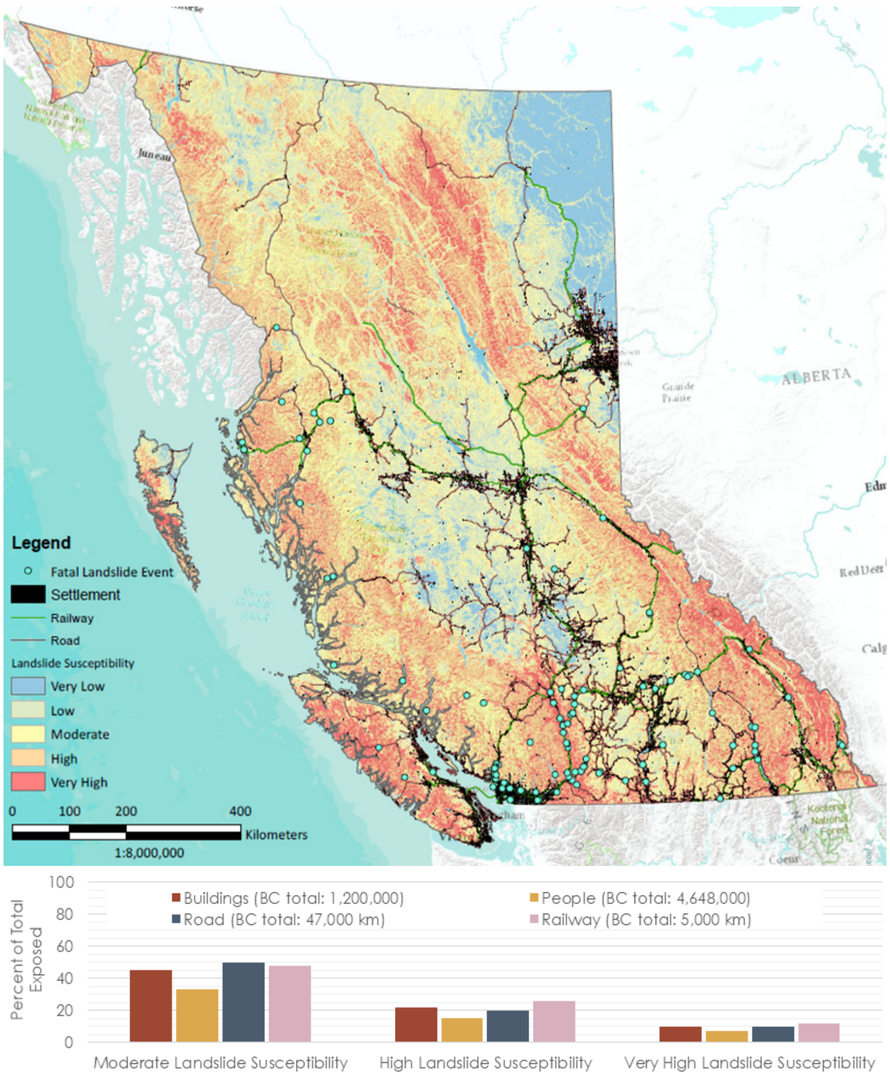

Figure 1: Landslide susceptibility in BC and the percentage of buildings, peoples, roads, and railways exposed to moderate, high, and very high levels of landslide susceptibility. Landslide susceptibility data is from NASA's global landslide susceptibility model;[17] the count of buildings and people in settlements are from NRCan;[18] railway centrelines are from GeoBC;[19] road centrelines are from BC Ministry of Transportation and Infrastructure;[20] and fatal landslide events are from NRCan.[21]

river which led to widespread flooding and landslides across southwestern BC in November 2021, more frequent wildfires, which can remove surface vegetation and increase the susceptibility to landslides, and faster deglaciation, which can expose and debuttress landslide-prone slopes.

LANDSLIDE THREAT AND PAST EVENTS

In BC, landslides mainly pose risks to public safety, infrastructure, resource development operations, forest harvestable land, agriculture, and fisheries. It is currently unclear who or what is most at risk from landslides, but there are a few apparent trends.

Landslides appear to be particularly problematic along linear infrastructure (Figure 2).[22] Commonly traversing long distances, linear infrastructure can be exposed to multiple landslide hazards at once. Impact from any one event can cause direct damages that require repair and mitigation as well as interruption of business services that can exceed direct damage costs.[23] People travelling along linear infrastructure can also be injured or killed,[24] with over half of all reported landslide fatalities in BC taking place along roads or rail lines.[25] Debris flows and debris floods also pose notable risks; these hazards terminate on alluvial fans, which form gently sloped areas among mountain terrain and have historically been favorable for residential development. Debris flows have historically caused almost 90% of reported landslide fatalities in residential areas.

Between 1880 and 2019, there have been 390 recorded fatalities caused by 123 landslide events in BC.[26] Most of these resulted in a single fatality, five events caused 10 or more fatalities, and the highest-fatality event was a rock avalanche in 1915 that killed 54 people living in a mining camp near Britannia Beach. Landslide events kill one person per year on average in BC.[27]

The total annual economic cost of landslide events in BC is unknown, but it is likely within the hundreds of millions per year.[28,29] To provide context, the costs from 32 fast-moving landslide events in BC from 1885 to 2012 have been estimated at $9 billion (2009), with most events

Figure 2: Assessing damage at Ruby Creek and Highway 7 after mudslide closes the road, November 15, 2021 (Photo: flickr/Ministry of Transportation and Infrastructure).

costing below $50 million (2009).[30] The most expensive event was estimated to cost $8.2 billion (2009) and included a rockslide in 1914 that dammed the Fraser River causing considerable impacts to salmon stocks and BC's salmon fishery. The slow-moving Ten Mile Landslide has been impacting Highway 99 and a CN railway line since the late 1980s. It has cost the BC Ministry of Transportation and Infrastructure (MoTI) between $240,000 and $2.3 million annually and has a total mitigation expenditure of $83 million dollars.[31]

DRIVERS OF RISK

Development within landslide hazard areas leads to landslide risk. Development can cause landslides by undercutting slopes with excavations, overloading slopes with fills, removing vegetation, and increasing the water level within the slope. For example, logging and road building has been attributed to a ten-fold increase in landslide activity in coastal BC.[32] In residential areas, such as on Vancouver Island and in North Vancouver, construction of non-engineered retaining walls on slopes, decades' worth of yard waste disposal, and poorly controlled discharge of stormwater from roof drains onto slopes make up common causes for development-related slope failures.[33] On a larger scale, suburbanization is affecting groundwater levels in many areas of the Interior, which has partly led to several landslides in the Kelowna area and several slow-moving landslides in both Quesnel and Kamloops. Development also increases the exposure to landslides when buildings, roads, utilities, and other infrastructure are placed in landslide hazard zones and when the volume of traffic increases on existing roads in landslide terrain.

In most cases, the above issues can be managed using best practices for landslide risk management. For example, over the past 60 years, BC's average landslide fatality rate has dropped from five to one fatality per year, despite a five-fold population increase. This suggests that the evolution of landslide risk management has outpaced development pressures and the associated potential increase in landslide risk.[34] However, given that it was not until the late 1970s that landslide assessments were commonly used to support land and resource development projects,[35,36] a considerable amount of development was constructed within landslide-prone terrain without consistent consideration of landslide hazard. There is ongoing demand for scarce resources to manage landslide risk at these development sites.

UNDERSTANDING RISK

Current practice to understand landslide hazard and risk assessment can be grouped into three broad categories: risk identification, risk analysis, and risk evaluation.[37,38]

RISK IDENTIFICATION

Landslide risk identification primarily includes identifying and characterizing landslide-prone terrain or confirming that a potential landslide risk exists;[39] these are commonly used as screening tools to inform the scope of further study. Common practice includes using one or all of these approaches: geomorphic mapping, landslide susceptibility mapping, and priority ranking systems of landslide hazard sites.

Geomorphic maps are factual in nature and show the landforms in an area, including landslides and landslide-related features.[40] Mapping practices in BC have traditionally been based on air-photo interpretation and field visits,[41] but have since evolved to include interpretation of a variety of remotely sensed data.[42] While there are many forms of geomorphic mapping carried out in practice, terrain mapping, which uses a terrain classification system specifically developed for BC,[43] is by far the most common. Terrain mapping is publicly available for several areas of the province at various scales but there are still considerable gaps in coverage. Comprehensive guidelines for practitioners to complete terrain mapping include the *Guidelines and Standards to Terrain Mapping in British Columbia* published by the Resources Information Standards Committee.

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Landslide susceptibility maps show areas prone to landslides.[44] Common mapping practices use geographic information systems (GIS) along with available digital terrain and earth science data to estimate landslide susceptibility in the source and runout zones. There are many forms of landslide susceptibility mapping to identify source zones, ranging from slope mapping to quantitative multivariate assessments,[45,46] with terrain stability mapping being the most common in practice. Terrain stability maps have been an integral part of forest and resource development planning for several decades in BC. Most publicly available terrain stability mapping covers areas used for resource development[47] and is not often detailed enough for site-specific landslide assessments.[48] Guidelines for terrain stability mapping include *Mapping and Assessing Terrain Stability Guidebook*[49] and *Terrain Stability Mapping in British Columbia: A Review and Suggested Method for Landslide Hazard and Risk Mapping*.[50] Mapping runout areas susceptible to landslides (i.e., those at the bottom of slopes) is commonly based on simple empirical methods,[51] but more advanced terrain-based modelling techniques are starting to be used.[52,53] Maps that delineate landslide runout zones in BC are relatively scarce.

Priority rating includes creating a ranked inventory of landslide hazard sites, with the purpose of informing resource allocation and risk management actions. Priority rating systems have been used in planning and management of linear infrastructure in BC for decades,[54,55,56] and recent studies have used this approach to prioritize landslide hazards across some regional districts.[57] Landslide rating systems commonly used in BC are often semi-quantitative, are hazard- or risk-based (i.e., consider both hazard and consequences), and are typically tailor-made for specific projects or stakeholders. One of the main drawbacks is that creating priority rankings to meet the needs of multiple stakeholders simultaneously is challenging and sometimes not practicable.

RISK ANALYSIS

Landslide risk analysis involves estimating the level of hazard or risk from a landslide[58] and is used to gather information required for evaluating whether risks can be tolerated and for implementing risk reduction measures. In this step, hazard analysis involves estimating factors related to landslide occurrence (e.g., landslide mechanisms, the likelihood or probability of the landslide, frequency-magnitude relationships, the slope factor of safety, slope activity) or landslide runout (e.g., runout extents, landslide flow depth and velocity). Risk analysis involves estimating the probability of certain consequences from landslides (e.g., the probability of fatality). There are a variety of approaches that can be used to assess landslide hazard and risk and several resources are available for practitioners (see Resources section). The level of effort, type of assessment, and assessment outcomes depend on the project objectives, landslide characteristics, available background information, and level of exposure.[59] In many cases, estimating landslide risk is not needed nor is carried out in current practice, and risk management decisions can be based on hazard assessments alone.

Landslide hazard and risk analyses are routinely performed by qualified professionals (engineers and geoscientists) as part of the application processes for proposed land development, forestry, and other resource use projects[60] or to inform landslide risk reduction where existing development is exposed. Engineers and Geoscientists of British Columbia (EGBC) publishes guidelines for professionals carrying out landslide hazard or risk assessments in BC, such as the *Legislated Landslide Assessment for Proposed Residential Development in BC*.[61,62] However, there are ongoing challenges in current practice. For example, qualified professionals conducting these studies are not always landslide specialists, so assessments can lack consistency and important aspects of professional practice guidelines. Also, understanding the magnitude of very-low-probability events, the mechanisms of large slow-moving landslides, and the impacts of climate change on landslide frequency and magnitude are challenging and prone to considerable uncertainty.

RISK EVALUATION

Landslide risk evaluation includes comparing the estimated level of hazard or risk to tolerance criteria. In BC, governments and infrastructure owners define these criteria; it is not the role of landslide professionals. For land development planning, qualified professionals are responsible for evaluating if a development is "safe" from the effects of landslides; however, no defined level of landslide safety has been adopted province wide. A few incorporated jurisdictions have defined landslide safety standards, and MoTI provides guidance for unincorporated areas, but there are differences between regulations that have been adopted.[63] As examples, the Fraser Valley Regional District has used a hazard-based standard since the early 1990s that depends on hazard type and size of development,[64] and the District of North Vancouver uses a risk-based standard that considers the probability of death of a person in individual homes.[65] Despite the lack of broad regulatory guidance on landslide hazard or risk tolerance criteria, current practice in risk analysis seems to be trending away from fundamental geomorphological interpretation and experience-based judgment and towards quantitative risk assessments. Quantitative risk assessments are powerful tools to support landslide risk management decision making, but can also be complex, expensive, and in some cases no more effective than simpler approaches at leading to good risk management decisions.

REDUCING RISK

WHAT SOURCES HELP US REDUCE RISK

In BC, there is no single entity responsible for coordinating and overseeing landslide risk management. Instead, the province, local governments, infrastructure owners, and resource development companies are responsible for managing landslides on their own lands or that pose a risk to their assets or to worker and public safety. Many entities are involved to support risk management activities (Table 1).

There are benefits and drawbacks with the current governance model for landslide risk management in BC. Different organizations can adopt plans, policies, and risk reduction strategies that are suitable to their context and based on resources available. However, issues related to consistency, coordination, and disparity in available resources for landslide risk management arise between different organizations and jurisdictions.

PRACTICE AND CAPABILITIES

Landslides impacts are the result of a chain of events where a landslide occurs, reaches an element (e.g.,

Table 1: Organizations involved in landslide risk management (overview)

Organization	Type	Role
Academics/Researchers	Community of practice	Researches landslide fundamentals and produces tools.
Emergency Management BC	Provincial ministry	Leads landslide emergency response for events occurring on Crown land, except for those that affect highways, or when a local government requests provincial support with a landslide emergency.
Engineers and Geoscientists BC	Non-profit	Regulates practicing engineers and geoscientists, sets and maintains the academic, experience and professional practice standards for its members, and publishes professional practice guidelines.
BC Ministry of Transportation and Infrastructure	Provincial ministry	Manages landslide hazards that affect or potentially affect highway infrastructure and public safety, plans new infrastructure in respect of landslide hazards, considers improvements to network reliability and resiliency, and is the approving authority for residential development in unincorporated areas.
BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development	Provincial ministry	Conducts post-wildfire landslide assessments and preliminary assessments of landslide hazards on Crown land where there is potential risk to public safety, private property, or ministry infrastructure (e.g., forest service roads). Supports EMBC in emergency landslide response, and researches causes and impacts of landslide processes in BC.
Local governments	Municipalities, regional districts	Responsible for managing landslides on their own lands/leases or that pose a risk to their assets or public safety, including landslide mapping, community planning, policy development, bylaw development and enforcement, assessing and controlling landslide risks, emergency management, and public communication when hazards are identified.
Crown or private infrastructure owners and resource development enterprises	E.g., forestry, mining, utilities, hydroelectric	Responsible for managing landslides on their own lands/leases or that pose a risk to their assets or worker/public safety, including hazard and risk assessment, risk control, emergency management, and stakeholder engagement.
Professional Engineers and Geoscientists	Community of practice	Are employed or contracted by governments, private organizations, or landowners to lead or support with landslide risk management.

asset, person), and causes a loss depending on the element's vulnerability. Interventions in this event chain will reduce landslide risk. Interventions include: 1) reducing exposure to landslides, 2) reducing the potential for a landslide to release, 3) controlling the landslide impact zone, and 4) reducing the vulnerability of elements to landslide impacts. Many methods are used to achieve these outcomes, which can be implemented individually or in combination. The appropriate risk reduction strategy for a particular landslide risk is highly specific, depending on the type of consequence (e.g., loss of life, service disruption, or economic loss), landslide characteristics (e.g., fast moving or slow moving), risk reduction objective (e.g., tolerable life-loss risk, economic loss reduction, infrastructure protection, or economic risk transfer), and available resources.

REDUCING EXPOSURE TO LANDSLIDES

Methods that reduce exposure to landslides aim to prevent elements from being within the path of a landslide should one occur. Common approaches include landslide hazard zone avoidance and landslide monitoring and evacuation systems.

Landslide avoidance is applicable to all landslide types, consequence types, and risk reduction objectives, and is the first line of defense against landslide hazards. Avoiding landslide hazard zones is achieved by prohibiting development, restricting certain types of development, setting back infrastructure from landslide hazard zones, or relocating existing properties and infrastructure away from identified hazard zones. In residential development, landslide hazards are avoided through community planning and the subdivision approvals process.[66] Approving authorities rely on qualified professionals to: prepare maps that help define landslide development permit areas (DPAs); assess landslide hazards and risks if a proposed development or subdivision falls within a landslide DPA; and declare that development areas are "safe for the use intended" in landslide DPAs. However, the definition of "safe" remains undefined in many municipalities, and landslide hazard maps that can be used to define landslide DPAs are inconsistent and not widely available. In jurisdictions where landslide mapping is unavailable, simple rules are used to identify landslide DPAs (e.g., based on slope percentage or degree), but these often do not capture the full extent of landslide-prone terrain.[67] Acquisition of existing property and sterilization of land in developed landslide hazard areas has been rare in BC and is often neither practical nor economically viable.[68]

Landslide monitoring (e.g., using rainfall, groundwater pressure, or slope displacement) and evacuation or road closure systems are used to remove people and elements from harm's way when a landslide appears likely to occur. As such, they can reduce safety risks and some economic risks, such as those related to pipeline spills, but do not reduce economic risks related to repair and service disruption. While these approaches are often the only feasible methods of risk reduction from low-probability, high-consequence landslides (e.g., rock avalanche), they are challenging to implement due to technical uncertainties about landslide triggers, a commonly high rate of false alarms, and concerns about legal liability to the entity that owns the monitoring equipment and signals the evacuation.[69] Furthermore, evacuations tend to be incomplete, imperfect, and require a population that is well educated in how to respond to an evacuation notice.[70] Regional landslide early warning systems can be useful tools for improving situational awareness and are less prone to issues associated with site-specific systems described above,[71] but cannot be used to detect an imminent landslide.

REDUCING POTENTIAL LANDSLIDE RELEASE

Methods that reduce the potential for landslide release aim to increase slope stability. Methods include: following best design and construction practices for development in landslide terrain; protecting existing vegetation and promoting growth of new vegetation in landslide terrain; and designing and constructing measures that stabilize slopes or reduce displacement rates (e.g., drainage systems, erosion protection, buttresses, anchors, removal of destabilizing loads, and head scarp stabilization).[72,73] These methods are employed by qualified professionals. Best practices for design are defined in local government design standards, professional practice guidelines prepared by EGBC, and informal guidebooks from various Canadian and international government agencies, such as the *Forest Road Engineering Guidebook*[74] and the *Washington State Department of Transportation, Geotechnical Design Manual.*[75] These methods for reducing the potential for landslide release are generally successful at reducing landslide risk from engineered slopes and from land development, except when the designers lack sufficient experience and expertise. It is generally not feasible nor cost effective to fully stabilize large natural slopes and large existing landslides, although drainage measures and re-vegetation can improve some landslide types (Figure 3).

CONTROLLING THE LANDSLIDE IMPACT ZONE

Methods that control the landslide impact zone aim to stop or redirect a landslide away from harm after it has released. These methods are applicable primarily to fast-moving landslides like rockfalls, debris flows, and debris avalanches that tend to pose life-loss and service disruption risk. Methods include rockfall barriers and nets (commonly used along highways and railways), debris flow barriers, basins, diversion berms, and engineered channels.[76]

> Local governments have a political mandate to protect citizens, yet they often lack the financial resources to undertake large engineering design and construction projects and to pay the long-term operation and management costs.

Highways and railways tend to have the land tenure and allocated resources needed to protect against high-frequency landslides, particularly at sites with a documented history of landslide activity. Local governments, however, particularly in rural areas, struggle to design and construct large protection structures that reduce landslide risk to "safe" levels,[77] despite such structures being technically feasible. Local governments have a political mandate to protect citizens, yet they often lack the financial resources to undertake large engineering design and construction projects and to pay the required long-term operation and maintenance costs. Local governments compete for funding of capital costs from a variety of provincial and federal grants, but the grants can take years to secure without a guarantee of success and often have a maximum value that is insufficient and unrelated to the cost of reducing risk to a tolerable level. Winning a grant is a function of many factors (e.g., number of applicants, timing of submittal, availability of grant money, quality of application) that are unrelated to the urgency of need for a particular community, and ultimately there is not enough funding to meet the requests of all applicants. Although funding is available through Emergency Management BC for imminent landslide threats during and following disasters, historically this funding stream has not been available for construction of proactive landslide protection measures.

Figure 3: Church Road slide at Highway 97, May 17, 2021. The spring freshet resulted in flooding and damage at over 90 road sites in the Cariboo (Photo: flickr/Ministry of Transportation and Infrastructure).

REDUCING VULNERABILITY TO LANDSLIDES

Methods that reduce vulnerability to landslides aim to reduce the level of consequence that could arise if a landslide were to encounter an element. Commonly used methods include constructing impact-resistant structures and proactive emergency response and recovery planning.

> Winning a grant is a function of many factors . . . that are unrelated to the urgency of need for a particular community, and ultimately there is not enough funding to meet the requests of all applicants.

Potential physical damages caused by landslides can be reduced by impact-resistant construction. Owners of linear infrastructure like pipelines, powerlines, roads, and railways have many methods for reducing physical damage caused by landslides, such as using heavy walled pipe, changing the depth of burial, using lightweight backfill, or using erosion-resistant materials for road surfacing and subgrades.[78] These practices are well established in BC and regularly applied. For residential development, physical damages can be reduced with elevated construction levels, reinforced walls, careful window and door placement, and building-specific protection berms and barriers. Although common in the European Alps, few landslide-resistant buildings have been constructed in Canada. Restrictive covenants and indemnity covenants are used by local governments to establish design requirements under which a property can be safely developed (e.g., flood construction level on a debris flow fan) and to provide a waiver of liability in favour of the local government or the Province.[79] The requirements can reduce physical damages that occur due to a landslide, but the waiver of liability transfers the financial risk from the government to the property owner. The liability transfer may be a necessary means of limiting liability exposure for governments and third-party consulting firms. Landslide insurance may offer homeowners some protection from the related financial risks; unfortunately, landslide insurance is not currently available in BC. From the insurance industry's perspective, it is not practicable to insure a relatively small group of potential high-risk policy holders.[80]

Proactive emergency response and recovery planning can reduce non-physical vulnerabilities to landslides. For economic risks, this can be done by reducing the duration of service disruption and optimizing the recovery and repair method by, for example, writing contracts with maintenance and repair contractors, establishing detours, developing maintenance designs in advance, and staging equipment. For safety risks, this can be done by developing emergency response plans, improving response coordination, and increasing public awareness of landslide hazards.[81] Local authorities in BC lead response activities in their jurisdictions and receive support for significant events through Emergency Management BC.[82] As soon as local authorities, the Province, and/or qualified engineers and geoscientists become aware of existing developments within landslide hazard areas, they are required to notify leaseholders or landowners of the landslide risk.[83]

> Province-wide guidance on the level of tolerable landslide risk is not available, and government authorities are developing their own definitions of "safe."

GAPS

While considerable strides have been made to reduce landslide risk in BC, gaps in practice remain, including:

1. **Hazard event record keeping** – Records of landslide events that include information such as impact intensity, duration, lives lost, injuries, service disruptions, direct economic losses, and indirect economic losses (e.g., business interruption losses) are limited, incomplete, or privately held by infrastructure owners. The lack of publicly available records introduces large uncertainties into consequence estimation for risk assessments, which impedes accurate risk estimation, the use of cost-benefit assessment for resource allocation, and comparison of risks between hazard types and hazard sites.

2. **Education of professionals** – In BC, there are examples of landslide risk management projects completed by practicing engineers and geoscientists that do not meet important aspects of professional practice guidelines. Continual education of practicing engineers and geoscientists, as well as knowledge sharing within the community, is ongoing through EGBC and is important for maintaining and improving professional practice standards.

3. **Public awareness of landslide hazards** – A lack of public awareness about landslides has

led to landslide damages in BC. For example, non-engineered slope modifications have caused landslides in the past, and people have been killed by landslides due to inappropriate reactions to events. Improving public awareness of landslide hazards is important for helping individuals manage their own landslide risk. Public education of landslide hazards has been an important part of landslide risk management within the District of North Vancouver for years and provides a good example of the associated benefits and challenges.

4. **Landslide susceptibility mapping** – Landslide susceptibility mapping in BC is not available for much of the province, including in many developed areas. Understanding the location of areas prone to landslides is one of the first steps in managing landslides, as it provides a basis for land-use regulation, development planning, and risk reduction planning.

5. **Landslide risks in context** – Currently, it is unclear which hazard types pose the highest risk, and which risks can be tolerated in BC. Furthermore, it is unclear which landslide sites pose the greatest risk relative to other landslide sites within BC. Comparing all hazard sites (regardless of hazard type) in a common risk-based framework would facilitate communication and better resource allocation decisions.

6. **Guidance on landslide safety levels** – Province-wide guidance on the level of tolerable landslide risk is not available, and government authorities are developing their own definitions of "safe." In the absence of overarching guidance, BC is becoming a patchwork of different policies that challenges the consistency of provincial reporting and planning. Establishing provincial guidance on landslide safety levels will be a difficult task that requires dedicated resources and collaboration between governments, qualified professionals, and the planning community. There are many challenges to overcome, including: developing guidelines for different development types (e.g., existing/proposed, developments of different sizes), managing inconsistency between jurisdictions that have existing policies, and implications for development in existing landslide hazard zones. These challenges will be easier to overcome the sooner they are addressed.

7. **Unavailable landslide insurance for private property owners** – There is currently no means to insure properties against landslide hazards in BC. Landslide insurance could provide the incentive for implementing risk reduction measures through rate control and could help distribute economic risks more evenly. The business case for landslide insurance in Canada is likely only practical if risk from multiple hazards is pooled. New Zealand and Norway have functional multi-hazard insurance schemes available for homeowners that cover landslides.

8. **Information sharing** – Most information that describes, or that could be used to understand, landslide hazard and risks in BC is not publicly available. This is primarily information collected by consultants for individual homeowners or the private sector, but also includes information collected by public agencies or university researchers. There are legal and practical barriers to sharing this information, such as copyright and limitation of liability, which are reducing public access to this information.

9. **Coordinated risk management activities** – Landslide risk management decision making and resource allocation is currently spread among many entities, including multiple provincial government agencies, local governments, private companies, and individual professionals. Coordination between the entities can improve consistency, data sharing, and resource allocation as well as reduce potential duplication.

OPPORTUNITY

RECOMMENDATIONS

The gaps described above are opportunities to improve the efficiency of landslide risk

Table 2. Recommendations

Recommendation	Description of Impact	Capabilities Needed
1. Assign responsibility to a single entity, task force, or working group to provide provincial leadership on landslide management issues in BC, and coordinate sactivities to address gaps.	Gaps identified in this article, as well as other potential issues not listed here, are much more likely to be addressed.	Funding; interagency coordination; leadership.
2. Establish a single responsible entity to maintain a landslide event database for BC that records quantitative information about landslide location, type, size, movement rate, economic loss, damages, injury, and life loss.	Provides a basis for better understanding and assessing landslide risks in BC and how they compare to other risks.	Funding; interagency and research coordination; leadership.
3. Investigate opportunities to improve education of professionals related to landslide risk and risk management practice.	Improves quality and consistency of professional practice.	Funding and leadership.
4. Investigate opportunities to develop a landslide hazard and risk awareness program for the public that educates about where and when landslides occur and how to respond.	Reduces vulnerability and increases resilience to landslides.	Funding and leadership.
5. Complete province-wide landslide susceptibility mapping, with a priority on developed areas. (The State of Washington Landslide Inventory Mapping Protocol[84] is a good example.)	Provides a basis for: identifying landslide-prone areas across the province; province-wide landslide risk reduction planning; and understanding landslide risk across BC.	Funding; provincial lidar coverage; interagency and research coordination.
6. Develop provincial guidance for landslide safety evaluation. As a first step, different policy options should be developed and their benefits/drawbacks assessed.	Improves consistency in the level of landslide risk to manage across the province; reduces inconsistency in how qualified professionals define "safe."	Funding; collaboration between all levels of government, EGBC, qualified professionals, owners, and researchers; leadership.
7. Investigate the feasibility of: 1) establishing landslide insurance for homeowners in BC; 2) improving data sharing between public and private entities; and 3) improving coordination of risk management activities in BC.	Provides a basis for potentially overcoming these complex gaps in current practice, which would likely require governance reorganization or new legislation.	Funding, interagency coordination; leadership.

management practice and reduce landslide risk in BC. The recommendations in Table 2 are more immediate steps that can be taken to address those gaps. The recommendations provided above are solely the opinion of the authors and not the contributors or their organizations.

THE CHALLENGE

When considering gaps listed in this article, overcoming information-sharing barriers presents a complex challenge with no clear path forward. In the current context, sharing information about landslide hazards and risks can lead to litigation, economic damages, or opportunity losses for the parties involved. In extreme cases, this has led to situations where owners of different infrastructure that cross the same landslide hazard zone won't share data. There are also cases where data collected by researchers through publicly funded grants is not shared due to limitations in data sharing infrastructure, is only shared to obtain co-authorship rights, or is not shared at all. Overcoming data sharing challenges will likely require specific legislation or significant changes to provincial organization and input from many groups, including professional engineers and geoscientists, the legal community, all levels of government, researchers, and the private sector.

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1.4 VOLCANOES

June 2022

DRRPathways.ca

RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 1 Understanding and Managing Climate and Disaster Risk: Hazard Threat*. To read all articles in the report, see DRRPathways.ca.

The Resilience Pathways Report is a project of Natural Resources Canada.

1.4 VOLCANOES

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ABOUT VOLCANOES

DESCRIPTION

Volcanoes are complex systems with multiple potentially destructive interacting hazards. The types and characteristics of hazards depend on eruption magnitude, intensity, style (explosive or non-explosive) and duration, and may include explosions of tephra (volcanic ash, lapilli, blocks and bombs), pyroclastic density currents (PDCs: hot flows of gas, ash and rock that travel downslope at high speeds), lahars (volcanic debris flows), lava flows, gas emissions, landslides, outburst floods, earthquakes and tsunamis (at volcanoes beside or beneath water). Volcanic hazard footprints vary in space and time: For example, lahars may travel tens of kilometres downstream in valleys, while ash and gas may be carried thousands of kilometres downwind (Figure 1). Some hazards occur only during eruptions, while others may continue long afterwards (e.g., resuspension of loose ash by wind). Landslides are common at many volcanoes, even in the absence of volcanic unrest, due to steep, fractured rock altered and weakened by interaction with heated acidic fluids. Some hazards (e.g., ash) are unique to volcanoes.[i]

VOLCANO THREAT AND RISK

All of Canada's potentially active volcanoes are in BC and Yukon, though most (326 of at least 348 vents, distributed across 28 complexes or fields) are in BC. The annual probability of an eruption is at least 1/200[1]; this estimate is based on a count of the total number of eruptions in Canada over the last 10,000 years. Annual probabilities of eruptions at most individual volcanoes are poorly known. Canadian volcanoes have been ranked for threat[2] using a semi-quantitative system developed by the United States Geological Survey[3]; this threat is not synonymous with quantitative risk (which cannot be assessed because of insufficient information on the probability of the hazard) but instead evaluates the qualitative risk to people and property by scoring each volcano on a series

[i] *For definition of all volcanogenic hazards, see* Resources: Hazard Information Profiles.

All of Canada's potentially active volcanoes are in BC and Yukon, though most are in BC. The annual probability of an eruption is at least 1/200. Five BC volcanoes pose "high" to "very high" threat levels.

Figure 1: Eruption column produced during the May 18, 1980, eruption of Mount St. Helens, WA. Explosive eruptions produce tephra (rock fragments). While the largest fragments are deposited near the volcanic vent, the smallest material, ash (particles less than 2 mm across), is easily carried upwards within the plume and then carried downwind for very long distances (hundreds or thousands of kilometres). Due to its small size, abrasiveness, and widespread distribution by wind, ash can cause major damage to buildings, transportation networks, water treatment systems, power supplies, communications, machinery (including aircraft), and agriculture and may also pose health hazards to people and animals. (Photo: A. Post).

of geology and exposure factors, thus allowing identification of the volcanoes most likely to harm people or damage property.

Five BC volcanoes pose "high" to "very high" threat levels. Although Canadian volcanoes are virtually unknown and are commonly overlooked in tabulations of natural hazards, it should be noted that these are significant threats that merit mitigation. The "very high" threat classification, into which Mounts Meager (Qw'elqw'elústen) (Figure 2) and Garibaldi (Nch'k̲ay') fall, is the same category that includes numerous US volcanoes widely recognized as dangerous, including Mount Baker and Mount St. Helens in Washington. Mounts Cayley (Sxel'tskawu7), Price, and Edziza fall within the "high" threat category (which includes Mount Adams in Washington and Yellowstone in Wyoming). Four of Canada's highest-threat volcanoes (Meager, Garibaldi, Cayley, and Price) are located in southwestern BC's Sea to Sky corridor (in the area of Highway 99, from south of Squamish to north of Pemberton) (Figure 3), which has more than 33,000 permanent residents and lies on busy air traffic corridors of western North America. US volcanoes may also produce ash fall or (for Mount Baker) lahars or floods that may impact Canada, particularly Southwest BC, which includes Metro Vancouver.

Depending on the location and nature of an eruption, many types of assets may be exposed. Landslides, lahars, and PDCs may bury or destroy people, buildings, and infrastructure. Lava flows destroy buildings but typically move slowly enough for people to escape easily. Volcanic ash can cause roof collapse, reduce visibility, make surfaces slippery, damage machinery (including heating and ventilation systems, telecommunications, and aircraft), damage power transmission lines, affect water treatment, damage crops, contaminate soils, harm animals, and pose respiratory health risks.

The dynamic multi-hazard nature of volcanoes means risks, vulnerabilities and impacts are complex. Remote volcanoes may pose ash risks to regional air corridors or settled areas hundreds of kilometres downwind. Buildings on low ground near rivers may be more at risk from lahars than those on high ground, while buildings directly downwind may be more at risk of ash fall than those upwind. Roof construction affects building vulnerability to ash deposition, while wetting of ash by rainfall makes all buildings more vulnerable. Remote communities may have greater risks of disruption of transportation or power infrastructure, which is commonly located in valley bottoms at risk of lahars and PDCs. Potential impacts could be significant for those Indigenous communities whose populations and cultural resources are located near a volcano. Cascading impacts are also probable (e.g., ash fall on transportation corridors limits access and evacuation and may disrupt supply chains; cleanup of ash is necessary but time consuming, costly, and labour intensive, and thus

Figure 2: Mount Meager, showing Plinth Peak and the Job Glacier, including fumaroles (hot gas vents) that melted through the ice and were reported in 2016. (Photo: R. Warwick).

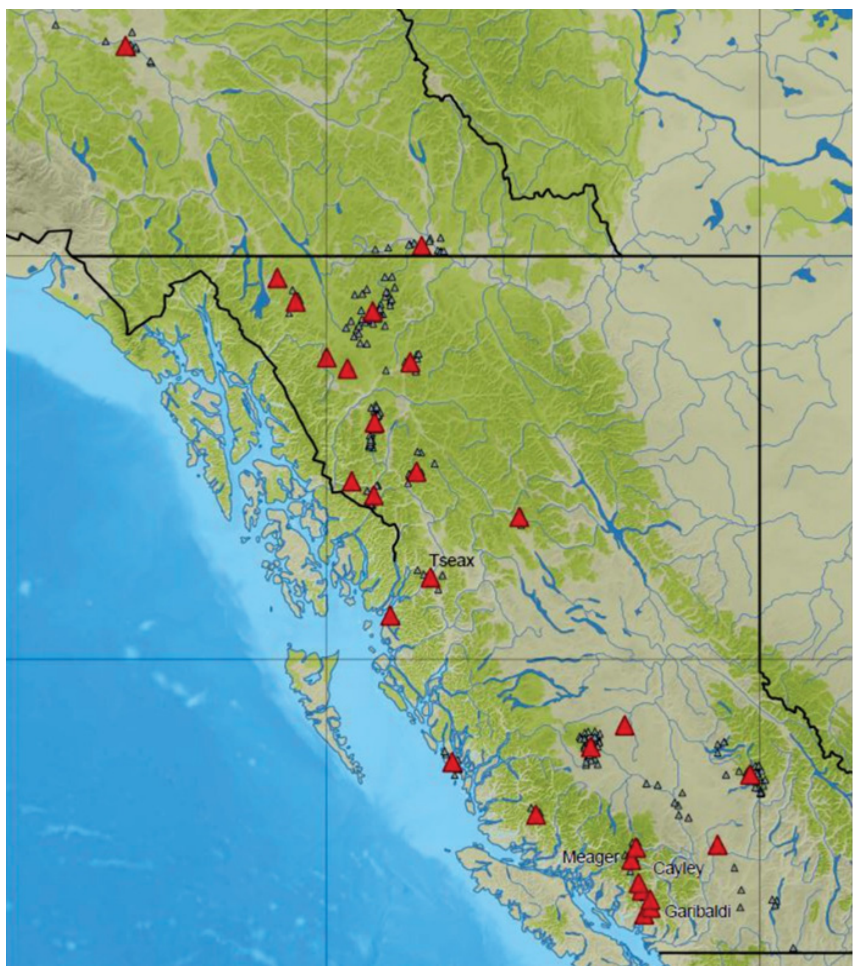

Figure 3: Location of Canadian volcanic vents (grey triangles), and the volcanic complexes or fields that have been ranked according to threat level (red triangles). Modified after Wilson and Kelman, 2021.

may interfere with other components of crisis response).

The nature of many volcanic hazards makes recovery difficult, as lava, PDCs and lahars may completely destroy or bury infrastructure. Volcanic eruptions also differ from other natural hazards in their timelines because unrest prior to an eruption may last days to years, and lahars and ash remobilization by wind may continue for years after an eruption. Unrest does not always lead to eruptions, and even under the best conditions of intensive monitoring at well-understood volcanoes, there will be uncertainty in forecasting the outcome of unrest. This can result in lengthy periods of uncertainty and crisis linked to unrest, whether or not an eruption actually occurs (Figure 4).

Climate change may affect hazards and risks at glaciated volcanoes because melting of glaciers (which may be significant) removes support from unstable slopes and may lead to higher pore pressure in ground water, increasing the probability of landslides. Climate change may also impact crisis response, since extreme weather, wildfires and other hazards linked to climate change may divert needed resources and make access difficult if they occur simultaneously with volcanic crises.

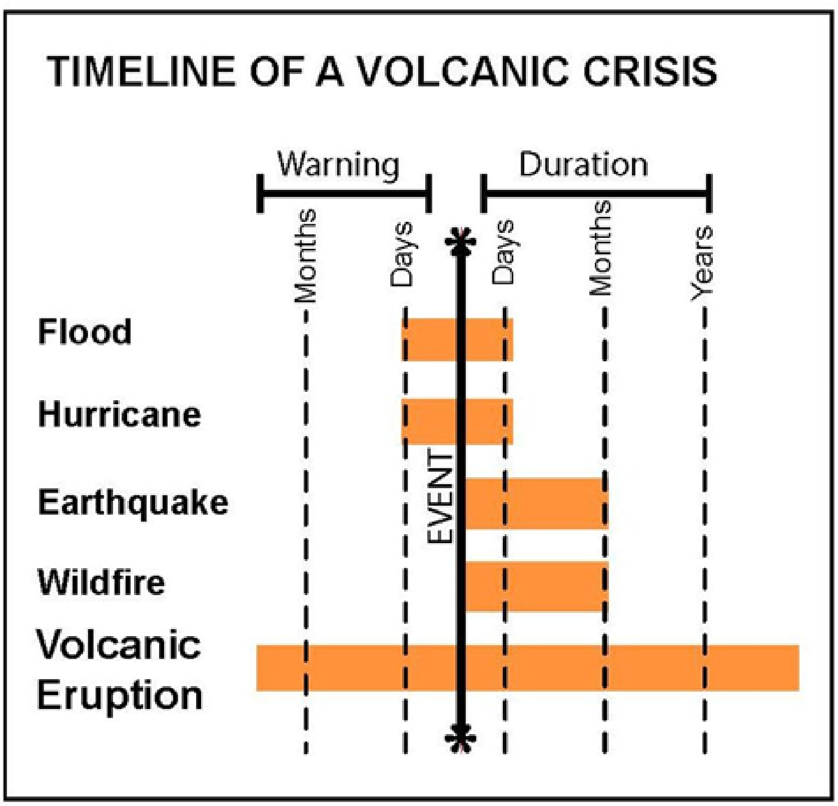

Figure 4: Comparison of the event timelines of natural hazards. Volcanic eruptions typically have a much longer warning phase before the onset of eruption, and eruptions can last much longer than other natural hazards. Modified from USGS.

PAST EVENTS

At least 49 eruptions in Canada have been identified in the geological record since the last ice age. Many were highly destructive. The eruption of BC's Mount Meager around 2,400 years ago scattered ash across central BC and Alberta and caused an outburst flood and lahar traceable 65 km downstream in the Lillooet valley.

Only one historical eruption is well documented, but it gives an idea of the level of destruction possible from a relatively small-volume eruption: The Tseax Cone eruption in northwestern BC, around 1700 CE, caused up to 2,000 deaths in the Nisga'a Nation, and lava flows modified the course of a river.[4] Landslides occur at many BC volcanoes, especially at Mount Meager: Its 2010 landslide of 53 million m^3, conditioned by glacier retreat and triggered by hot summer weather that increased ice and snow melting and led to heightened pore water pressure,[5] was the largest historic slide in Canada, and a 1975 landslide at Mount Meager killed four people.[6] Worldwide, there is substantial evidence for the destructiveness from eruptions; even unrest not followed by eruptions has had, in some cases, socioeconomic impacts.

DRIVERS OF RISK

Volcanic risk varies with eruption magnitude, style (explosive or non-explosive), and hazards, but is generally linked to proximity to the volcano, particularly in low-lying areas. Infrastructure development along river valleys is a significant driver of risk: Along the Lillooet valley near Mount Meager, the landslide threat exceeds international risk tolerance thresholds for loss of life[7] and continued development increases the exposure to this hazard. Similarly, development in Squamish and along Highway 99 increases exposure to volcanic hazards, especially landslides.

Increases in air traffic, infrastructure development, and population also drive increases in risk from volcanic ash. The moderately sized 2010 Eyjafjallajökull eruption in Iceland caused about US$5 billion in losses to aviation and businesses globally,[8] and the recent 2022 eruption of Hunga Tonga–Hunga Ha'apai in Tonga shows the wide reach of volcanic hazards across the Pacific basin.[9] There is clearly significant potential for losses in BC from explosive eruptions both within and outside the province.

UNDERSTANDING RISK

WHAT SOURCES HELP US UNDERSTAND HAZARD AND RISK

The key information needed for volcanic disaster risk reduction is identification of the highest-threat volcanoes, hazard mapping and risk assessment, and monitoring data. Volcano monitoring is the systematic collection, analysis, and interpretation of data about seismic activity, ground deformation, gas emissions and other phenomena, and is the only scientific basis for short-term (hours to weeks) forecasts of volcano behaviour.

Natural Resources Canada (NRCan) is the lead federal government geoscience agency in Canada. Its mandate includes informing natural hazard risk reduction, and it conducts research and monitoring of multiple natural hazards, including volcanoes. However, a large proportion of volcano research and monitoring comes from universities, industry, and government agencies. International collaborations and Canada's Indigenous communities are a major potential source of knowledge and expertise, although these have not yet been explored in detail through effective engagement and partnerships. Data platforms such as the Federal Geospatial Platform and the numerous satellite geodata platforms may also be used to support evidence-based assessment and planning for volcanic risks; most available information is qualitative.

GAPS IN RISK INFORMATION

Significant gaps in the information needed for volcanic risk reduction exist in Canada. The Canadian Disaster Database does not include volcanic eruptions, there is no publicly available eruption database, and knowledge about volcanic risk in Canada is minimal. Canada has no guidelines for volcanic hazard and risk assessment.[ii]

These information gaps limit understanding of long- and short-term volcano behaviour through cycles of dormancy, unrest and eruption. The highest-threat volcanoes have been identified, an activity which is key to prioritizing limited resources for risk reduction, but the lack of basic geological information of even these highest-threat volcanoes limits the capacity for hazard assessment. Only two preliminary volcanic hazard assessments[10,11] and one volcano landslide risk assessment[12] have been done. The lack of hazard assessments is the most significant information gap because hazard maps present information about location, type, magnitude, and frequency of hazards, and thus are key to fully informed land use, emergency planning and monitoring as well as a prerequisite for any risk assessment. The lack of information about Canadian volcanoes has led to a perception of minimal to insignificant risk not commensurate with available evidence.

A second critical information gap in Canada stems from the lack of continuous dedicated monitoring initiated while volcanoes are dormant. Eruptions are almost always preceded by days to years of unrest, including small earthquakes, ground deformation, and gas emissions. However, lack of monitoring means that these warning signals may be

[ii] Globally, guidelines for volcanic hazard and risk assessment and data collection are being developed (e.g., Global Volcano Model), and numerous databases exist, notably, the Smithsonian Global Volcanism database, the Volcano Global Risk Identification and Analysis Project (VOGRIPA), and WOVOdat (a database of precursors to eruptions).

missed entirely or not detected within a time frame that allows for a meaningful scientific interpretation and a practical emergency response. Volcano monitoring data inform the understanding of a volcano's structure, hydrothermal systems, and potential hazards, thus also improving the quality of hazard assessments. The ability to detect unrest and track the course of unrest is a key component of volcano early warning systems, including short-term forecasting of behaviour (over hours to weeks).

Canada's monitoring resources are distributed across government, academia, and industry, and thus are not easy to locate and integrate when needed. Volcanoes lie within NRCan's regional seismic network, but this network is not optimized to detect and locate the numerous tiny earthquakes characteristic of volcanic unrest. NRCan has resources for infrasound and GPS monitoring of ground deformation, as well as landslide expertise, though these resources are not currently deployed for volcano monitoring. An InSAR (Interferometric Synthetic Aperture Radar) ground deformation monitoring program is under development by NRCan. Local universities, in partnership with NRCan, have monitoring equipment and expertise that has been applied most recently to Mount Meager, and landslide detection and alerting systems are being developed in collaboration with corporate partners. Many satellite platforms are available to acquire various types of volcano data that may indicate unrest.

Almost all monitoring is done only in response to perceived or potential unrest (often discovered by chance), routine funding is minimal, and most collaborations are informal. If unrest were to be detected at a Canadian volcano, it would be challenging to interpret, because of the lack of baseline (non-unrest) monitoring data, and because of the paucity of geologic knowledge (about rock types, faults, groundwater, and other features that may influence unrest signals and eruptions). It would also likely be challenging to try to install sufficient monitoring equipment during an escalating unrest crisis.

In Canada, there has been no coordinated approach to prioritizing the most urgent volcanic risk reduction activities, and the scope of any given activity depends largely on funding availability. The inability to provide information about long-term volcano behaviour (through hazard mapping) hinders risk management through land-use planning. The inability to provide information about short-term volcano behaviour (through monitoring) means early warning systems are effectively nonexistent.

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REDUCING RISK

PRACTICE AND CAPABILITIES

The current practice of volcano risk management in Canada is shaped by the lack of volcano risk governance and paucity of information. Volcanic risk reduction requires a number of key activities: identification of threatening volcanoes, hazard mapping and risk assessment at the most threatening volcanoes, and monitoring of parameters (like earthquakes, deformation, and gas emissions) that may indicate unrest. Without these basic information provision activities, higher order risk reduction activities like land-use planning and emergency preparedness planning (including evacuation planning) are impossible.

Volcano risk reduction activities in BC and Yukon are not comprehensive or consistent and occur only where they are driven either by research interests unrelated to hazards or by specific events. For example, the geology and structure of Mount Meager are comparatively well-understood due to geothermal exploration and development there. Similarly, the fortuitous discovery of fumaroles under the Job Glacier at Mount Meager in 2016 led to investigations of its gas emissions. However, other threatening volcanoes, such as Mount Garibaldi and Mount Cayley, have been less thoroughly investigated. In addition, the role of climate change in volcanic risk is only beginning to be explored.

The Emergency Management Act outlines the federal policies and roles of stakeholder agencies in promoting public safety for hazards, while in BC, the Emergency Program Act, currently being updated, provides the legislative framework for management of disasters. However, inclusion of volcanoes within a generalized risk management framework does not necessarily facilitate the assembling of the resources and interagency cooperation needed to complete basic risk reduction activities. Multiple agencies (e.g., Emergency Management BC) have roles in public safety with respect to volcanoes but their ability to fulfill them depends on the provision of scientific information from NRCan and its partners. Thus, many emergency plans include volcanoes on lists of hazards but not in detailed emergency planning.

Available public education resources about Canadian volcanoes are few and general awareness of volcanic risk is low.

A key strength is Canada's ability to deal with airborne volcanic ash. The Volcanic Ash Advisory Centre (VAAC) in Montreal conducts volcanic ash transport and dispersal modelling and ash forecasting in concert with the other VAACs worldwide. The Interagency Volcanic Event Notification Plan (IVENP) ensures rapid and effective communication of information to the aviation community (and other key agencies) about the sudden onset of volcanic eruptions within or near Canada. Events like the 2010 Eyjafjallajökull eruption in Iceland show that moderate eruptions adjacent to critical transportation networks can have widespread impacts.

GAPS IN RISK REDUCTION PRACTICE

The main gap in volcanic risk reduction practice in BC is the lack of a volcanic disaster risk governance framework: a system of institutions, mechanisms, policies, legal frameworks, and other arrangements that guides, coordinates, and oversees volcanic disaster risk reduction. The governance framework should be transparent, inclusive, collective, and efficient in order to reduce the existing risks and avoid creating new risks. Without such a governance framework, a systematic approach to understanding and managing volcanic risk is impossible.

The other significant gap is the lack of guidelines for volcano hazard and risk assessment and monitoring. Such guidelines should be informed by international examples but adapted to fit the Canadian setting. Threat-based monitoring guidelines similar to those developed for the US National Volcano Early Warning Systems (NVEWS)[13] could be created for Canada. As Canadian volcanoes are now ranked by threat with the same system used in the US, there is justification for the recommendation of similar monitoring levels for Canadian volcanoes of similar threat levels. Guidelines for long-term risk reduction (through land-use planning and emergency response planning) would also be beneficial, but such guidelines will not be meaningful unless agencies that engage in these activities have the basic scientific information they need for rational decision making, which can only be provided through basic geological research, volcanic hazard and risk assessment, and monitoring.

OPPORTUNITY

RECOMMENDATIONS

Three key activities will substantially improve the understanding of volcanic risk and the practice of volcano risk reduction in Canada. Development of a volcano risk governance framework would significantly facilitate their implementation (Table 1).

Table 1: Recommendations

Recommendation	Description of Impact	Priority Level	Capabilities Needed
1. Undertake hazard and risk assessment at "high" and "very high" threat volcanoes.	Makes possible land-use planning and emergency planning based on volcanic hazard and risk; informs monitoring.	Critical	Financial
2. Establish dedicated volcano monitoring at "high" and "very high" threat volcanoes, starting with at least one seismic station, and continuous deformation monitoring with InSAR.	Increases the likelihood of early unrest detection. Informs our understanding of long-term volcano behaviour. Is a first step in building monitoring infrastructure that may eventually be sufficient to forecast short-term behaviour.	Critical	Financial
3. Develop a real-time detection and alerting system for volcanic landslides in the Lillooet valley; develop the necessary concomitant communications systems, emergency plans, and public education.	Makes evacuation possible prior to arrival of a dangerous volcanic debris flow (which is most likely to occur in the absence of any volcanic unrest), thus reducing loss of life.	Critical	Financial and legislative (because such a system would require significant interagency cooperation and roles and responsibilities for this are unclear).
4. Develop a volcano risk governance framework.	Enables efficient and effective data-driven decision making before, during, and after a volcanic crisis.	Critical	Financial and legislative (because such a system would require significant interagency cooperation and roles and responsibilities for this are unclear).

THE CHALLENGE

The most challenging aspect of reducing volcanic risk in Canada is dealing with the risk from long-dormant volcanoes with limited or no historic unrest—a challenge common to some other high-impact, low-frequency hazards. Volcanoes may be dormant for many hundreds or thousands of years (e.g., the last known eruption of Mount Meager was 2,400 years ago), and many large eruptions worldwide have occurred at volcanoes perceived to pose negligible risks or to be extinct. Because of the lack of personal or institutional experience of eruptions in Canada, people tend to underestimate their probability and potential consequences. The long recurrence intervals of Canadian volcanoes greatly exceed the length of program funding cycles or political administrations, so mitigation activities may be deferred indefinitely and repeatedly in order to fund risk management activities for frequently occurring hazards that are more likely to occur during a given time period.

Volcano risk reduction is also hindered by perceptions that there are few or no mitigation options, that mitigation is too costly to justify, or that a volcanic crisis can be successfully mitigated by adding monitoring equipment after unrest has begun. There is a lack of understanding that the most fundamental actions to take to support volcanic risk reduction are hazard and risk assessment and long-term monitoring. Early warning systems for volcanoes effectively consist of monitoring (in order to understand what a volcano will do over time frames of hours, days, or weeks) and the capacity to convey this information effectively to those who need it (such as emergency management agencies, civil authorities and the public). There is also a lack of understanding that higher order risk reduction activities (e.g., emergency response planning and land-use planning) require the information from hazard and risk assessment and monitoring in order to be effective.

These misperceptions make designing risk reduction actions difficult. Because all actions carry at least some cost, if quantitative risk information is lacking, there is no cost justification for any action, and it is likely that there will be no actions taken or that only low-cost actions will be taken. The issue needs to be approached from the perspective of needing to provide the basic hazard and risk information required to do land-use and emergency planning at volcanoes.

The above challenges can be better addressed in Canada by creating a volcano risk governance structure that identifies roles and responsibilities of all agencies and stakeholders clearly and includes guidelines for hazard risk assessment and monitoring. It would also be advantageous to find synergies with other scientific work and to emphasize the positive benefits of volcano risk reduction activities,

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such as informed development and the ability to provide ongoing volcano status, which will increase public confidence and awareness.

Learning about volcanoes has many areas of overlap with other sciences and arenas of hazard and risk knowledge: Geologic research for hydrothermal or mineral exploration provides information key to evaluating volcanic hazards, while studies of glaciers may reveal information useful to assessing volcanic landslide hazard and risk. Many types of monitoring provide information relevant to volcanoes: For example, stream gauges and other river monitoring can provide information relevant to volcano-related flooding and lahars, while satellite platforms used to monitor weather systems and pollution may be used to monitor volcanic ash and gas. Other natural hazard risk reduction work has benefits for volcanic risk reduction too. For example, Canada's existing seismic network provides at least some information about potential unrest, and future system upgrades might be planned in order to provide more information about volcanic activity. Identifying and taking advantage of these synergies may help to reduce the risk from both volcanoes and other hazards.

RESOURCES

1. A description of each of hazard information profiles (HIPs), developed using a consultative process by scientists and experts across the globe:

UNDRR-ISC, Hazard Information Profiles: Supplement to UNDRR-ISC Hazard Definition & Classification Review — Technical Report (2021): 203–237. Accessed February 28, 2022. https://www.undrr.org/publication/hazard-information-profiles-supplement-undrr-isc-hazard-definition-classification

2. International network of institutions and organizations with the aim of creating a sustainable, accessible information platform on volcanic hazard and risk:

Global Volcano Model network. Accessed March 3, 2022. https://wovo.iavceivolcano.org/news/5-global-volcano-model-website

3. A proposed United States national-scale plan to ensure volcano monitoring at levels commensurate to their threats:

National Volcano Early Warning System. Accessed March 3, 2022. https://www.usgs.gov/programs/VHP/national-volcano-early-warning-system-monitoring-volcanoes-according-their-threat

4. The USGS Volcano Hazards Program is aimed at enhancing public safety and minimizing social and economic disruption from volcanic unrest and eruption:

USGS Volcanic Hazards Program. Accessed March 3, 2022. https://www.usgs.gov/programs/VHP

5. A resource provided by Natural Resources Canada to inform the public about volcanoes and volcanic hazards in Canada:

Volcanoes Canada, Natural Resources Canada. Accessed March 3, 2022. https://chis.nrcan.gc.ca/volcano-volcan/can-vol-en.php

6. This project aims to provide systematic information on global volcanic activity, hazards and vulnerability to identify locations at high risk from volcanism and gaps in knowledge about hazards and risk:

Volcano Global Risk Identification and Analysis Project (VOGRIPA). Accessed March 3, 2022. https://www2.bgs.ac.uk/vogripa/

7. A comprehensive global database on volcanic unrest aimed at understanding pre-eruptive processes and improving eruption forecasts:

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1.5 WILDFIRES

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RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 1 Understanding and Managing Climate and Disaster Risk: Hazard Threat*. To read all articles in the report, see DRRPathways.ca.

The Resilience Pathways Report is a project of Natural Resources Canada.

1.5 WILDFIRES

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ABOUT WILDFIRES

DESCRIPTION

Wildfires can occur anywhere there is flammable wildland fuel. In BC this includes about 65 million hectares of forest and grasslands. However, wildfire hazard—understood as the probability of a severe wildfire fire event at a particular location in a specified time period—varies over an order of magnitude in BC, depending on the prevalence of hot, dry, and windy weather conducive to the drying of forest fuels and fire spread, the incidence of lightning and human ignitions, and vegetation and topographic conditions.

Wildfires can be ignited in wildland vegetation (natural or modified forest, grassland, or shrub fuels) by lightning strikes or human causes (such as sparks from vehicles and equipment, friction from machinery, electrical arcing, downed power lines, campfires and other open burning, discarded matches and cigarettes, and arson) when the moisture content of surface fuel particles drops to ≲15%. Once wildland fuel particles are ignited, the heat generated by combustion can dry, heat, and ignite adjacent fuel particles resulting in fire spread; a wildfire will continue to spread as a self-sustaining process as long as there is available fuel. The rate of fire spread varies depending on the fuel and topographic conditions, wind speed and exposure, and the type of fire (crown, surface). Spread rates can reach up to 6 km/hr in coniferous forest crown fires and 12 km/hr in open grassland surface fires. The amount of heat that is released at the fire front, or fire intensity, depends on the fire spread rate and the amount of fuel that is consumed, and is an important determinant of the difficulty of control and the severity of biophysical impacts to vegetation and soil. Flame lengths, an indicator of fire intensity, can range from <0.1 m to 50 m.[1]

Smoke produced during incomplete combustion of wildland fuel contains a variety of chemical components, including greenhouse gases (CO_2, NO_x, CH_4), low levels of pollutants (CO, aldehydes, polynuclear aromatic hydrocarbons), and fine particulate matter (<2.5 microns) that pose a risk to human health. Smoke can be injected into the atmosphere in a vertical convective plume and transported hundreds to thousands of kilometres, but it can also be trapped locally under atmospheric inversion layers, particularly in valleys. Embers produced by strong convection in wildfires are lofted in the smoke plume and transported downwind where they can ignite flammable vegetation or structures ahead of the main fire front. The number and size of embers deposited ahead of a fire varies with fuel conditions, fire intensity and distance; most embers are deposited within ~100 m of the fire front, but they can also be transported two or more kilometres.

In BC's Northern Interior, boreal forests typically sustain large crown fires starting in early spring. In the Southern Interior, diverse vegetation from valley bottoms to upper mountain slopes sustain mixed-severity (surface and crown) fires; peak fire season is mid-July to mid-August. Large wildfires are less common in coastal forests as marine influences keep temperatures lower and humidity moderate, and there are fewer lightning storms. Severe coastal wildfires burn during extreme droughts and can be exacerbated by offshore outflow events bringing hot, dry air from the Interior with high winds. Large landscapes with similar biophysical characteristics and potential fire hazard and overlays of similar human systems of settlement and land use have been termed "firescapes."[2] Many precolonial firescapes had different seasonal patterns and fire severity due to Indigenous fire stewardship, which included intentional cultural burning practices (Figure 1).

WILDFIRE IMPACTS, VULNERABILITY, AND RISK

Forests and grasslands in BC and their associated ecosystem services and natural resource values are directly impacted by wildfires. People, homes, and infrastructure located in the wildland-urban interface (WUI, or landscape community interface) are potentially exposed when wildfire spreads from wildlands to a settlement (Figure 2). The likelihood of exposure to flame, heat, and embers increases with fire size and the length and dispersion of the settlement edge; most structure losses are due to ignition by embers. Because wildfire smoke can be transported over long distances and dispersed oved large regions, most settlements in BC can be affected by smoke.

Direct, immediate impacts of wildfire include combustion of vegetation and damage or destruction of buildings

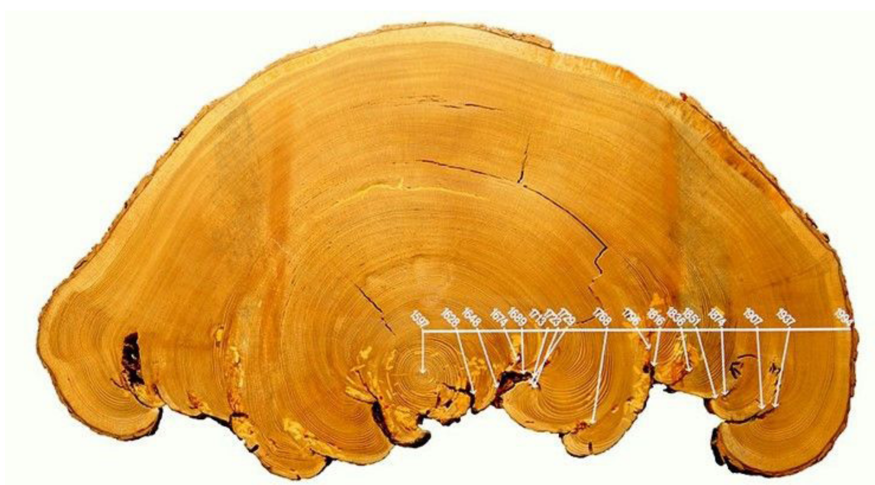

Figure 1: Fire scars on a western larch from Canal Flats showing an approximate 40-year historical fire return interval (Photo: Natural Resources Canada).

Figure 2: Okanagan Mountain Park fire at the wildland-urban interface in Kelowna, 2003 (Photo: BC Wildfire Service).

and fences, cultural resources and archaeological sites, industrial structures and infrastructure, agricultural crops, forest resources, and critical wildlife habitat. Wildfires at the WUI can trigger urban conflagrations where a fire spreads from structure to structure, independent of the wildfire. Wildfire evacuees experience psychological, emotional, and economic stress, exacerbated by repeat or extended evacuations. Exposure to smoke can have negative health impacts, particularly in vulnerable individuals. Smoke reduces visibility, disrupting road and air transportation, tourism, and can negatively impact some agricultural crops.

Longer-term impacts of wildfire can include physical and psychological health impacts to people, particularly for evacuees, emergency services personnel, and firefighters. Economic losses result from interruptions to resource extraction, tourism, and local businesses. Both direct suppression costs and costs of recovery from damage to structures, infrastructure, and ecosystem services (e.g., drinking water supply) can be substantial.

Wildfire can contribute to subsequent disasters or disturbance cascades. Wildfires reduce the cover of vegetation and surface organic layers that shelter soils from the impact of rainfall. Intense precipitation on bare, burned soils increases overland and stream flow and may result in erosion, debris and mud flows, slope failures, sedimentation, and degraded water quality and aquatic habitats in streams.

Approximately 45% of dwellings in about 200 Indigenous communities, 154 municipalities, and numerous unincorporated communities across 28 regional districts in BC are situated within 2 km of potentially flammable wildland fuel[3] (this is similar to estimates in Washington and Oregon) but have differing potential exposure and vulnerability to wildland fire. Vulnerability refers to the physical attributes of a structure, the social and demographic attributes of a population, the social and economic attributes of a community, and the characteristics and processes in ecosystems that increase their susceptibility to wildfire impacts.

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Wildfire risk comprises the total value of the potential loss of life, injury, or health impacts, destroyed or damaged assets, ecosystem services and cultural values, and economic and business losses from fire events in a specified time period, as a function of hazard, exposure, and vulnerability. Wildfire risk to structures increases with fire hazard and exposure and their vulnerability to ignition. Community wildfire risk varies with hazard, socioeconomic vulnerability, and the capacity to plan for, mitigate, and respond to and recover from wildfire disasters. The likelihood of multiple structure losses and large evacuations is greater in larger communities with a high density of structures at the WUI edge. However, smaller communities in remote rural locations surrounded by forests may have limited egress routes, thereby increasing the need to evacuate while the route remains open. Indigenous communities face unique risks where evacuation, fire suppression, and recovery measures are not culturally appropriate or impact cultural values. Smaller communities face significant barriers accessing expertise and funding to develop wildfire response and mitigation plans and to treat hazardous flammable fuels in the WUI. Forest-dependent communities are at economic risk to reductions in timber harvest or destruction of industrial infrastructure due to wildfires.

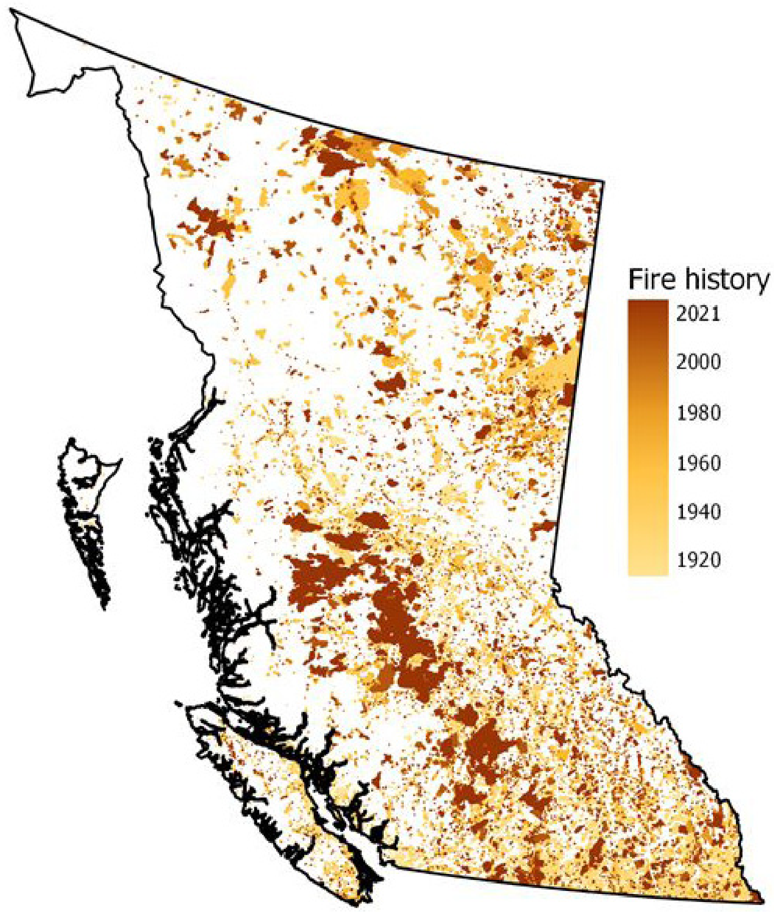

Figure 3: The recorded area burned by wildfire in BC between 1920 and 2021 is approximately 15 million hectares. Three of the largest fire years in the past 100 years in BC have occurred since 2017 (Map: Natural Resources Canada).

IMPACT OF PAST EVENTS

An average of 1,350 wildfires burn in BC each year, with extreme events and fire seasons driving large ecological, social, and economic impacts. There were 55,696 wildfires in the 1980–2018 period (Figure 3); 313 of these events (~0.6%) resulted in the evacuation of approximately 176,500 people (some for multiple events in a fire season, some multiple times over different fire seasons), and 39 events destroyed 625 structures.[4] The areas burned in 2017, 2018 and 2021 (1.22, 1.35, and 0.87 million hectares, respectively) were the three largest years in the past century. Smoke from these wildfires resulted in prolonged periods of reduced air quality over extensive areas of BC, triggering advisories and recommendations for mitigation. Provincial states of emergency were declared in each of these years and direct suppression costs were from $565 million to $645 million per year. Several personnel were killed in wildfire response operations between 2004 and 2020 and two people perished in the 2021 Lytton fire. Fires that have caused multiple fatalities in similar firescapes in the western US in recent years, as well as historically in BC in the late 1800s and early 1900s (Barkerville, Vancouver, Fernie), provide a further reminder that deadly wildfires can occur in BC.

Evacuations and structure and business losses have led to ongoing and long-term social, psychological, and financial impacts to individuals, families, communities, and regions. Post–fire season reviews have resulted in administrative tools such as community wildfire resilience plans (see Practice, Policy, and Programs).

DRIVERS OF HAZARD AND RISK

Wildfires are a natural and important ecological process in many ecosystems in BC. However, land management practices, including fire suppression, timber harvesting, livestock grazing, and the disruption of Indigenous fire stewardship, have altered forest and grassland composition, biomass, density, and continuity, and have increased potential fire severity over substantial portions of BC, particularly in ecosystems with shorter natural fire cycles. At the same time, human-caused climate change is resulting in more extreme fire weather in BC[5] and western North America, as elsewhere,[6] including increases in daytime high and overnight low temperatures, concurrent decreases in daytime and overnight relative humidity, increased vapour pressure deficits, and prolonged droughts. These changes translate to increased fuel flammability and larger and more severe wildfires that are more difficult to suppress. Climate change can also influence fire hazard by altering vegetation dynamics (growth, mortality, and regeneration) in wildlands. A legacy of the mountain pine beetle epidemic (which is partly attributed to climate change) is approximately 19 million hectares of forest containing various proportions of dead lodgepole pine. Extreme heat and drought may increase plant and tree mortality and fuels in some ecosystems as well as reduce the success of vegetation regeneration, delaying ecosystem recovery. Wildfire activity in BC is projected to continue to increase over the next century. Over time, and coupled with a warmer climate, this may lead to loss of closed forest cover and increases in grasslands and shrublands in portions of the Interior "drybelt."

We have known for several decades that wildfire risk in BC has been increasing as the built environment has expanded into fire-prone wildlands, exposing vulnerable homes, communities, infrastructure, and other assets to changing wildfire hazard.[7] Because relatively few homes and communities in Canada have been constructed to be resistant to wildfire, some experts claim that this is not a fire problem, but a structure ignition problem. Furthermore, half of all fire ignitions are caused by human activity; these are concentrated around settlements and transportation corridors.

> Some experts claim that [increasing wildfire risk] is not a fire problem, but a structure ignition problem.

UNDERSTANDING RISK

WHAT SOURCES HELP US UNDERSTAND HAZARD AND RISK

Wildfire hazard and risk varies from place to place, from the level of the individual property to the scale of the province, over time. Short-term wildfire hazard varies over hours to days with changing weather conditions, while medium- and long-term wildfire hazard and risk varies between firescapes and over years to decades with differences in terrain, climate, fuel conditions, the likelihood of ignition, suppression and other risk control capacities, and the exposure and vulnerability of assets at risk.

Wildfire hazard and risk assessments are based on data and knowledge of the likelihood and severity of wildfires, the potential exposure of people, structures, and other assets to wildfires, and the vulnerability of communities, structures, and other assets to wildfires.

DATA SOURCES

Primary data on weather and climate, vegetative fuels, topography, the built environment and infrastructure helps us understand wildfire hazard and risk (Table 1). Data on past fire events and post-fire damage and loss also helps us understand risk. BC reports statistics on the number of fires and area burned each year, based on operational mapping, and

Table 1: Data sources used in wildfire hazard and risk assessment

Data Source	Availability	Responsible Authority[i]
Weather/climate, vegetation/fuels, and topography		
Hourly/daily fire weather and danger observations[10]	Public (historical)	BCWS
ISI rose; 90th percentile fire weather for BCWS stations[11,12]	Public	BCWS
Historic weather and climate observations for BCWS and other network stations[13]	Public	PCIC
ECCC lighting strike records	Internal	ECCC
Vegetation Resources Inventory[14]	Public	Province of BC
BC fuel type map[15]	Internal layers; public PDF file	BCWS
LiDAR (light detection and ranging) data	Public and proprietary	Province of BC, companies
Digital elevation models[16]	Public	NRCan
Built environment, assets and infrastructure		
BC Wildland Urban Interface map	Internal	BCWS
National Wildland Urban Interface map[17]	On request	NRCan
Address and parcel data[18]	ICI members	ICI Society
Provincial road database[19]	Public	GeoBC
Wildfire events, damage, and loss		
Wildfire incident data	Internal	BCWS
Fire perimeter polygons[20]	Public	BCWS
National Fire Database[21]	Public	NRCan
Wildfire evacuation database[22]	Public, on request	NRCan

[i] BC Wildfire Service, Pacific Climate Impacts Consortium, Environment Canada and Climate Change, Natural Resources Canada, Integrated Cadastral Information Society

assesses changes in forest properties, including timber volume. Natural Resources Canada maintains an evacuation database that records the location, time, and duration of wildfire evacuations, the number of evacuees, and the number of structures damaged or destroyed. These data are gathered mainly from media reports. Detailed information on health impacts and vulnerability factors of evacuees, or the characteristics of structures damaged in wildfires, are not collected systematically, excepting that insurance industry groups track insured losses.

Knowledge also comes from observations and experience, from Indigenous Knowledge Keepers, from case studies of significant or unusual events,[8] and from experimentation and adaptive management. A guidance document was recently developed to encourage case studies of WUI fire events.[9] Many communities rely on external professionals to conduct wildfire hazard and risk assessments.

INFORMING DECISION MAKING

Wildfire data and knowledge are used to develop information systems, quantitative models, qualitative rating schemes, and best practice guides, which inform short- and mid- to long-term wildfire risk management decisions.

Information on short-term wildfire hazard:

- The Canadian Forest Fire Danger Rating System, including the Canadian Forest Fire Weather Index and the Canadian Forest Fire Behaviour Prediction Systems, is used to portray short-term fire hazard. These systems indicate the flammability of different fuel components in relation to weather and the potential fire behavior (e.g., spread rate, intensity) in relation to fuel flammability and wind speed, should a fire occur. Outputs are portrayed nationally in the Canadian Wildland Fire Information System (CWFIS)[23] and provincially in Fire Danger Rating classes.[24]

- The locations, size, and status of active fires or the Current Wildfire Activity.[25] Estimated fire spread rates can be used to project the growth perimeter expansion of these active fires.

- Satellite (MODIS/VIRS) hot spot mapping (e.g., Fire Information for Resource Management System US/Canada[26]; CWFIS[27]).

- Short- and medium-term weather forecasts (ECCC, Spotwx.com, other platforms).

- Estimates of fire growth and fuel consumption are coupled with atmospheric models to project smoke transport in the BlueSky Canada[28] and FireWork[29] smoke models.

- BC Environment air quality advisories and Smoky Skies Bulletins.

- Short-term fire behaviour and weather forecasts during Emergency Management BC Coordination Calls. These calls occur during wildfire season and enable the coordination of federal and provincial response organizations.

- Indigenous and local knowledge holders who have expertise in local climate and weather patterns, snow level and stream flow, fuel conditions, and access and egress.

Information on mid- to long-term wildfire hazard:

- The Provincial Strategic Threat Analysis[30] provides a qualitative rating of wildfire hazard (threat) across BC. The threat rating for a particular location includes the historical lightning- and human-caused fire density, the potential fire intensity for the local fuel conditions and ground slope on a day with extreme fire weather (more severe than 90% of days in the fire season), and the potential for ember spotting based on fire intensity and fuel conditions.

- Wildland Urban Interface Risk Class Maps[31] portray the wildfire threat within 2–2.75 km of settlements mapped as Wildland Urban Interface over the province.

- Burn probability maps (the long-term annual expectation of a fire burning a location) are in preparation for BC and Canada.

- First Nation's Emergency Services Management Tool for comprehensive, integrated, spatial, structural, community, and landscape-level risk information to support planning and design of fuel treatments, and the Lightship decision-support tool to integrate Home Ignition Zone assessments for Indigenous communities.

CURRENT PRACTICE IN HAZARD AND RISK ASSESSMENT

The current guidelines for conducting wildfire hazard and risk assessments in BC are aimed mainly at homeowners, local authorities, and forest professionals.

Hazard and risk assessment guides for homeowners, local authorities, and First Nations:

- BC FireSmart assessments[32]
- *Wildfire Exposure Assessment* outlines the steps in carrying out an assessment of home and community exposure to fire.
- Score cards to rate the vulnerability of homes and critical infrastructure.
- Home Partners Program
- Hazard, risk, and vulnerability analysis (HRVA)[33]
- National guide for WUI fires[34]

Hazard and risk assessment guides for forest professionals and industrial and commercial operators:

- BC Wildfire Service tools for fuel management and wildfire assessment[35]
    - *2020 Wildfire Threat Assessment Guide and Worksheets*
    - *Determining Wildfire Threat and Risk at a Local Level*
    - Procedures for measuring downed woody fuel are included in the *Field Handbook for Prescribed Fire*; these measurements can be used to calculate surface fuel loading in FuelCalcBC
    - *Fuel Management Stocking Standards Guidance Document*
- *A Guide to Fuel Hazard Assessment and Abatement in British Columbia* (for logging and land clearing debris)[36]
- CSA ISO 31000:18 framework for risk management[37]

The BC FireSmart Committee coordinates a provincial approach to wildfire hazard and risk assessment. However, linkages between quantitative estimates of wildfire hazard and exposure and potential losses are poorly developed in Canada. This is because of incomplete methodologies to quantify aspects of hazard and exposure, an absence of quantitative damage, loss, and impact functions, and incomplete spatially explicit data on the value of assets. This makes quantitative comparisons of risk with other natural hazards difficult. There is potential for sharing or the interoperability of some inputs, such as structure and infrastructure data and LiDAR, and to learn from an all-hazards approach.

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GAPS IN UNDERSTANDING RISK

Short-term wildfire risk information and guidance in BC consists mainly of qualitative and quantitative measures of fire danger and behaviour and smoke concentrations, while mid- to long-term risk information is focused on qualitative estimates of fire threat and structure exposure. Information is held by different agencies, leading to a silo effect, and some information is not readily or publicly available. Comprehensive hazard and risk assessments and methods are needed that are applicable to and linked across property, community, and landscape levels as well as time scales, to support the four pillars of emergency management (prevention, mitigation, response, recovery). Furthermore, methods are needed to project changing hazard and risk in future decades, while assessments need to be accessible to different risk managers and stakeholders. We need:

- Better understanding of the types of wildfire exposure, vulnerability, and impacts, such as potential fire spread and ember transport into and through communities (e.g., structure-to-structure ignition) and spread in WUI fuels; health impacts of smoke on vulnerable groups; social, cultural, psychological determinates of vulnerability to wildfire impacts, particularly evacuations; and post-fire impacts such as contaminated soils and erosion.

- A common portal for integrated spatial databases of landscape-, community-, and property-level hazard, exposure, and vulnerability data and assessments. This portal needs to be accessible to the public and local government decision makers and include high-resolution data and maps of fuels and structures derived using new technologies (LiDAR, unmanned aerial vehicles) around settlements.

- An enhanced common operational picture (COP) of active fire incidents that includes fire position, status, and potential growth, the location and vulnerabilities of infrastructure, and the position and status of resources to enhance situational awareness among agencies and whole system resilience.

- Enhanced knowledge transfer, targeting elected officials, to develop a common understanding of risk at local, regional, and provincial scales, including the limits of suppression.

- Pathways to incorporate Indigenous and local knowledge to inform wildfire hazard and risk assessment.

> Information is held by different agencies, leading to a silo effect, and some information is not readily or publicly available.

REDUCING RISK

Wildfire risk management provides the policies, strategies, plans, and actions to reduce the likelihood and severity of wildfires. It also reduces the exposure to and vulnerability of structures, communities, people, and sensitive ecosystems to fire events and impacts and/or enhances their recovery from damaging wildfires (Figure 4).

A large number of government and non-government organizations and private entities are responsible for, or have an interest in, preparing and responding to and recovering from immediate threats and mitigating longer-term threats on public and private lands in BC (Table 2).

PRACTICE, POLICY, AND PROGRAMS

GUIDELINES FOR ACTION

Forest and fire practitioners and Indigenous Knowledge Keepers have experiential and Traditional Knowledge that can guide the reduction of wildfire risk. The experience of practitioners as well as research findings are captured in the following information sources and guides targeted at audiences that have a primary wildfire risk management responsibility.

Wildfire risk reduction guides for homeowners or farmers/ ranchers, business owners, building professionals, builders, developers, local authorities, and First Nations:

- FireSmart BC Tookit[38] (Figure 5)
  - *Firesmart BC Homeowner's Manual*
  - *Firesmart BC Landscaping Guide*

- FireSmart BC resources
  - *The Farm and Ranch Wildfire Guide and Workbook*[39]

- *Open Burning Practices for Farmers and Ranchers*[40]
- *FireSmart Critical Infrastructure Guide*[41]
- *FireSmart Last-Minute Evacuation Checklist*

- FireSmart Canada resources[42]
  - *FireSmart Begins at Home Manual*
  - *Firesmart Canada Home Development Guide*
  - *FireSmart Guide to Landscaping, Second Edition*
  - Wildfire Resilience Best Practises Checklist for Home Construction, Renovation and Landscaping
  - *Protecting Your Community from Wildfire*
  - *FireSmart Guide for the Oil and Gas Industry*
  - *Blazing the Trail: Celebrating Indigenous Fire Stewardship*

- Emergency Management BC's *Wildfire Preparedness Guide*[43]

- National Research Council's *National Guide for Wildland Urban Interface Fires*[44]

- Institute for Catastrophic Loss Reduction Resources
  - *Development Permits: An Emerging Policy Instrument for Local Governments to Manage Interface Fire Risk in a Changing Climate*[45]
  - *Open for Business Guide*[46]

Figure 4: Duhamel Creek fire near Nelson, 2015 (Photo: Adrian Wagner Studio).

Figure 5: A property in Kamloops with FireSmart landscaping and construction features (Photo: FireSmart Canada).

- National Fire Protection Association Standards[47]
  - NFPA 1140 -Standard for Wildland Fire Protection
  - NFPA 1141 -Standard for Fire Protection Infrastructure for Land Development in Wildland, Rural, and Suburban Areas
  - NFPA 1142 -Standard on Water Supplies for Suburban and Rural Firefighting
  - NFPA 1143 -Standard for Wildland Fire Management

- NFPA 1144 -Standard for Reducing Structure Ignition Hazards from Wildland Fire

- *First Nations Wildfire Evacuations: A Guide for Communities and External Agencies*[48]
- Heath Canada's *Guidance for Cleaner Air Spaces during Wildfire Smoke Events*[49]
- Canadian Red Cross's *Fire Recovery Guide*[50]

Wildfire risk reduction guides for forest professionals and industrial and commercial operators:

- BC Wildfire Service Tools for Fuel Management[51]
  - FLNRORD Standard for Developing Tactical Plans for Wildfire Risk Reduction
  - Wildfire Risk Reduction Best Management Practices
  - BCWS Fuel Management Prescription Guidance
  - Fuel Management Stocking Standards Guidance
  - Fuel treatment design wildfire intensity tool (worksheet)
  - ABCFP Interim Guidelines – Fire and Fuel Management (guidelines for professional practice)
- *A Guide to Fuel Hazard Assessment and Abatement in British Columbia*[52] (for logging and land clearing debris)
- "Fire-smart forest management: a pragmatic approach to sustainable forest management in fire-dominated ecosystems," in *Forestry Chronicle.*[53]

Table 2: Organizations involved in wildfire risk management[54]

Entity	Type of Organization	Legal Mandate or Role	Key Programs
Primary responsibility/mandate for preparedness, response, mitigation or recovery			
Residents and property owners	Individuals, companies	Emergency preparedness; reduces risk in the home or structure ignition zone.	
Businesses	Companies	Business continuity planning	
Municipal governments and fire departments	Local government	Emergency planning; subdivision approval, development and building permits, and local bylaws; fuels mitigation; fire response and structure protection within Local Fire Protection Areas; establishes emergency operations centres to coordinate resources, evacuations, communication; initiates community recovery.	
Regional districts	Federations of municipalities, electoral areas, and in some cases Treaty First Nations	Emergency response planning for unincorporated communities; volunteer fire departments; evacuations; fuels mitigation; development and building permits.	
First Nations	Band council	Can initiate community wildfire plans and fuels management projects on reserve and in some cases adjacent lands; authorize evacuations.	

Entity	Type of Organization	Legal Mandate or Role	Key Programs
Primary responsibility/mandate for preparedness, response, mitigation or recovery			
First Nations Emergency Services Society (FNESS)	Society	Fuels mitigation and response capacity.	Fire services; forest fuel management; emergency management.
Canadian Red Cross	Charitable society	Disaster relief and recovery; emergency preparedness.	Evacuation and recovery support; emergency preparedness and Fire Recovery Guide.
Emergency Management BC	Provincial ministry	Emergency preparedness information; supports local governments and coordinate provincial disaster response; compensation to individuals, small businesses, farms and charitable organizations for unexpected uninsurable losses.	Emergency support services; disaster financial assistance.
BC Wildfire Service	Element of Ministry of Forests Lands Natural Resource Operations and Rural Development	Lead agency for managing wildfires across Crown and private lands outside of organized areas through wildfire prevention, detection, and suppression.	Risk management (fire bans, restrictions); fund fire prevention activities; fire prevent-ion requirements for industry; lead FireSmart BC.
BC Parks	Element of BC Environment and Climate Change	Vegetation and fuel management in provincial parks.	
Parks Canada	Federal department	Fuel and fire management in National Parks and National Park Reserves.	Ecosystem restoration; mutual aid with BCWS.
Forest companies	Corporation	Hazard mitigation by volume and area-based tenure holders on Crown land and owners of private forest land.	Requirements under the Forest and Range Practices Act.
Support for preparedness, response, mitigation or recovery activities			
Office of the Fire Commissioner	Element of Emergency Management BC	Training and coordination of fire departments to provide structure protection on WUI fires outside their jurisdiction; coordinates deployment of structure protection units; evacuation powers.	Structural protection program.
Government Communications and Public Engagement	Provincial agency	Implements the provincial communications plan; supports EMBC and BCWS communications.	

Entity	Type of Organization	Legal Mandate or Role	Key Programs
Support for preparedness, response, mitigation or recovery activities			
Ministry of Health	Provincial ministry	Supports health authorities; monitors health risks due to diminished water or air quality; supports vulnerable populations within the medical system; assists with evacuations of health facilities.	
British Columbia Center for Disease Control	Public health organization	Wildfire smoke impacts.	Prevention of wildfire smoke health impacts; wildfire smoke response planning.
Canadian Interagency Forest Fire Centre (CIFFC)	Corporation	Facilitates interagency (provincial, territorial, federal, international) resource transfers; national training and equipment standards.	
Public Safety Canada	Federal department	Coordinates federal response to disasters; disaster financial assistance to provinces and territories.	All-hazards integrated federal emergency response; disaster financial assistance.
Royal Canadian Mounted Police	Federal agency	Assist/manages traffic control, evacuation, temporary re-entry and return in wildfires.	
Department of National Defense	Federal department	Supports provincial response at request of Attorney General; fire management on DND property; safety and security research.	Operation LENTUS for response to natural disasters; Canadian Safety and Security Program .
Indigenous Services Canada	Federal department	Funds on-reserve risk reduction.	Emergency management partnerships.
Health Canada, Public Health Agency of Canada, First Nations Health Authority	Federal department	Identifies high-risk individuals in First Nations communities and health conditions impacted by wildfires; conducts health assessments and makes response `.	First Nations Health Authority.
Industry Canada	Federal department	Represents telecommunications interests in emergencies.	
Agriculture Canada, CFIA	Federal department	Assists producers; relocation of livestock during wildfires.	
Fisheries and Oceans	Federal department	Provides marine transportation and surveillance aircraft as needed.	
Ministry of Agriculture	Provincial ministry	Facilitates relocation of livestock; supports the agricultural industry during wildfires.	

Entity	Type of Organization	Legal Mandate or Role	Key Programs
Programs or policies that influence wildfire hazard and risk or risk management			
Utilities and Railway Companies; Oil and Gas Commission	Corporations/ commission	Advises on impacts to critical infrastructure.	
Forests Lands Natural Resource Operations and Rural Development	Provincial ministry	Forest stewardship on Crown land; permitting of forest roads.	Ecosystem restoration.
Forest Enhancement Society of BC	Provincial agency	Enhances forest resilience to wildfire and climate change.	Funds wildfire prevention and mitigation projects across BC.
Union of BC Municipalities	Association of local governments	Supports community risk reduction.	
BC FireSmart Committee	Committee	Facilitates greater direction and integration of the seven FireSmart disciplines across BC.	Wildfire mitigation information.
Ministry of Municipal Affairs	Provincial ministry	Promotes effective local government services, infrastructure, and governance structures.	
Ministry of Transportation and Infrastructure	Provincial ministry	Subdivision approval and road development outside of municipalities; close provincial transportation routes for visibility or fire risks.	
Attorney General and Housing BC, Building Standards Branch	Provincial ministry	BC Building Code and related codes.	BC Building Code.
Insurance Companies	Corporation	Fire and other insurance for property and business owners.	
Hazard and risk information or knowledge			
BC Environment and Climate Change	Provincial ministry	Monitors and reports air quality.	Air quality advisories and Smoky Skies Bulletins.
Environment and Climate Change Canada	Federal department	Severe weather forecasting; national wildfire smoke modelling; Canadian Meteorological Service weather models and regional preparedness forecasts.	FireWork smoke model.
FireSmokeCanada Project	AB/BC/UBC Consortium	Wildfire smoke modelling in BC and Alberta.	BlueSky Canada smoke model.

Entity	Type of Organization	Legal Mandate or Role	Key Programs
Hazard and risk information or knowledge			
FireSmart Canada	Program of Canadian Interagency Forest Fire Centre	Helps more Canadians to become FireSmart.	Wildfire mitigation information and programs.
Natural Resources Canada	Federal department	Research to support the Canadian Wildland Fire Strategy; supports CIFFC and FireSmart Canada; provides fire and weather modelling mutual aid.	Canadian Wildland Fire Information System.
National Research Council, Construction Innovation	Federal agency	Improves fire safety in the built environment; adapts the National Building Code to climate change.	WUI construction guidelines.
Institute for Catastrophic Loss Reduction	Corporation	Disaster prevention research and communication.	Wildfire prevention and mitigation information for homeowners, municipalities, small businesses, and insurers.

LEGISLATION AND POLICY

There is no overarching, comprehensive strategy guiding wildfire hazard and risk reduction in BC. Rather, wildfire risk and risk management are influenced by a variety of local, provincial and federal/ national legislation and policies (Table 3). Some noteworthy policy developments include:

- While the actions of individual property owners to mitigate wildfire risk on private land have been mainly voluntary, some municipalities have introduced bylaws, such as those that define Wildfire Development Permit Areas in official community plans, in which FireSmart measures are required for new developments. However, municipal councils face pushback to approve developments in the WUI without requiring FireSmart provisions because of increased development and building costs.

- In 2021, the Government of BC passed Bill 23, the *Forest Statutes Amendment Act*, which included provisions to strengthen shared decision-making opportunities through forest landscape planning and to expand provisions for wildfire management and practices within Wildland Urban Interface Areas, including the addition of wildfire as a forest management objective.

- In 2020, the federal government initiated the *Emergency Management Strategy for Canada* to coordinate sharing of responsibilities between federal, provincial, and territorial governments and other partners.

INSURANCE

Insurance practices also influence and are influenced by risk management practices. Individual property owners reduce their financial losses by purchasing insurance. While insurance policies can be purchased for physical damage or financial losses from business interruptions, the issuing of new policies is typically suspended when active wildfires threaten a home or settlement. As well, wildfire insurance or expectations of post-fire recovery funding from governments may inadvertently encourage development in areas at risk of wildfire, or may be a disincentive for property owners to take measures to reduce wildfire risk around homes and

Table 3: Legislation and policy framework for wildfire hazard and risk reduction

Scale	Scope
Local	
Official community plans, development permit areas, bylaws, covenants	Permit or restrict types of development, construction, maintenance in the built environment.
Provincial[55]	
Wildfire Act and provincial parks legislation	Authority for fire prevention and control; cost recovery for fire control; fire prevention regulation.
Forest Act and *Forest and Range Practices Act*	Governs licensee activity on Crown land base.
Bill 23 *Forest Statutes Amendment Act*, 2021	Amended existing legislation including requirements for forest landscape planning and managing risk of wildfire.
Parks Act	Vegetation and fire management plans in provincial parks.
Special Accounts Appropriation and Control Act	Forest management and wildfire costs.
Mutual aid agreements for response	BCWS aid to municipalities, and, in some cases, First Nations.
Emergency Program Act and Regulations	Preparedness and response.
Compensation and Disaster Financial Assistance Regulations	Compensation from structural wildfire damage.
Local Government Act and Local Authority Emergency Management Regulation	Development permit areas; local emergency plans and powers.
Land Title Act, *Strata Property Act*, *Real Estate Development and Marketing Act*, *Local Government Act*	Subdivision approvals within and outside municipal boundaries.
BC Building Act and Codes	Provides the minimum requirements for a safely built environment.
Open Burning Smoke Control Regulations	Burn permits.
Professional Governance Act	Regulation of professionals and professional organizations.
BC's *Wildland Fire Management Strategy*	Restore the natural role of wildfire in BC ecosystems while continuing to provide an effective response to unwanted fires.
BC's *Climate Preparedness and Adaptation Strategy*	Draft strategy to ensure BC stays safe and responds effectively to a changing climate.
Federal and National[56]	
Emergency Preparedness Act	Disaster Financial Assistance Program.
Department of Defence Act	Aid to a civil authority.

Scale	Scope
Federal and National	
Indian Act	Federal responsibility for on-reserve activities.
Canadian Interagency Mutual Aid and Resource Sharing Agreement	Resource sharing between provincial, territorial, and federal fire management agencies.
CIFFC's Wildland Fire Prevention and Mitigation Action Plan	Strengthen and transform FireSmart Canada, CIFFC, and Canada's wildland fire management agencies into an integrated collective.
Canada–US Reciprocal Forest Fire Fighting Arrangement	Cross-border movement of firefighting resources.
Parks Act and *Species at Risk Act*	Vegetation and fire management in national parks.
Emergency Management Strategy for Canada	Describes the sharing of emergency management (EM) responsibilities among the federal, provincial, and territorial governments and with EM partners.
Canadian Wildland Fire Strategy	Intergovernmental agreement to pursue broad wildfire management strategic goals.
National Adaptation Strategy (forthcoming)	Establishes a shared vision for climate resilience in Canada.

buildings. Similarly, overestimation of the true effectiveness of wildfire suppression may be a disincentive to mitigating risk as well as a cultural tendency to disregard worst case scenarios.[57] Increasingly, insurance underwriters include an assessment of community wildfire preparation and fire department response capacity in fire ratings for home insurance. This trend may incentivize the public to put pressure on local governments to demonstrate preparedness.

FUNDING PROGRAMS

The BCWS and the Thompson-Okanagan Interface Committee began building awareness and promoting fire smart principles in the 1990s; these programs have been expanded provincially through FireSmart BC and FireSmart Canada. However, on-the-ground progress has been slow and limited by funding.

The catastrophic wildfire seasons of 2003, 2017, 2018, and 2021 directly impacted tens of thousands of British Columbians through evacuations and property loss, while prolonged smoke exposure across the province increased awareness of wildfire in larger urban centres. These events were catalysts of change. Following 2003 and 2017, high-level reviews influenced policy, practice, and generated new funding programs. Firestorm 2003 prompted the Strategic Wildfire Prevention Initiative (SWPI), administered by the Union of BC Municipalities. This matching-funds program aimed to address WUI risk through grants to support development of community wildfire protection plans, now called community wildfire resilience plans, and implementation of fuel treatments in forests surrounding municipalities.

In 2015, the Forest Enhancement Society was created to provide funding for landscape-level wildfire risk reduction, low-value fibre utilization, and rehabilitation of stands damaged by wildfire—programs that complement and reinforce WUI treatments. In parallel, fuel mitigation (Figure 6) on First Nations reserves was funded by Indigenous and Northern Affairs Canada's On-Reserve Forest Fuel Reduction Treatment Program and facilitated by the First Nations Emergency Services Society of BC. As of 2019, Indigenous Services Canada's Emergency Assistance Program also provides five-year

Figure 6: A fuel reduction treatment near Kimberley (Photo: Natural Resources Canada).

funding for FireSmart projects on reserves. BC's Ecological Restoration program also uses mechanical thinning and prescribed burning in grasslands and dry forests, in many cases contributing to fuel hazard mitigation and wildfire risk reduction. Following the extreme 2017 and 2018 wildfire seasons, SWPI was replaced by the Community Resiliency Investment (CRI) program, with three funding streams to address risk across scales. To date, more than 300 community plans have been prepared; nevertheless, fuel treatments remain incomplete for all communities in BC.

Nevertheless, funding for wildfire remains asymmetrical—with significant resources for fire response in emergency situations but constrained investments in wildfire prevention and proactive management. An incomplete understanding of the cost and benefits of mitigation may hinder investment in programs that avoid future losses.

DISASTER RISK REDUCTION GAPS

CLIMATE CHANGE

Wildfire hazard and risk are projected to continue increasing in BC due to climate change. The BC Preliminary Strategic Climate Risk Assessment[58] rated severe wildfires as having the highest expected consequences across all climate risk events by 2050. Projections include severe wildfire seasons in which one million hectares burn, increasing in frequency, with a return period decreasing from 1 fire in 50 years to 1 in 10 years. Recent research suggests that annual area burned may increase by 1.5 times by 2050 in the southern and interior Cordillera.[59] Nevertheless, climate change is not included in current provincial-scale wildfire threat assessments. The uncertainties inherent in climate models pose challenges when projecting local temperature, relative humidity, precipitation, and wind that determine specific wildfire behaviour and effects. Projections of future climate impacts on expected changes in burn probability and other relevant measures are needed across relevant spatial scales.[60]

To address these limitations, the BC Climate Preparedness and Adaptation Strategy[61] emphasizes the importance of implementing wildfire adaptation options. The 2022–2025 goals include:

- Improving the provincial response to extreme heat and wildfire smoke for unhoused and housing-insecure populations.
- Enhancing predictive services and early warning capacity, to bring the future climate into forecasting droughts, water scarcity, and wildfires.

Funding for wildfire remains asymmetrical—with significant resources for fire response in emergency situations but constrained investments in wildfire prevention and proactive management. An incomplete understanding of the cost and benefits of mitigation may hinder investment in programs that avoid future losses.

RESEARCH PRIORITIES

The *Blueprint for Wildland Fire Science in Canada (2019–2029)*,[62] *the Climate Change and Fire Management Research Strategy*,[63] and contributors to this article have identified a number of additional research priorities, many of which relate to disaster risk reduction, as follows:

- Better understanding of what makes a wildfire-resilient community (planning, construction, access/egress), informed by:
  - Models of integrated risk, from landscape to community to home, to guide planning and prioritize mitigation.
  - Quantitative models of WUI hazard, exposure, and impact in built environments, including ember exposure, pathways of fire progression, flammability of WUI fuels (e.g., landscaping, roadside weeds and brush) and structural vulnerability.
  - Community-scale sociopolitical factors that influence perspectives on wildfire risk and preferences for action.
  - The efficacy of fuels treatment and other mitigation options, across varied landscapes and geographic areas.
  - Cost-benefit analyses of trade-offs and co-benefits for various response and risk mitigation scenarios.

- Formal monitoring or a database of risk reduction treatments to help inform subsequent risk assessments.

POLICY AND PRACTICE INTEGRATION

The key word for practitioners is *integration*. There is a need to integrate policy, plans and practice for mitigation, preparedness, response, and recovery—from the landscape, through the WUI and into communities—through meaningful collaborations across organizations that affect decision making on the land base, including First Nations, municipalities, regional districts, provincial authorities, and the private sector (e.g., forest industry, developers, insurers). Specifically, there is need for:

- Policy support and best practices for local governments , fire departments, and First Nations that carry the majority of the burden for WUI management and community wildfire preparedness, including:
  - FireSmart standards for new construction and development in wildfire-prone areas, including requirements for access or egress routes and turnaround for new roads.
  - Preplanning of wildfire suppression, structure protection, and evacuations (e.g., preparedness levels, defensible locations, water sources, safe refuges, fire-specific evacuation plans, fire-safe routes, public notification).
  - Tools to aid the design of fuel mitigation treatments and a streamlined approval process for prescriptions.

- Policy support for innovative practices that have proven effective in other jurisdictions, including use of prescribed (Figure 7) and cultural fire led by Indigenous practitioners.

There is a need to integrate policy, plans and practice for mitigation, preparedness, response, and recovery—from the landscape, through the WUI and into communities—through meaningful collaborations across organizations that affect decision making on the land base, including First Nations, municipalities, regional districts, provincial authorities, and the private sector.

CAPACITY BUILDING

The following resources are needed to enhance capacity to execute policy and practice:

- Long-term, sustained, committed funding for fuel and other mitigation treatments at community and landscape scales.

- Enhanced support for local governments who are responsible for initiating wildfire recovery. In addition to remediating and rebuilding public infrastructure, local governments may have to deal with removing debris and remediating contaminated soil on private properties if owners are uninsured or underinsured and not eligible for government disaster assistance. Disaster assistance for wildfire losses is often not available where fire insurance is available. This is a substantive administrative and financial burden for small communities.

- Continuing education to enable forest practitioners to gain expertise integrating forest and fire management planning.

- Professional certification programs for developing prescriptions to mitigate hazardous fuels, including application of prescribed and cultural fire.

- Projection of relevant measures of potential fire activity with climate change at planning scales; downscaling climate scenarios and local climate change visioning.[64]

- Evidenced based, cost-effective development and building standards to reduce structure ignitions from wildland fires, commensurate with hazard.

- A credible community-level preparedness rating scheme for insurance underwriters.

Figure 7: Prescribed fire to restore wildlife habitat in the Vaseux-Bighorn National Wildlife Area in the southern Okanagan, 2013 (Photo: Tree-ring Lab at UBC).

OPPORTUNITY

Wildland Urban Interface fire has been recognized as a coupled socio-ecologic system,[65] where a rapid increase in fire activity will challenge the resilience of both human communities and ecological systems. It is important to think beyond basic resilience or maintenance of the status quo in order to adapt and transform the systems be more resilient to future conditions.[66,67] Many prevention, mitigation, preparedness, response, and recovery "risk controls"—including vegetation and fire management, community planning, construction, and capacity building—are available to mitigate wildfire risk and increase resilience within this socio-ecologic system. It is critical to integrate efforts between institutions, levels of government, residents and property owners, and research disciplines to advance risk management, adaptation, mitigation, and resilience.[68]

RECOMMENDATIONS

Although there has been a significant effort to develop wildfire risk assessment and risk management tools in BC, it is evident that if we continue with the same wildfire risk management approach we will get the same impacts.[69] Furthermore, wildfire requires that we work together across jurisdictions and at different scales, incorporating expertise and best practices from Indigenous and local communities, public and private sector fire managers and forest professionals, and that we connect with other provinces, federal programs, and national strategies. A comprehensive understanding of wildfire risk and risk reduction is needed among the many participants and risk managers, and continued efforts are needed to:

- Enhance fire resilience in wildlands.
- Create more fire resilience in communities.
- Develop more resilient fire and emergency management organizations.

We recommend a number of potential actions to advance these goals in Table 4.

Table 4: Recommendations

Recommendation	Impact	Priority Level	Capabilities Needed
1. Sustain funding and support for wildfire resilience planning and capacity building in vulnerable communities, including pre-suppression and evacuation planning.	Vulnerable communities have effective community wildfire resilience plans and enhanced risk reduction capacity.	Critical	Policy, financial
2. Integrate risk reduction planning and coordination across wildfire prevention, preparedness, response and recovery organizations, and levels of government, including an integrated spatial database of hazard and risk information and common operational picture of active incidents.	Improved "whole system" resilience.	Critical	Practice
3. Develop a better understanding of what makes for a fire-resilient community and policies or standards to foster adoption of FireSmart measures for development and construction in fire-prone areas; develop best practices for pre-suppression and evacuation *planning*.	More fire-resilient developments and structures.	Critical	Policy, technical
4. Enhance Indigenous and community forest stewardship and include local expertise in identifying assets at risk and in risk reduction plans.	Indigenous and rural communities have greater influence on fire hazard reduction and decision making.	Critical	Policy
5. Increase prescribed burning capacity, reduce liability for prescribed burning for risk reduction, and increase opportunities for Indigenous-led burning.	Increased use of prescribed and cultural fire; more resilient landscapes.	Critical	Technical, policy

Recommendation	Impact	Priority Level	Capabilities Needed
6. Integrate forest management, landscape fire management, and community level plans, including forest industry participation; integrate with multi-hazard planning.	Enhanced landscape and forest resilience to fire across multiple scales (within and beyond the WUI) and interacting hazards, such as floods and debris flows.	Necessary	Policy, technical
7. Increase capacity in risk assessment, risk management, and recovery planning; renew regional fire committees to share best practices and research; communicate case studies of successful community-level risk reduction; outreach and education for elected officials and general public.	Continuous improvement in risk reduction and resilience planning; a broader common vision of what success looks like.	Necessary	Technical
8. Renew the BC *Climate Change and Fire Management Research Strategy*,[70] including research into fuel treatment efficacy and to identify barriers and opportunities for uptake of proactive fire management.	Enhanced scientific and social basis for proactive wildfire management.	Necessary	Technical
9. Research physical and mental health effects of wildfire and mitigation solutions on emergency response personnel, evacuees, and the general public.	Practices to maintain personnel wellness and understanding of determinants of wellness.	Necessary	Technical
10. Encourage leadership from civic leaders and influencers, sustained messaging and outreach about living with fire, promotion of prescribed fire, fuel treatments, and property-level mitigation.	Greater cultural acceptance of fire; more engaged public.	Recommended	Policy, technical
11. Enhance ability to predict wildfire surges and surge capacity.	Increased preparedness for surges in fire activity.	Recommended	Technical

THE CHALLENGE

The challenge in BC is for the whole of society to recognize that: 1) wildfires may not be quickly controlled during periods of extreme fire weather; 2) there is an increasing likelihood that communities and properties in fire-prone areas will be exposed to extreme fire weather and damaging wildfires; and 3) we need to learn to live with and respect wildfires. This may require a cultural shift from our focus on reducing the immediate wildfire risk to adapting to wildfire risk over time.[71]

RISK PERCEPTION

Risk perception is a key limiting factor in our willingness to invest in risk reduction. BC experienced several decades of moderate, declining fire activity in the latter half of the last century,[72] a period when severe damaging fires were often viewed as unpredictable "Black Swan" events.[i] However, while the drivers of wildfire risk in BC (an expanding WUI and changing fuel and climate conditions) have accelerated over the past decades, we have yet to accept that BC has entered a different fire era where damaging WUI fire events are inevitable.

[i] *A Black Swan event is an unexpected outlier that results in unprecedented extreme impacts at the time that it occurred, but which seems explainable and predictable after the fact.*

> Risk perception is a key limiting factor in our willingness to invest in risk reduction. . . . We have yet to accept that BC has entered a different fire era where damaging WUI fire events are inevitable.

"TOTAL CHANCE" WILDFIRE RISK REDUCTION

An integrated "total chance" risk reduction approach is needed to prevent WUI fire damage during extreme burning conditions.[ii] It is increasingly recognized that neither long-term mitigation measures, such as fuel reduction and building more wildfire-resilient structures, nor short-term wildland or community-based fire response measures, are sufficient on their own. Instead, wildfire suppression and emergency response actions, including burning off wildland fuels adjacent to settlements, are enhanced by managing fuels around communities, which, along with building more fire-resistant structures, allows for safer and more effective structure protection.

DIFFUSE OR FRAGMENTED GOVERNANCE AND RESPONSIBILITY

An integrated approach remains challenging because wildfire risk is "everyone's problem and no one's problem." As fires spread from wildlands to settlements, different risk reduction options fall within the jurisdiction of different levels of government, or are the responsibility of private property owners along a fire's path from the hillside to the doorstep. No single stakeholder or risk manager can influence all aspects of hazard, exposure, and vulnerability. Furthermore, wildfire risk has economic, sociopolitical, and ecological dimensions, as well as interactions and feedbacks with other challenges and hazards, including Indigenous land governance, flooding and landslides, extreme heat events, and resource industry stability. Collaboration and integration among participants is a major challenge, as they have different incentives, capacities, and barriers to engage in proactive risk mitigation; this can lead to moral hazards (free-riding) if an entity defers its responsibility for risk reduction in the belief that another's actions will provide protection.

Voluntary engagement of residents in risk reduction (e.g., making changes to existing buildings, maintaining home ignition zones) is an ongoing challenge for many reasons including financial constraints, issues of trust in government, and because many of us believe "it will never happen to me." Code development processes are exceedingly slow and conservative[73]—it may be decades before community and structure ignition measures are widely incorporated into buildings and communities. There are no guidelines and few examples of effective collaboration to plan, design, and implement wildfire risk reduction activities across different jurisdictions or with different groups. One important example are the lessons learned from the joint recovery process undertaken after the 2017 Elephant Hill fire, with 30 calls to action to help advance First Nations' leadership and partnerships in all phases of emergency management.[74]

A WHOLE OF SOCIETY APPROACH

Wildfire management and risk assessment, and emergency management and disaster risk assessment, have largely developed as separate disciplines. It is essential that we shift to a multi-disciplinary, multi-participant approach, to collectively identify and address gaps in wildfire risk management knowledge and practice following the four pillars of emergency management, where we learn from different kinds of expertise (Indigenous, local, government, others) and train upcoming generations to successfully manage wildfire risk. These efforts must be better connected to other risks to understand where risk reduction efforts may benefit more than one hazard risk (e.g., wildfires and landslides). Mitigation measures need to be placed-based, depending on the socio-ecological context—a common vision of what wildfire resilience looks like for communities in different firescapes is needed. Strong

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[ii] *Whether firefighters can safely protect structures from wildfire depends on the degree to which a fire spreads near structures and potentially exposes both structures and firefighters to embers, radiant heat, or flame, and whether multiple structures are ignited simultaneously. Thus, opportunities to reduce fire hazard, structure exposure, and vulnerability and opportunities for community-level wildfire pre-suppression planning should be considered together to maximize the total chance that structures or other assets will survive wildfire.*

leadership will be needed to move BC towards greater cultural acceptance of fire and to motivate and coordinate efforts between disciplines and participants and across jurisdictional boundaries—a comprehensive wildfire risk reduction, communication, and outreach strategy could be a good next step.

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Photo: Tim Shields

1.6 COASTAL FLOODS

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RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 1 Understanding and Managing Climate and Disaster Risk: Hazard Threat*. To read all articles in the report, see DRRPathways.ca.

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1.6 COASTAL FLOODS

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ABOUT COASTAL FLOODS

DESCRIPTION

British Columbia is a coastal province, with the majority of people and infrastructure situated in coastal regions. The ways of life of coastal Indigenous Peoples have been intertwined with the sea in this region for millennia. For instance, salmon has deep cultural significance to Coast Salish peoples, beyond its practical significance as a food source. Today, people in BC remain dependent on proximity to the coast for economic and sociocultural reasons, including needs and desires related to shipping and transportation, tourism, recreation, and connectivity with nature. BC coasts are also home to some of the most unique and sensitive ecosystems in the world, and the coast is arguably the most biologically diverse region of the province.

Coastal flood hazards in BC originate from a variety of sources and combinations of sources, including tides, storm surges, waves, regional fluctuations in sea levels (e.g., due to El Niño–Southern Oscillation), seiches (sloshing of water in bays and inlets), rainfall, river flows and tsunamis. However, in this article, we limit our definition of coastal flooding to inundation of coastal lands driven primarily by elevated sea levels and/or waves; precipitation-driven flooding (such as the floods associated with the damaging November 2021 atmospheric river events) can impact areas much further inland.

Coastal flooding is a natural process contributing to ecosystem function; for example, the disturbances resulting from storms are integral in creating "patchiness" (e.g., in shoreline morphology, sediments, and habitat type) in coastal zones, which supports biodiversity. Risk only arises when there is an intersection of vulnerable people, infrastructure, and other valued assets with coastal flood hazards (Figure 1).

The most damaging coastal flooding events in BC's recent history have tended to occur in fall or winter when spring tides coincide with storm surges and/or high waves, sometimes superimposed on sea levels that are already regionally elevated by El Niño events. The extra-tropical storms that are the predominant drivers of storm surges and high waves also commonly bring intense and prolonged rainfall to BC coastal regions upon landfall, which can lead to jointly occurring fluvial (riverine) and pluvial (rainfall-driven) flood hazards. Storm surges in BC are primarily the result of the inverse barometer effect, which is the rise in water level accompanying a fall in sea-level pressure, such as occurs during the passage of storms. Storm-driven winds, currents, and their interactions with shorelines

Figure 1: Rescue at the White Rock Pier, December 20, 2018 (Photo: Tim Shields).

and bathymetry contribute to locally elevated surges. Progressive or storm-driven erosion can create new pathways for flood hazards to reach people, infrastructure and valued assets. The presence of debris (e.g., logs and trees) in BC coastal waters can exacerbate flood hazards. Over time, coastal flooding is expected to become more frequent and severe in many parts of BC due to relative sea-level rise, which is the combined result of rising global sea levels and vertical land motion (subsidence or uplift).

COASTAL FLOODING THREAT AND PAST EVENTS

Coastal floods resulting from elevated sea levels and/or wave effects have tended to be relatively localized events in BC (compared, for example, to the widespread, predominantly rainfall-driven flooding in mainland BC in November 2021). However, there have been damaging events in recent history. In 1982 (a strong El Niño year), storm surges caused significant flooding damage in parts of the Fraser River delta.[1] A report prepared for the Adaptation to Climate Change Team at Simon Fraser University documented coastal flooding events and near misses in Metro Vancouver from the late 1800s through 2011.[2] Damaging coastal flood events have not been limited to the Lower Mainland; for example, a storm surge event on the coast of Haida Gwaii in 2003 resulted in erosion of a highway and extensive coastal flooding, which damaged buildings and transported driftwood onto roads and properties.[3] However, the major threats from coastal flood hazards in BC lie in the coming decades, with the looming threat of sea-level rise.

DRIVERS OF RISK

Coastal development, population growth, and historical failures in coastal zone management practices are contributing to increased exposure and risk. For example, many parts of the densely populated Lower Mainland coastal region are located at or below mean sea level, protected by sea dikes. These dikes are generally vulnerable to seismic hazards (ground shaking and liquefaction) and, in the event of a damaging earthquake, there may not be sufficient time to repair the entire network of flood protection infrastructure before a coastal storm impacts the region. Without intervention, large swaths of urban and high-value agricultural land in this region (located in Vancouver, Surrey, Richmond, and Delta) are projected to be at high risk of coastal flooding even for non-storm scenarios by the end of the century. Many First Nations communities at risk of coastal flooding are not protected by sea dikes and will be disproportionality impacted by sea-level rise. Extensive historical development in areas of moderate to high hazard limits or restricts the range of adaptation options that are feasible or palatable. Low awareness of risk among the general public has also led to increased vulnerability and perpetuation of planning and development practices and policies that contribute to increased flood risk over time.

Nationally, critical infrastructure that forms part of the Asia-Pacific Gateway and Corridor passes through the coastal floodplain in BC. Though predominantly driven by intense precipitation (as opposed to elevated water levels and/or wave effects), the flooding events in BC's Interior in November 2021 highlighted infrastructure and supply chain vulnerabilities and economic ripple effects that could materialize in the event of widespread coastal flooding.

Climate change effects such as sea-level rise,[4] and, possibly, changes in the frequency and intensity of storms,[5,6] combined with land subsidence in some areas, are contributing to escalating hazards over time. Economic activity, population growth, demand for waterfront property, and failures in urban and land-use planning practices have resulted in significant development in coastal floodplains. Risk management practices to date have not kept pace with the increasing hazards and floodplain development, resulting in increased flood risk. Without intervention or improvement of risk management practices, these risks are projected to continue to increase over time.

UNDERSTANDING RISK

The collective understanding of coastal flood hazard risk in BC is largely based on flood hazard mapping commissioned by local governments, sometimes supported by provincial or federal government funding. Most of this mapping has involved static mapping of water levels and wave runup allowances onto coastal topography to assess the inland extent of exposure for a single, extreme event. Only a few municipalities have been able to muster the resources needed to apply advanced modelling techniques or approaches that consider risk in all its dimensions, including the change in risk over time and the vulnerability of people, communities and ecosystems. Even where sophisticated mapping

NEAR MISS, WHITE ROCK PIER COLLAPSE

Coastal flood hazards can develop with little to no warning, and a hazardous situation during a coastal storm can result in rapidly cascading impacts putting human life at risk. An example of a near miss involving human life safety took place at the White Rock Pier on December 20, 2018. High waves during a large tide and storm surge overtopped the White Rock breakwater, a structure intended to shelter several sail boats moored to the dock at the end of the 470-metre-long pier. During the storm, dock broke free resulting in several boats striking the pier, visible in Figure 2, causing the collapse of one segment and leaving one person stranded. Waves overtopped remaining sections of the pier. A Canadian Forces Cormorant helicopter was dispatched from CFB Comox to assist. Highly trained search and rescue technicians were able to rescue the stranded individual, returning them safely to shore.

Figure 2: White Rock Pier Collapse, December 20, 2018 (Photo: Tim Shields).

Reopening of the pier took place on September 21, 2019, following approximately $16 million in repairs and upgrades, while the moorage facilities have not yet been replaced. Many local businesses were impacted from the reduced tourist and recreational activity during the pier closure. While the pier has not been raised to accommodate sea-level rise, the section that was replaced has been made to be flexible to accommodate raising in the future.

With sea-level rise, life safety, property and infrastructure are expected to be impacted more frequently with greater consequences during storm conditions in the future. There have been at least five other events documented in the Canadian Disaster Database since 1933 for this area.

has been undertaken, communication and dialogue surrounding risk has often been lacking, resulting in a poor collective understanding.

> Economic activity, population growth, demand for waterfront property, and failures in urban and land-use planning practices have resulted in significant development in coastal floodplains. Risk management practices to date have not kept pace . . . resulting in increased flood risk.

The absence of a province-wide hazard or risk mapping program, alongside inconsistent mapping approaches and technical guidance that lags behind international best practices, have contributed to a generally poor understanding of coastal flood hazard risk. Encouragingly, the provincial government has acknowledged the need to prioritize the development of clear, consistent, up-to-date flood maps and has committed to working with other levels of government to achieve this. In March 2022, the federal government committed over $63.8 million to a new national flood hazard identification and mapping program. It remains to be seen how these commitments from multiple levels of government will materialize and be implemented and how they will contribute to an improved understanding of coastal flood risk.

WHAT SOURCES HELP US UNDERSTAND HAZARD AND RISK

The provincial government has published guidelines for the mapping of coastal flood hazards and establishment of setback distances and flood construction levels (Flood Hazard Area Land Use Management or FHALUM guidelines),[7] high-level guidance on sea-level rise adaptation,[8] and prescriptive guidelines for implementing structural flood control structures. The National Research Council published coastal flood risk assessment guidelines for building and infrastructure design applications[9] in 2020, and the federal government is continuing to work on updating and improving federal flood mapping guidelines, with several publications relevant to risk-based analysis for coastal zones expected in 2022. Detailed risk assessments depend on the availability of supporting data (including local datasets) and are often prohibitive due to resource and capacity constraints, or inaccessible to wider audiences due to restrictions arising from confidentiality.

CURRENT PRACTICE IN HAZARD AND RISK ASSESSMENT

Coastal flood hazard assessment practice in BC has mainly followed the provincial FHALUM guidelines.[10] These methods have provided the basis for establishing setback distances and flood construction levels by many local governments. However, the guidelines have not been regularly updated to keep pace with international best practice and emerging climate change projections, nor do they align with risk-based or all-hazards approaches (as per the Sendai Framework for Disaster Risk Reduction) or facilitate options appraisal to guide strategies for flood risk management (e.g., nature-based solutions, managed retreat, property-level resilience measures). The extent to which other guidelines, such as federally developed guidelines or those developed by professional associations (e.g., Engineers and Geoscientists BC), have been used in practice is unclear. Coastal flood risk assessments, in the strict sense (i.e., where consequences and likelihoods of a variety of flood events are assessed), are extremely rare.

> Only a few municipalities have been able to muster the resources needed to apply advanced modelling techniques or approaches that consider risk in all its dimensions, including the change in risk over time and the vulnerability of people, communities and ecosystems.

GAPS IN UNDERSTANDING RISK

There are gaps in the data needed to support decision making surrounding coastal flood risk management, particularly in the context of a changing climate. Data collection is often ad hoc, short term, and reliant on the limited fiscal capacity of municipal governments. Lessons learned during post-disaster recovery are often forgotten, not finding their way into planning and preparedness activities.

BC is in need of an integrated, long-term, open access coastal monitoring system that would provide baseline information needed to support a range of coastal flood risk management activities. At present, data coverage (such as water level and wave records) is scarce and managed by various government departments and academic or non-profit institutions. Sustained, long-term federal and/or provincial investment in a monitoring program is needed to support effective coastal flood risk assessment.

Flood hazard maps are not available for many coastal communities, and for communities where maps exist, many are out of date. Information on vulnerability to, or consequences of, different types of flood events is rarely communicated, which is a major barrier to understanding risk. Mapping methodologies and approaches have been inconsistent, owing to highly variable capacity, expertise, and supporting datasets. These studies vary in quality and emphasis depending on the strengths of the organization undertaking the work. More recently, collaborative efforts at the regional and sub-regional levels have been undertaken.

SEMIAHMOO NATION'S FLOOD STORY

An emerging practice in coastal flood risk management in BC is to include Indigenous oral history along with published data sources early in the process of planning for and understanding risk. Flood events documented following European settlement of the Salish Sea represent a comparatively shorter history than that of First Nations' oral history; such oral history can provide greater context to complement modern data sources.

Figure 3: Chief Chappell speaking on May 4, 2018, at a Classrooms to Community event (Photo: City of Surrey).

In 2016, City of Surrey convened various possible partners in risk reduction to a tour of the coastal floodplain. Each jurisdiction was invited to speak to the group and Semiahmoo First Nation provided its perspective, including an oral history of past floods. Later in the process, Chief Chappell of Semiahmoo First Nation agreed to share his Nation's Flood Story as part of a Classrooms to Community event for local schoolteachers, as shown in Figure 3. It has been made available on the City of Surrey's YouTube account.

Inclusive planning with Indigenous Peoples, such as in the case of Surrey, has helped to build trust and cooperation that is ultimately improving coastal risk reduction. Implementation of specific projects requires additional knowledge exchange that continues to build on the initial planning work.

Workshop-based approaches such as PIEVC, Circle Tool, and BARC Program have been employed but in inconsistent ways. These workshop-based assessments typically help to build a framework to prioritize more technical, focused works. However, resources and organizational mandates to comprehensively maintain and publish the results have not emerged.

REDUCING RISK

WHAT SOURCES HELP US REDUCE RISK

Flood damage in Canada has become the costliest insured loss.[11] While avoidance is generally the preferred risk reduction strategy for coastal flooding, and is the strategy supported by FHALUM guidance, buildings and infrastructure can be designed or retrofitted for enhanced flood resistance[i] or resilience to further reduce residual risk. Unfortunately, the National Building Code of Canada (the model code on which the BC Building Code is substantially based) is largely silent on flood resistance and resilience measures. In 2021, the National Research Council published two reports providing guidance and best practices for increasing the flood resistance of buildings in Canada.[12,13] However, it is not clear if or when such measures might be incorporated in model National Building Codes or mandated by provincial jurisdictions like BC. Applied research and guidance is needed on how to design and retrofit other types of infrastructure to enhance flood resistance and resilience.

[i] *In this context, "resistance" is taken to mean the ability to prevent flood water ingress and flood damage, whereas "resilience" refers to measures that ensure faster and more economical recovery following a flood event.*

The National Building Code of Canada (the model code on which the BC Building Code is substantially based) is largely silent on flood resistance and resilience measures.

RISK REDUCTION PRACTICE, POLICY, AND CAPABILITIES

Coastal flood risk management practice and policy in BC is affected by a complex history and governance context. Pre-contact, many Indigenous coastal communities relied on oral histories, Traditional Knowledge and seasonal migrations to coexist with flooding. Post-contact, decisions by federal, provincial and municipal governments related to flood management and land use have disadvantaged many First Nations communities or ignored or minimized the role and perspectives of First Nations in managing flood risk. Today in BC, as is the case across Canada, responsibilities for flood risk management are distributed across multiple levels of government.

The fragmented governance context has in some cases locked in decisions of regret (e.g., the need to continue raising dike levels). Recently, there have been some moves towards collaborative, "whole of society" approaches to coastal flood risk management with efforts by municipalities (e.g., City of Surrey[14]) and non-profit groups (e.g., Fraser Basin Council, Living Dike Roundtable), as well as the provincial government's recognition of the need for a province-wide flood strategy, but more is needed to ensure flood risk is managed in a more sustainable way going forward.

While recent flood management decisions have had limited First Nations involvement or engagement, there are signs this is beginning to change. Several examples signaling this shift include establishment of an Emergency Planning Secretariat, First Nations representation on the Leadership Committee of the Fraser Basin Council, inclusion of First Nations in local planning, and commitments from the provincial government to bring all provincial laws into harmony with the *UN Declaration on the Rights of Indigenous Peoples Act*. Through the Federal Disaster Mitigation and Adaptation Fund (DMAF), several projects with First Nations and local government partnerships have been established, and several First Nations are partners in coastal flood risk assessment and management-focused research projects funded by the Canadian Safety and Security Program.

Despite (and hindering) efforts to work towards collaborative whole-of-society approaches, fragmented jurisdiction results in uncertainty and difficulty implementing projects. Conflicting regulations, and regulations that do not keep pace with emerging science (e.g., failing to contemplate the effects of climate change, or to recognize trade-offs between short-term impacts and long-term benefits of nature-based solutions), make it difficult for proponents to proactively adapt. In other cases, the proponent is caught between conflicting legislation such as surface water rights and fisheries protection, resulting in sub-optimal solutions. The complexity of regulatory processes and the funding landscape also hinders timely design and implementation of coastal flood risk management strategies, particularly for smaller communities or those that lack the resources to navigate them.

Land-use planning and regulation of development in areas prone to flooding has primarily remained the responsibility of local governments since the province devolved authority in 2003. However, local governments are required to consider provincial FHALUM guidelines (first published in 2004, with the most recent amendment in effect since 2018) under the *Local Government Act*. Under the *Emergency Program Act*, local authorities are also responsible for developing emergency response plans, with provincial funding assistance.

A significant portion of BC's coastal population and infrastructure is protected from coastal flooding by sea dikes. A range of entities have

PARTNERSHIPS REDUCE COASTAL FLOOD VULNERABILITY

Over a period of four years, the City of Surrey worked to engage various stakeholders to co-develop a Coastal Flood Adaptation Strategy (CFAS) to reduce coastal flood risk and adapt to one metre of global sea-level rise. Figure 4 depicts a portion of the coastal floodplain in Surrey. A four-phase approach to develop CFAS assisted the City of Surrey in strengthening relationships with various stakeholders and all orders of government.

The first intake of the Infrastructure Canada Disaster Mitigation and Adaptation Fund (DAMF) required a minimum project size of $20 million (to access federal funding of 25% to 75%) to increase community resilience to natural hazards and climate change. DAMF provided the opportunity for the City to build upon the relationships developed in CFAS through new partnerships with Semiahmoo First Nation, the Province of British Columbia, and Southern Railway to reduce coastal flood risk by implementing win-win solutions to adapt to sea-level rise.

Figure 4: Coastal Floodplain in Surrey, BC (Photo Credit, City of Surrey).

Within the City of Surrey organization, innovative projects have also been developed because of the DMAF opportunity, including nature-based solutions involving deep collaboration between various departments. Access to federal funding and a shared desire to maximize the evaluation criteria provided the environment to improve the proposal and ultimately to accelerate implementation of complex infrastructure projects to reduce coastal flood risk.

taken responsibility for maintaining the dikes. The province has enacted legislation dating back to 2002 to transfer the responsibilities to maintain and upgrade dikes throughout the region to local governments.[15] The limited fiscal capacity of some local governments to tackle these responsibilities in the face of escalating risks and aging infrastructure is a problem yet to be resolved.

To support local governments engaged in flood management, the provincial and federal governments sporadically provide a portion of capital funding and some technical tools and support. In the event of a damaging flood whereby a state of emergency is established, financial assistance is provided by the federal and provincial governments under a cost-sharing arrangement. A succinct list of federal government departments and their role in flood risk management is provided by Golnaraghi et al.[16]

Federal funding for coastal flood risk management in BC is provided through various programs. For example, funding for large-scale infrastructure projects to help communities better manage the risks of disasters triggered by coastal flooding is available through the DMAF. While large government funding programs have traditionally focused on structural flood mitigation projects implemented by a single organization, DMAF has encouraged a broader range of approaches and explicitly encourages innovation, partnership and nature-based solutions.

Indigenous Services Canada provides funding for flood protection infrastructure, mitigation and preparedness in First Nations communities, and BC-region officials work closely with Indigenous leaders to support emergency response when flooding occurs. The federal government generates and disseminates data often used to support coastal flood hazard or risk assessment and management (e.g., Fisheries and Oceans Canada maintains a network of permanent tide gauges, and the Canadian Hydrographic Service surveys and disseminates bathymetric data). A number of federal government departments and agencies are also engaged in funding or conducting fundamental and applied research on topics related to coastal flood and erosion risk management, including Natural Resources Canada, Fisheries and Oceans Canada, Defense Research and Development Canada, and the National Research Council of Canada.

The BC Storm Surge Forecasting System was developed as a joint program between the BC Ministry of Environment and Fisheries and Oceans Canada. The system provides six-day forecasts of storm surge and total water levels at several coastal sites in southern BC. The system is described as a research tool, and it uses a predictive numerical ocean model and real-time measurements to generate bulletins for Victoria, Vancouver and Campbell River. Long-term financial support to maintain operation and improvement of the system has been lacking, with funding provided by various contributors including Fraser Basin Council, Port of Vancouver, and the municipalities of Vancouver, Richmond, Surrey and Delta. In 2019, the federal government invested $4.9 million over five years for Environment and Climate Change Canada to improve Canada's ability to predict coastal floods and to develop early warning systems; but at the time of writing, there is no federally operated real-time coastal flood forecasting system in use in BC.

GAPS IN REDUCING RISK

GUIDANCE AND GOVERNANCE

While high-level provincial guidance for sea-level rise adaptation planning exists, there is no provincial guidance for implementing nature-based solutions or strategies such as planned or managed retreat (Table 1). The federal government has recently published reports to highlight case studies and the needs and gaps on these topics,[17,18,19] and international guidelines on natural and nature-based features for flood risk management were published in 2021.[20] However, existing guidance lacks the granularity and technical detail needed for local governments to implement these solutions. Government programming, policies and mechanisms to implement planned retreat strategies have yet to be established and are needed for proactive implementation in BC.

Table 1: Organizations and industries involved in coastal flood risk management

Organization	Type of Organization	Legal Mandate	Role	Key Programs
Public Safety Canada	Federal government	Yes	Emergency preparedness and response; funding for mapping, risk assessment, non-structural or small-scale mitigation	National Disaster Mitigation Program
Indigenous Services Canada	Federal government	Yes	First Nations emergency preparedness and response; funding mitigation; flood insurance	First Nations Adapt
Infrastructure Canada	Federal government	Yes	Infrastructure standards; project funding; research funding	Disaster Mitigation and Adaptation Fund
Natural Resources Canada	Federal government	Yes	Research; research funding; funding for adaptation; data and tools	Federal Floodplain Mapping Guidelines; Sea-Level Rise Projections
Defence Research and Development Canada	Federal government	Yes	Research funding	Canadian Safety and Security Program
National Research Council of Canada	Federal government	Yes	Applied research; data and tools	Ocean, Coastal and River Engineering Research Centre, Ocean Program
Fisheries and Oceans Canada	Federal government	Yes	Research; data provider; regulator	Marine Environmental Data Section, Canadian Hydrographic Service
Environment and Climate Change Canada	Federal government	Yes	Weather forecasts; climate change projections; operational flood forecasting	Environmental data
Emergency Management BC	Provincial government	Yes	Coordination of emergency response, planning, training, testing and exercising	Education; training; response and recovery
Forests, Lands, Natural Resource Operations and Rural Development	Provincial government	Yes	Tools and data; regulating dike safety and upgrades	Coastal floodplain mapping guidelines
Fraser Basin Council	Non-governmental organization*	No	Studies, planning, outreach and education	Facilitator of Regional Flood Management Strategy

Organization	Type of Organization	Legal Mandate	Role	Key Programs
First Nations	Local government	Yes	Infrastructure provider; emergency response; rights holder; advocacy, outreach and education	Land-use regulations; infrastructure maintenance; emergency response; Living Dike Roundtable; community engagement
BC Stewardship Centre	Non-governmental organization*	No	Guidelines, studies, advocacy and outreach	Green Shores for Shoreline Development; Green Shores for Homes; Green Shores for Local Government
Engineers and Geoscientists BC	Professional association / regulatory body	Yes	Protecting the public interest	Professional practice guidelines
Insurance industry	Private sector, for profit	Yes	Risk transfer	Overland coastal flood property insurance
Financing industry	Private sector, for profit	Yes	Providing capital for real estate and resilience investments	Mortgages for real estate; resilience bonds for infrastructure investment
Municipalities	Local government	Yes	Infrastructure provider; emergency response; regulator	Land-use regulations; infrastructure maintenance; emergency response
Post-secondary institutions	Research and education	No	Science, policy and research	Engineering; Coastal Adaptation Lab; community and regional planning

Notes: Non-exhaustive list of non-governmental organizations for illustration. Other organizations are involved in coastal management, advocacy and research, either directly or indirectly contributing to disaster and climate risk reduction.

> There is no provincial guidance for implementing nature-based solutions or strategies such as planned or managed retreat. . . . Existing [federal and international] guidance lacks the granularity and technical detail needed for local governments to implement these solutions. Government programming, policies and mechanisms . . . are needed for proactive implementation in BC.

The complex, disjointed governance context has been criticized for contributing to a lack of coordination, imbalances in the distribution of resources for managing flood risk, stilted or absent dialogue, and disincentives for effective risk management. For example, in 2003, the provincial government devolved land-use permitting for flood hazard areas to local governments. However, many local governments lack the fiscal capacity and support needed to assume this burden. Since many municipalities are reliant on taxes from high-value waterfront properties, an obvious conflict arises when it comes to permitting development in coastal areas. Moreover, there is limited incentive or opportunity to proactively consider flood risk management options like planned retreat, particularly when liability for flood damages is shared with provincial and federal governments. Harmonization and coordination of governance, regulations and approaches to flood risk management across all levels of government (including Indigenous government) is needed to remove confusion, blind spots and inconsistencies that currently plague coastal flood risk management practice.

Organizational mandates to reduce risk driven by climate change are missing. Having clear, well-defined organizational mandates will direct staff to be more open about releasing information that will ultimately support better decision making and public support.

INCLUSIVE PLANNING AND RECOVERY

Often, those who bear the costs of flood are not aligned with or involved in risk management decisions. Home financing, for example, is rarely subject to restrictions that depend on coastal flood risk. As well, federal and provincial disaster assistance does not incentivize "building back better," and there is limited guidance or direction to private homeowners on how best to manage their risk or participate in risk reduction on a system-wide basis. A crucial prerequisite for strengthening governance is increased recognition of the role, rights and self-determination of First Nations in accordance with the *UN Declaration on the Rights of Indigenous Peoples* (UNDRIP) and the *Sendai Framework for Disaster Risk Reduction 2015–2030*, and support (and adequate funding) for meaningful involvement of First Nations in decision making surrounding coastal flood risk management. Improving First Nations involvement in flood resilience decision making has been identified as a priority action by the provincial government as it works towards a flood strategy, following the BC *Declaration on the Rights of Indigenous Peoples Act* in 2019 (DRIPA). However, some local governments have called for guidance on how best to work with local First Nations to implement DRIPA and UNDRIP.

SUSTAINABLE FUNDING

Fiscal capacity and resources at the front lines of implementation for coastal flood risk management (i.e., local government level) are rarely commensurate with needs. Funding by federal and provincial governments has been criticized for being reactive (e.g., Disaster Financial Assistance Arrangements (DFAA)) and difficult to access, owing to myriad and complex funding programs. The sustainability of DFAA funding has also been called into question by the escalating number and scale of extreme weather-related disasters across Canada. Funding for proactive disaster risk reduction measures has been less readily available (compared to post-disaster assistance) and previously focused on structural solutions. Following strong and growing advocacy for nature-based solutions by First Nations, researchers, and (mostly non-profit) groups like Stewardship Centre for British Columbia, Municipal Natural Assets Initiative, Fraser Basin Council, Living Dike Roundtable, and Living with Water initiative, federal government funding agencies are beginning to trial and implement funding programs for green infrastructure.

RECOVERY PLANNING

The lack of clarity on roles and responsibilities at different levels of government is a barrier to enhancing disaster preparedness and recovery. The flooding in BC's Lower Mainland in November 2021 (driven by extreme precipitation) highlighted vulnerabilities and gaps in emergency response coordination and the extent of supply chain disruption that could result from widespread coastal flooding. Many communities reported a lack of early warning, and delays in receiving support and assistance. Early warning is of particular concern for coastal flooding events when without sustained, long-term funding to support development and maintenance of operational flood forecasting systems. Sustained and increased investment is needed to support the modernization of forecasting tools and dissemination techniques (e.g., social media, mapping) so that they can guide preparedness and response. While emergency response planning is conducted by local governments with provincial funding assistance, post-flood recovery planning is virtually non-existent. Building back better requires planning in advance for recovery following a damaging event (during which resources are always stretched) and dedicated, rapidly accessible funding programs for post-flood improvement works (in parallel to DFAA).

EDUCATION

A shortage of highly qualified professionals with coastal flood risk assessment and management expertise has contributed to a lack of consistency and innovative practice in understanding and managing risk. There are few programs or institutions where individuals can receive in-province post-secondary training in coastal flood risk management concepts and practice; such programs would support the development of a homegrown network of expertise and innovation. Governments and private-sector firms are therefore heavily reliant on attracting professionals from elsewhere and often struggle to retain talent, resulting in a transient professional community. This transience limits the extent to which local knowledge, and First Nations' Traditional Knowledge in particular, is applied in coastal flood risk management practice. Professional associations are slow to recognize needs for dedicated, specialist designations to raise technical standards, instead relying on publishing professional practice guidance that is often underfunded or conflicting with other technical guidance. Recently, a number of academic and government research institutions, led by the University of Windsor, have proposed to establish a nation-wide coastal careers training network. If funded, such an initiative has potential to be a game-changer in training and developing the next generation of skilled, multi-disciplinary coastal hazard and risk professionals.

OPPORTUNITY

RECOMMENDATIONS

A range of actions are needed (Table 2) to reduce coastal flood risk that involve the organizations listed in Table 1. The recommendations are grouped to align with the four priorities of the Sendai Framework.

THE CHALLENGE

A key challenge is moving beyond coastal flood risk management strategies that are based solely on protecting the most valuable assets indefinitely. Funding programs and risk assessments in BC have focused on monetary valuation of cost-to-benefit, with limited evaluation of environmental and social impacts or benefits, and have prioritized structural flood protection measures. This has incentivized municipalities and others applying for coastal disaster risk reduction funding to develop proposals that prioritize reducing risks to the most valuable infrastructure and urban land but ignore or de-emphasize the inherent (if perhaps less tangible from a monetary perspective) value of other assets and land uses (e.g., natural assets, farmlands, heritage, cultural

Table 2: Recommendations

Recommendation	Description of Impact	Priority Level	Capabilities Needed
Understanding Disaster Risk			
1. Develop strategic shoreline management plans for all coastal reaches in BC.	Provides a strategic framework for managing risk (to guide more specific, local actions) and defines system boundaries within which whole-of-society needs, risks and opportunities are identified. Raises public awareness of risk. Takes a long-term view.	Necessary	Federal and/or provincial government leadership; multi-disciplinary expertise and whole-of-society participation.
2. Develop a more comprehensive understanding of flood hazard event types and scenarios impacting coastal communities.	Increases awareness and understanding that multiple event types can impact communities. Moves towards an "all hazards" understanding of risk.	Necessary	Federal and/or provincial government leadership; multi-disciplinary expertise and whole-of-society participation.
3. Conduct comprehensive post-event analyses that consider stakeholder and community values.	Establishes a cycle of continuous improvement where learnings from flood events inform planning and preparedness in ways that reflect stakeholder and community values and perspectives.	Necessary	Federal and/or provincial government leadership; multi-disciplinary expertise and whole-of-society participation.
4. Establish an integrated, province-wide coastal monitoring network and program.	Provides the baseline data needed to support flood risk assessment, forecasting and early warning, adaptation planning, and preparedness.	Recommended	Sustainable, long-term funding; federal and provincial government commitment and accountability; partnership with private sector and academic/non-profit technical specialists.
5. Enshrine risk-based approaches and a broader portfolio of adaptation strategies in updated provincial guidance on coastal flooding.	Modernizes provincial coastal flood risk management practice and expands portfolio of risk management strategies.	Recommended	Adequate funding for updates to guidance; peer review of guidance prior to publication.

Recommendation	Description of Impact	Priority Level	Capabilities Needed
Strengthening Disaster Risk Governance			
6. Implement UNDRIP best practice guidelines in flood management and increased First Nations participation in all aspects of risk reduction.	Meaningfully engages First Nations and includes Traditional Knowledge in decision making.	Critical	Competencies needed, technical guidance and training to enable practitioners to implement UNDRIP; financial capacity to First Nations to meaningfully participate.
7. Harmonize and modernize regulations and guidelines.	Reduces conflicting regulations/guidelines that prohibit implementation of risk reduction measures and innovative solutions.	Necessary	Public awareness to build political support.
8. Establish risk reduction mandates.	Enables information sharing to understand risk and increased collaboration to implement risk reduction measures.	Recommended	Public awareness to build political support.
Investing in Disaster Risk Reduction			
9. Set up sustainable funding and planning.	Allow for long-term planning and implementation of solutions outside of the status quo.	Critical	Long-term, sustained cost sharing programs to implement strategic work.
10. Streamline, consolidate and modernize funding programs and application processes.	Enables flood risk managers to quickly and easily access funding streams for a broader range of risk management activities and works (e.g., for green infrastructure). Align DFAA funding with "build back better" principles.	Necessary	Engagement at multiple levels of government; communications expertise; financial resources needed.

Recommendation	Description of Impact	Priority Level	Capabilities Needed
Enhancing Disaster Preparedness for Effective Response and to "Build Back Better"			
11. Increase capacity and reduce barriers to implementing natural and nature-based solutions.	Sets out a path forward for solutions outside of the status quo. Avoids decisions of regret. Provides more sustainable options for managing flood risk. Harnesses ecosystem services to deliver multiple co-benefits.	Necessary	Competencies needed, invest in training programs for professionals; financial capacity to support pilot projects; harmonization of regulations; long-term research and monitoring programs centred around pilot projects.
12. Develop and maintain a province-wide coastal flood forecasting system.	Provides early warning to communities and emergency managers to enhance preparedness.	Necessary	Initial investment to bring existing systems up to "state-of-the art" and sustained, ongoing financial investment to maintain and operate.
13. Raise performance standards for buildings and infrastructure to provide enhanced resistance and resilience.	Reduces residual risk, emergency response resource demands, and post-flood recovery times in the event of flood exposure.	Necessary	Investment in rapid advancement of building codes, and/or alternative mechanisms (e.g., standards); training of construction professionals; insurance industry involvement.

sites). More balanced methodologies for options appraisal are needed to ensure risk reduction plans better reflect community values—such as the expectation of food security and recreational opportunities—and are more equitable. Shoreline management plans can provide an effective platform for options appraisal on a whole-of-society basis and facilitate discussion on difficult strategies like planned or managed retreat (in a proactive rather than reactive way); such strategies are increasingly being adopted by communities across Canada.

Moving forward, greater incentives must be offered to avoid decisions of regret. For example, a transportation mandate to construct or widen a highway within a coastal floodplain is not currently subject to any provincial requirements for flood risk assessment or flood risk mitigation measures. By contrast, infrastructure investments funded by the federal government require a climate lens assessment[21] to align investments with acceptable risk.

Perhaps the greatest challenge is to overcome the barriers create by the fragmented governance of coastal flood risk management in BC, which hinders coordination and progress. This will require whole-of-society dialogue and political will to adapt to changing flood hazards.

RESOURCES

BC AND CANADA

1. High-level coastal planning and engagement for the Fraser River Foreshore area that identifies community values:

City of Vancouver. *Vancouver Coastal Adaptation Plan – Fraser River Foreshore*. 2018. https://vancouver.ca/files/cov/coastal-adaptation-plan-final-report.pdf

2. A master plan for a coastal community on Vancouver Island that sets out short-term actions to advance the vision for the waterfront:

Town of Qualicum Beach. *Waterfront Master Plan*. 2020. https://www.qualicumbeach.com/waterfront-master-plan

3. An action plan for a coastal community on Vancouver Island that prioritizes key actions to year 2050:

City of Campbell River Sea Level Rise Action Plan. 2020. https://www.campbellriver.ca/docs/default-source/default-document-library/sealevelriseactionplanfinal---w-copyright-no-watermark.pdf?sfvrsn=4c026b08_0

INTERNATIONAL

1. A state-wide coastal adaptation plan that prioritizes projects, updated on a five-year cycle.

Coastal Protection and Restoration Authority of Louisiana. *Louisiana's Comprehensive Master Plan for a Sustainable Coast.* 2017. http://coastal.la.gov/wp-content/uploads/2017/04/2017-Coastal-Master-Plan_Web-Single-Page_CFinal-with-Effective-Date-06092017.pdf

2. A comprehensive international guide to conceptualizing, planning, designing, engineering, and operating nature-based solutions for flood and erosion risk management in coastal and riverine settings:

Bridges, T. S., J. K. King, J. D. Simm, M. W. Beck, G. Collins, Q. Lodder, and R. K. Mohan, eds. *International Guidelines on Natural and Nature-Based Features for Flood Risk Management* (Vicksburg, MS: U.S. Army Engineer Research and Development Center, 2021). https://ewn.erdc.dren.mil/?page_id=5630 (Overview document: https://ewn.erdc.dren.mil/?page_id=5698)

3. The first of two volumes of technical guidance for developing shoreline management plans in England and Wales:

Department for Environment, Food and Rural Affairs. *Shoreline management plan guidance – Volume 1: Aims and requirements* (London, 2006). https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69206/pb11726-smpg-vol1-060308.pdf

4. Part of a series of guidelines on national disaster risk assessment, compiling useful international examples and resources for coastal erosion hazard and risk assessment:

UNISDR. *Words into Action Guidelines: National Disaster Risk Assessment Hazard Specific Risk Assessment, 7. Coastal Erosion Hazard and Risk Assessment*. 2017. https://www.unisdr.org/files/52828_07coastalerosionhazardandriskassess.pdf

5. One of a series of books by international experts on water management, specifically providing guidance on strategic flood risk management techniques that enable longer-term, system-wide approaches.

Sayers, P., Y. Li, G. Galloway, E. Penning-Rowsell, F. Shen, K. Wen, Y. Chen, and T. Le Quesne. *Flood Risk Management: A Strategic Approach* (Paris: UNESCO, 2013). http://www.sayersandpartners.co.uk/uploads/6/2/0/9/6209349/flood-risk-management-web.pdf

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1.7 EARTHQUAKES

June 2022

DRRPathways.ca

RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 1 Understanding and Managing Climate and Disaster Risk: Hazard Threat*. To read all articles in the report, see DRRPathways.ca.

The Resilience Pathways Report is a project of Natural Resources Canada.

1.7 EARTHQUAKES

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ABOUT EARTHQUAKES

Earthquakes can occur almost anywhere, but they are primarily located along tectonic plate boundaries, where pieces of the earth's crust rub against one another. In BC, tectonic plate boundaries include the Cascadia Subduction Zone and the Queen Charlotte Fault offshore of Haida Gwaii. Earthquakes occur along these boundaries and also in the subducting Juan de Fuca slab, the deep portion of the Cascadia Subduction Zone, and as relatively shallow earthquakes in the North American plate. The earthquake hazard is generally higher in coastal areas of BC. Damaging earthquakes do not occur frequently in BC, but when they happen, impacts can be extremely damaging and widely felt.

DESCRIPTION

Large, damaging earthquakes are part of the overall earthquake threat in BC and can impact people, structures, infrastructure, and cultural and environmental sites. On average, there are several thousand earthquakes recorded in BC annually (Figure 1), of which approximately 50 earthquakes are felt. Three types of earthquakes can occur in Southwest BC: 1) large megathrust earthquakes along the plate boundary off Vancouver Island with magnitudes up to about 9.0; 2) deep intraslab earthquakes with magnitudes up to about 7.5, and 3) shallow crustal earthquakes with magnitudes up to about 7.5.

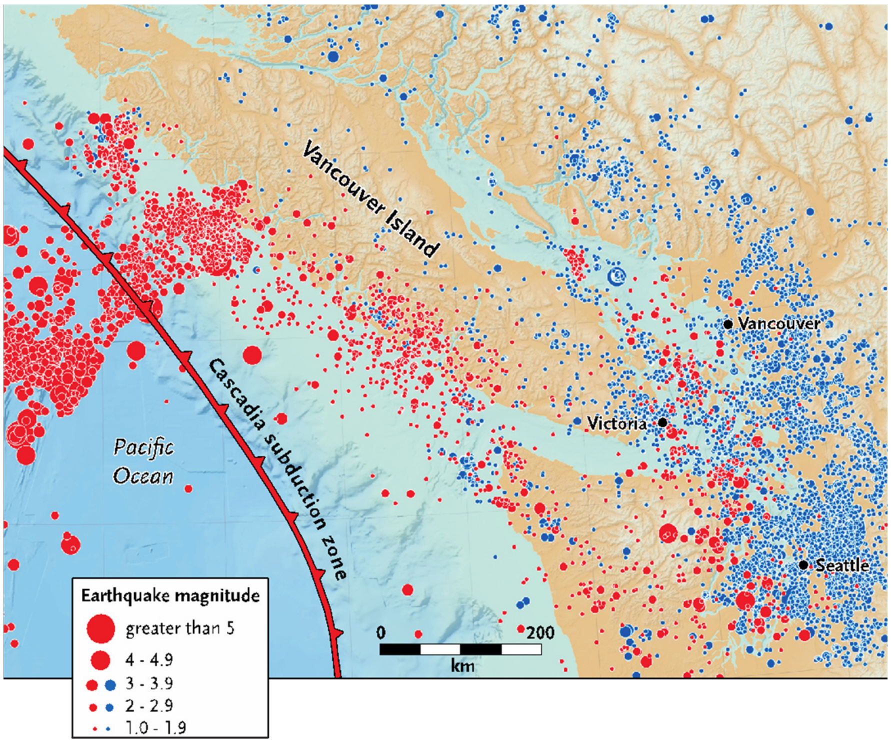

Figure 1: Distribution of recorded earthquakes (Graphic: Natural Resources Canada).

When a fault ruptures, seismic waves are propagated through the earth, causing the ground to shake. This shaking causes buildings or infrastructure to vibrate, potentially becoming damaged or collapsing. Intense ground shaking can last from seconds to minutes and may be followed by numerous aftershocks. Secondary effects can include landslides, liquefaction, floods, and fires. In addition, aftershocks, particularly from shallow crustal and megathrust earthquakes, are of concern as they exacerbate the impacts. Damage to critical infrastructure can cause disruption of services and have indirect impacts on lives, livelihoods, and the economy. Damage to industrial facilities from earthquake shaking can lead to cascading impacts such as release of chemical hazard substances that harm human health and the environment.

Tsunamis can be triggered by local and distant earthquakes. If the earthquake triggers land or submarine slides, these can create tsunami waves. Combined with sea level rise, this can put some communities in coastal areas at higher risk.

With the increase in intensity and frequency of hydrometeorological events, such as floods, wildfires, and extreme temperatures, there is a greater likelihood that a damaging seismic event will be followed by a meteorological hazard that intensifies the impact of the initial event. Sea level rise makes the impacts of coseismic subsidence and tsunamis more severe.

IMPACT ON BUILDINGS

BC has the highest concentration of assets at earthquake risk in Canada. Of the 1.2 million buildings in BC, more than 500,000 buildings[1] have a 10% in 50 years probability of being exposed to strong shaking (>MMI VII[i] or “very strong shaking”) that can cause moderate structural and heavy non-structural damage. Earthquake-resistant buildings designed to withstand strong lateral forces will fare better than older buildings without seismic design elements, such as unreinforced masonry and non-ductile concrete. In addition, buildings with structural irregularities such as a soft storey[ii] will not perform as well during earthquake shaking. Structures built on water-saturated granular soils can liquefy and have their foundations give way, causing structures to collapse. Seismic waves can be amplified where sediment has accumulated in great thickness (sedimentary basins), dramatically increasing the shaking experienced by structures built in such areas. This is the case in parts of the Lower Mainland, where development built on the thick sedimentary deposits of the Fraser River delta are more vulnerable to ground shaking.

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[i] *MMI is the Modified Mercali Intensity scale. “VII” on the scale represents “very strong shaking.” The degree of structural damage is dependent on the design and construction of the structure.*

[ii] *“Soft-storeys” are multi-storey buildings with large openings such as windows, often on the lower floor. Such storeys and are weaker and more flexible than the storeys above.*

IMPACT ON INFRASTRUCTURE

Earthquake ground shaking and secondary effects can damage infrastructure, disrupt services, and cause secondary impacts. Examples include:

- Dams and other structures, such as dikes and retaining walls, may be vulnerable, putting people and assets at risk from floods or landslides.
- Vulnerable linear structures, such as older, brittle water and sewer pipes, can be damaged or outright broken.
- Weakened telecommunication systems can be overwhelmed even if they don't fail outright, jamming local and regional communications.
- Outfall from sewer lines that break can spill into sensitive ecological areas, and debris can overwhelm waste management systems.
- Damage to transportation corridors may limit access to damaged areas and inhibit response and recovery.
- Impacts to port infrastructure can cause major disruption to the transportation of goods and services along rail lines and highways that support a significant portion of Canada's imports and exports.

IMPACT ON PEOPLE

Damaged buildings can lead to loss of life, injury, and the displacement of large numbers of people from their homes as well as result in significant direct and indirect social, cultural, and economic losses within days, months, and years after a major earthquake. Vulnerable people will be further challenged to cope with and recover from a damaging earthquake. Vulnerable populations include children, seniors, and people with chronic mobility, sensory, or cognitive disabilities. People with low

INSIGHTS FROM 2011 CHRISTCHURCH EARTHQUAKE FOR BC

Figure 2: Demolishing of a building destryoed by the earthquake of 2011 in Christchurch, New Zealand (Photo: KiraVolkov/istock).

The impacts of the 2011 earthquake in Christchurch, New Zealand, can provide insights into what we could anticipate in some of the larger communities in BC, such as Victoria and Vancouver. In Christchurch, a city of nearly 400,000 people, roads and bridges were damaged, which hampered rescue efforts. Liquefaction and surface flooding were prevalent, and road surfaces were damaged by liquefaction. Cars and buses were crushed by falling debris. Damage occurred to many older buildings built before stringent earthquake codes were introduced. As of 2015, 1,240 buildings were demolished as a result of the damage inflicted by the 2011 quake (Figure 2). Following the quake, the downtown core remained cordoned off for three years, impacting economic activity and growth in the area.[4]

incomes are also more vulnerable and will have a harder time to recover. Individuals and communities who are disadvantaged and face social barriers (racism, classism, sexism, ableism, etc.) are likely to experience disproportionate impacts from disasters, including earthquakes.[2] These communities are more likely to live in seismically vulnerable buildings, have less access to government support, fewer resources, and less adaptive capacity to survive and recover from disruptions.[3]

IMPACT ON ECONOMY

In addition to direct losses, overall economic activity will be significantly impacted by a major earthquake due to interruption of utilities, services, and supply chains supporting the movement of goods and services locally, regionally, and nationally.

EARTHQUAKE THREAT AND PAST EVENTS

The top five damaging earthquakes that have impacted BC[5] include events in 1700, 1929, 1946, 1949, and 2001. They ranged in magnitude from 7.0 for the 1929 Haida Gwaii earthquake (at the time known as Queen Charlotte Islands) to M9.0 for the 1700 Cascadia megathrust earthquake. The M8.1 earthquake in 1949 in Haida Gwaii is the largest earthquake recorded by instruments in Canada.

Some of these events caused damage. First Nations oral histories indicate coastal communities lost many lives, structures, fishing boats, the destruction of a village near Pachena Bay, and more in the 1700 earthquake and tsunami. The earthquakes from the 1940s were reported in newspapers of the time: the 1946 earthquake damaged a school and other structures in Courtenay, knocked down 75% of the chimneys in the nearest community, triggered more than 300 landslides, and ultimately caused two deaths; the 1949 earthquake caused damage to communities on Haida Gwaii. An earthquake in 2001 was widely felt in southwestern BC but caused minor damage, such as broken windows, pipes, and chimney damage.

The relatively low frequency of damaging earthquakes in BC affects the perception of risk and leads to less opportunity for action (as such opportunity is usually created after an event). Most of BC's earthquakes have been in remote areas or in the distant past, making our society relatively complacent to earthquake risk, leading to inadequate funding and low political will to reduce the risk.

DRIVERS OF RISK

Physical and social vulnerabilities in society are the leading drivers of seismic risk in BC. An overwhelming majority of structures in the existing building stock were designed and constructed using building codes with low levels of seismic provision. Limited funding options to update infrastructure to a higher standard beyond saving lives, and the lack of lived earthquake experience among residents, contribute to this physical risk. For example, in Vancouver, over half of the city's 90,000 buildings were built prior to 1974 and have no or little seismic resistance, leaving residents and workers vulnerable to disruption, displacement, and injury or loss of life. In Vancouver, as in much of the province, this building vulnerability is the primary driver of seismic risk.

With an increasing population and expansion of the built environment in areas of high seismic hazard, seismic risk increases. High seismic hazard zones are areas in the province susceptible to ground failures, liquefaction (where the soil turns to quicksand and cannot support structures), increased shaking, and earthquake-induced landslides.

UNDERSTANDING RISK

WHAT SOURCES HELP US UNDERSTAND HAZARD AND RISK

A wide range of data and information types contributes to understanding earthquake threat and risk in BC. Below is an overview of available data and information on earthquake hazard and risk. There are also private consulting and insurance companies that routinely model earthquake risk.

REAL-TIME HAZARD DATA

Real-time seismic data can be used for warning systems at the regional level or site level. This is useful for better understanding earthquake hazards in an area and their use in building codes. Earthquakes are detected in real-time through an array of sensors and integrated into the Canadian National Seismograph Network. The British Columbia Smart Infrastructure Monitoring System (BC SMIS) collects information at or near critical infrastructure locations, such as public schools, government offices, fire halls, ambulance stations, and bridges. In the offshore regions, Oceans Network Canada records and detects ground motion.

HAZARD ASSESSMENT

Seismic hazard assessment defines the extent and severity of ground motions and likelihoods. A probabilistic assessment refers to analyses that consider all possible earthquakes that could affect a region over a period of time. The Canadian Seismic Hazard Model[6] is the authoritative source for federal information on earthquake hazard, generated by Natural Resources Canada and updated every five years, most recently in 2020. The assessment is considered by the National Building Code (NBC) for the seismic provisions in the code. Subsequently, provinces and territories use the NBC as the basis for building codes, such as the 2018 British Columbia Building Code.

Higher resolution studies, including local seismic sources and site conditions, can be used by communities to refine risk assessments that account for local geological conditions. Earthquake hazard scenarios developed by Natural Resources Canada have recently become publicly available.[7] Other fundamental hazard research is undertaken by federal scientists, academic institutions, and joint working groups (e.g., Cascadia Coastal Hazards Research Coordination Network[8]).

RISK ASSESSMENT

Earthquake risk assessments in the form of damage and loss estimations are an important source of risk information. Robust methods have been developed to quantitatively assess risks associated with earthquakes. Most earthquake loss estimations focus on physical damage to buildings and direct impacts such as injury, loss of life, displacement, and economic loss. Only a few communities have completed an earthquake risk assessment in Canada, including the District of North Vancouver,[9,10] University of British Columbia,[11] City of Victoria,[12] and City of Vancouver.[13]

A provincial earthquake risk assessment was jointly developed between Emergency Management BC and Natural Resources Canada, although this is not available publicly.

A new national earthquake risk model developed by Natural Resources Canada using OpenQuake[14] software provides results at the neighbourhood scale.[15] The new public-facing website and the publication of the national earthquake risk model will be released in the fall of 2022 and will make earthquake risk information more widely accessible across Canada. The national earthquake risk assessment is based on aggregate building information and will be updated regularly in alignment with the national earthquake hazard assessment.

ASSETS (EXPOSURE) DATASET

The National Human Settlement Layer[16] and the National Social Vulnerability[17] dataset provide geospatial details about people, buildings, and assets across Canada. As new models become publicly available, feedback and guidance from practitioners will guide how risk information can guide business owners, financial analysts, emergency managers, community planners, and the public to become more resilient to earthquakes.

POST-DISASTER DAMAGE ASSESSMENT AND DATA COLLECTION

BC Housing is tasked to carry out post-disaster rapid damage assessments of buildings. This has been conducted for other hazards, including wildfires and floods, but not tested for earthquakes due to the paucity of recent damaging earthquakes in BC. Private modelling companies and insurance and reinsurance companies compile post-event data. Public agencies also compile data and publish bulletins, such as Public Safety Canada's Canadian Disaster Database[18] or the international EM-DAT database.[19] The Canadian Association for Earthquake Engineering conducts reconnaissance after damaging earthquakes and publishes findings in a report to document lessons learned and their applicability to engineering practice in Canada.[iii]

OTHER RESEARCH PROJECTS AND DATASETS

Ongoing academic research within BC is conducted to develop tools that quantify and mitigate earthquake risk. Multiple open-source tools exist to assess the performance and functionality of buildings following an earthquake, including a tool (TREADS)[20] developed at the University of British Columbia. Other efforts at UBC include the development of Canada-specific fragility and vulnerability functions, which enhance the accuracy and reliability of seismic risk assessment results. This work builds upon the Disaster Risk Reduction (DRR) Pathways project (2019–2021) that focused on decreasing systemic risk through evidence-based disaster risk management, evaluating socioeconomic incentives for investing in disaster risk reduction, and the governing of risk information and risk management practice in BC.

GUIDELINES AND TOOLS FOR HAZARD AND RISK ASSESSMENTS

There are no guidelines or standard approaches defined for conducting quantitative earthquake hazard and risk assessments in Canada and BC. When conducting a risk assessment, ongoing community engagement is essential to provide an understanding of associated risks. It is essential that First Nations and Indigenous communities be included in all engagements.

Natural Resources Canada recently became a member of the Global Earthquake Model. This platform provides access to open-source tools that can assess earthquake hazards and risks.[21]

[iii] *In the US, EERI, GEER, STEER, EEFIT, and other organizations study earthquakes in the immediate aftermath, using funding made available through agencies like the National Science Foundation.*

REDUCING RISK

Emergency Management BC developed the *BC Earthquake Immediate Response Plan*[22] in 2015, which is currently being updated. The plan lays out a shared and coordinated responsibility for sustained response and recovery. As of now, there is no provincial earthquake risk management strategy outlining priorities and requirements for earthquake risk reduction in the province. In 2018, BC became the first province to adopt the *Sendai Framework for Disaster Risk Reduction*, which encourages identifying and mitigating seismic risk. This, along with the ongoing Emergency Program Act Modernization in BC, provides an opportunity for implementing policies aiming to reduce earthquake risk in BC.

In BC, detailed earthquake mitigation plans can be found in the District of North Vancouver (*Earthquake Ready Action Plan*)[23] and in the City of Vancouver (*Earthquake Preparedness Strategy*[24] and *Resilient Vancouver Strategy*). Integrated Partnership of Regional Emergency Managers (IPREM) and Metro Vancouver have developed a disaster debris management plan[25] and regional temporary provision of drinking water guideline to support earthquake recovery.

PRACTICE AND CAPABILITIES

Managing physical risk from earthquakes is commonly approached by retrofitting existing buildings and developing building codes and standards for new buildings. It should be noted that financial losses from physical risk can never be fully eliminated and remaining losses should be managed by risk transfer mechanisms through insurance, reinsurance, and/or government funding. Social impacts of earthquakes are managed by building social capital through community networks, community resilience hubs, and community support programs—especially for marginalized and vulnerable groups.

SCHOOL SEISMIC UPGRADE PROGRAM AND GUIDELINES

A successful initiative in reducing existing earthquake risk is the provincial Seismic Mitigation Program (School Seismic Upgrade Program)[26] led by the Ministry of Education, working with Engineers and Geoscientists of BC with support from the University of British Columbia Civil Engineering Department. The program, started in 2004, aims to reduce the seismic risk of public schools through several mitigation measures, including retrofitting school buildings. Since launching the Seismic Mitigation Program, the Ministry has spent over $1.9 billion to complete high-risk seismic projects throughout the province. The program includes the development of seismic assessment tools and guidelines for the performance-based seismic retrofit of school buildings.[27]

EXISTING BUILDINGS RETROFIT PROGRAMS

Currently, the only program supporting retrofit of existing buildings is from the City of Victoria, which offers a Tax Incentive Program (TIP)[28] to eligible owners of heritage-designated commercial, industrial, and institutional buildings. Guidelines exist for those interested in voluntary retrofits to aid homeowners.[29,30]

BUILDING CODES

Building codes in Canada have evolved since the first National Building Code (NBC) was released in 1941. The seismic provisions are periodically updated to reflect new scientific knowledge. Risk tolerance levels have also evolved over time, from the first probabilistic ground motions with a 100-year return period (~40% chance of exceedance in 50 years) to the current 2,475-year return period (or 2% chance of exceedance in 50 years), reflecting a lower tolerance for risk of collapse in modern editions of the NBC. In Canada, the building code is developed at the national level, and each Province either adopts the code as is or modifies it, at which point the building code becomes law. One exception to this is in the City of Vancouver, which has its own unique bylaw.

High-importance buildings, such as schools and hospitals, are designed for higher loads and more stringent requirements. The BC Building Code, however, does not contain specific requirements for the seismic assessment of existing buildings, nor does it set minimum requirements beyond life safety. Safety design guidelines for critical structures, such as high- or extreme-consequence dams, are based on hazard intensities with less frequent but more severe earthquake events.

To develop these requirements, the Building Safety and Standards Branch has partnered with Natural Resources Canada and the National Research Council on a Seismic Retrofit Guidelines (SRG) Expansion Project. The SRG Expansion Project builds upon tools developed for the provincial school seismic upgrade program to develop new recommendations for the screening and retrofit of privately held buildings. These recommendations can be incorporated into future codes and regulations. A similar project[31] being completed by the National Research Council is a plan to assess the seismic safety of existing buildings.

SEISMIC VULNERABILITY OF DIKES

In a recent assessment of the vulnerability of dikes in BC to seismic hazards, more than 50% of the assessed dikes were found to have "very high" to "high" seismic risk, and 34% were at "high" to "moderate" risk of failure and subsequent flooding.[32]

Liquefaction is the most significant factor contributing to the vulnerability of dikes. In 2021, professional practice guidelines were developed by Engineers and Geoscientists BC to guide the seismic assessment and design of dikes in the province. The Ministry of Forests, Lands, Natural Resource Operations and Rural Development's *Seismic Design Guidelines for Dikes* (Second Edition) outlines technical requirements related to seismic assessment and seismic design of dikes under the *Dike Maintenance Act*. However, since then the Ministry has identified areas for improvement in how engineering professionals are applying the Ministry's guidelines and has requested that Engineers and Geoscientists BC develop practice guidelines to assist.[33]

GUIDELINES ON PERFORMANCE-BASED SEISMIC DESIGN OF BRIDGES

Professional practice guidelines in *Performance-Based Seismic Design of Bridges in BC* were developed in 2018 with the support of the BC Ministry of Transportation and Infrastructure, the Canadian Association of Earthquake Engineering, and the Structural Engineers Association of BC. These guidelines assist engineering professionals in carrying out the performance-based seismic design of bridges.[34]

MANAGING FINANCIAL RISK

Damages to physical assets lead to financial loss. Parties invested in physical assets are vulnerable to financial losses of varying levels. When an earthquake event happens in Canada, the losses will be borne by asset owners, such as personal or commercial entities, private and public infrastructure owners, developers, financial institutions, pension funds, and other collective investors. After a disaster, the Province may declare the event eligible for disaster financial assistance. Not every homeowner in BC knows, however, that earthquake damage is insurable and, therefore, not eligible for disaster financial assistance (DFA).[35] Disasters explicitly mentioned under the non-eligible section are wildfires, earthquakes, windstorms, snow load, sewer or sump-pit backup, and water entry from above the ground. To mitigate the risk of business disruption from a natural hazard event, businesses can purchase business disruption insurance.

Earthquake insurance provision in BC is much higher than elsewhere in Canada, with up to 70% uptake among residential properties.[36] This is a vast improvement over places like Quebec, where insurance rates remain around 3%–4% despite the appreciable risk.

By the end of the fiscal year 2022, the federal Office of the Superintendent of Financial Institutions and the British Columbia Financial Services Authority will require insurers to annually disclose earthquake exposures and meet a test of financial preparedness for the probability of a 500-year return period or 0.2% likelihood of occurrence in a given year.

Not every homeowner in BC knows, however, that earthquake damage is insurable and, therefore, not eligible for disaster financial assistance (DFA). Disasters explicitly mentioned under the non-eligible section are wildfires, earthquakes, windstorms, snow load, sewer or sump-pit backup, and water entry from above the ground.

STRENGTHENING SOCIOECONOMIC RESILIENCE

Strengthening social vulnerability and community resilience means working together across a broad spectrum of people, but the co-benefits of such social programs and approaches have a greater effect on increasing resilience to other shocks and threats (like earthquakes) than investing in physical risk reduction measures alone. Social capital has proven to be the strongest and most robust predictor of population recovery following a catastrophe. For instance, following the devastating earthquake in Kobe, Japan, the city staff developed programs to create stronger solidarity among survivors, recognizing that rebuilding the social capital in a disaster zone is an essential component of recovery.[37]

INDIVIDUAL PREPAREDNESS

Individual protective actions, such as having an earthquake kit, securing furniture to the walls, and having a post-earthquake household emergency plan are important and achievable risk management strategies that many households can undertake to some degree. PreparedBC has created extensive materials[39] for the public to use to assist with preparedness planning and is actively engaged in outreach.

The Great British Columbia ShakeOut[40] organizes an annual earthquake drill every October to practice how to safely respond immediately to an earthquake using the drop, cover, hold technique and how to review or update emergency kits or plans. Many of the recommended individual protective measures may not be feasible for the most vulnerable community members, such as people with complex health conditions, disabilities, or who are living in poverty and may not have the financial or physical means to prepare for an earthquake appropriately. This is a gap that needs to be addressed.

Figure 3: Residents participate in an emergency preparedness exercise organized by the Dunbar Earthquake and Emergency Preparedness group as part of the Resilient Neighbourhoods Program Pilot, alongside images of a Needs and Offers board and volunteer roles and responsibilities (Photo: City of Vancouver).

CULTIVATING RESILIENT NEIGHBOURHOODS IN VANCOUVER

The City of Vancouver has established a Resilient Neighbourhoods Program to reframe and transform the way communities collectively prepare for emergencies while integrating efforts related to community connection, equity, climate action, and emergency preparedness. The program takes a capacity-building approach to build on services and networks that enable communities to thrive day-to-day and consider how these can be leveraged to address future hazards. The Resilient Neighbourhoods Toolkit[38] was co-created by the City and community partners and provides a guide for evaluating resilience, mapping assets, and creating neighbourhood resilience plans (Figure 3).

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. EEW provides seconds to tens of seconds of notice before strong shaking starts. This warning time can be used to perform actions that reduce injuries, deaths, and property losses.

Natural Resources Canada is developing a national EEW system (Figure 4) with federal, provincial, Indigenous and other partners and the United States Geological Survey. Alerts will be sent to the public through the National Public Alerting System. Tailored alerts will be sent to critical infrastructure operators and technical users, with the potential to trigger automated protective actions—such as opening doors, closing valves, sounding alarms, and diverting traffic. The national EEW network is focused on the west coast of BC and in the densely populated regions of eastern Ontario and southern Quebec. This national EEW system is slated to be operational in 2024.

Alert Ready is the public-facing brand name for the National Public Alert System. The program allows government officials to issue public safety alerts through mobile devices, television stations, and radio stations and can be activated during a large-scale disaster.[41]

Other existing monitoring and warning systems include: Oceans Network Canada's offshore seismic sensor network to monitor subduction activity along the west coast of Vancouver Island; UBC's EEW for private and public schools and other facilities, which it has operated since 2014; and EEW services provided by private companies to institutions like the Ministry of Transportation (e.g., to clear the Lower Mainland's Massey Tunnel) and the BC Legislature building in Victoria.

UBC has been conducting research on new and more advanced technologies, such as using a large density of sensors in urban areas, effective use of 5G networks, and adaptability of smart meters for use in a seismic network, to improve the reliability and efficiency of EEW.

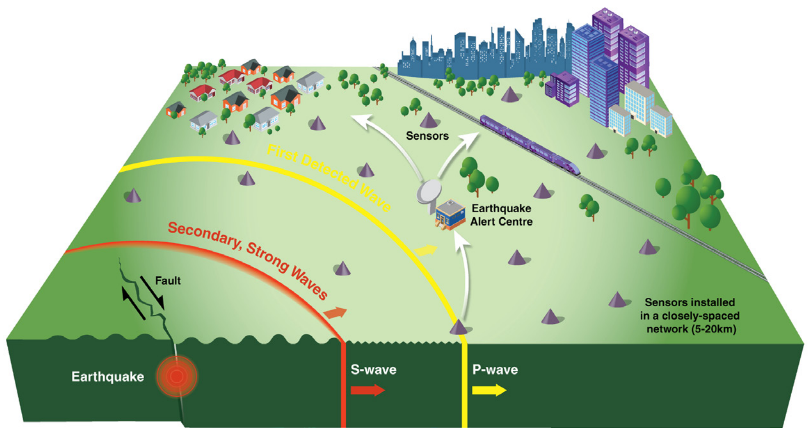

Figure 4: Natural Resources Canada is developing a national earthquake early warning system. Information on seismic P waves are collected before the damaging S waves to provide advance warning (Graphic: Natural Resources Canada).

ORGANIZATIONS INVOLVED IN EARTHQUAKE RISK MANAGEMENT

Organizations involved in earthquake risk management are summarized in Table 1.

GAPS IN REDUCING RISK

While considerable strides have been made to reduce earthquake risk in BC, gaps in practice remain, including:

1. **Community-level information, capacity, and resources** — Ideally, every community should have an earthquake risk profile with information about the threat levels of earthquake and secondary hazards and the vulnerability of critical infrastructure, buildings, and occupants to a damaging earthquake. Such information would help government and stakeholders, including the public, to understand: who and what are vulnerable to earthquakes; the likely impacts and consequences of a major earthquake; and how to design and target mitigation activities to reduce the risk and build resilience. However, very few communities have such information available for use in earthquake risk management.

   There is a severe lack of funds to quantify risk and address seismic risk mitigation. With the burden largely placed on property owners or municipalities, relatively few buildings have been retrofitted, even in cities exposed to potentially damaging earthquakes high, like Vancouver and Victoria. In smaller or rural towns with fewer resources, there may not be a person who specializes in seismic hazard and risk, let alone the opportunity to enact sweeping seismic risk mitigation programs. This is in part because governments and private citizens face myriad demands for their resources and seismic risk mitigation may not be the most urgent priority.

2. **Risk assessment** — A publicly available earthquake risk assessment for the Province does not exist. The publication of Natural Resources Canada's new national earthquake risk model in the fall of 2022 will help fill the gap. Some government agencies and communities have developed earthquake risk assessments for their specific infrastructure or location, but these assessments may not be publicly available or may be limited in scope. It is important to note that local assessments can provide more detailed and representative information than the national model; in such cases, those local details should be preserved to the extent possible.

3. **Buildings** — Building codes do not adequately address: 1) risk from aftershocks; 2) duration of shaking from subduction earthquakes; 3) seismic resilience of "housing and small buildings," although NBC includes a section on "Housing and Small Buildings," which provides prescriptive requirements that can be followed without the involvement of an engineer. There is a lack of local government enforcement of seismic provisions of the building code; most local governments leave it to engineers to self-check their seismic design.

   The largest gap in the building code is a lack of specificity on

Table 1: Organizations involved in earthquake risk management

Entity	Type of Organization	Legal Mandate and Role	Key Programs
Public Safety Canada	Federal government	Assesses capabilities and priorities of federal, provincial, territorial, and Indigenous partners for mitigation, preparedness and response to emergencies, and develops plans and preparedness strategies.	Federal Emergency Response Plan National risk profile (flood, earthquake, and wildfire) Requests for federal assistance Disaster Financial Assistance Arrangements Program Emergency exercises (tabletops)
Natural Resources Canada	Federal government	Provides authoritative geoscience knowledge for onshore and offshore lands.	Evaluation of regional earthquake hazard for the National Building Code National Earthquake Risk Profile Earthquake Early Warning System
Oceans Network Canada	Non-profit	Gathers real-time data for scientific research.	Earthquake Early Warning System
Emergency Management BC	Provincial government	Leads management of emergencies and disasters in BC and supports authorities within the Province's area of jurisdiction.	Emergency exercises and coordination during emergencies Provincial emergency plans and reports Indigenous Emergency Management Partnership Tables
BC Buildings Safety and Standards Branch	Provincial government	Sets standards and requirements for technical safety systems, equipment, and construction, renovation and alteration of buildings.	Seismic building codes
Technical Safety BC	Provincial government	Oversees safe installation and operation of technical systems and equipment across BC; independent, self-funded entity created under *Safety Authority Act* by the Province of BC.	Issues permits, licences and certificates for safe installation and operation of technical systems and equipment
Engineers and Geoscientists of BC	Professional association / non-profit	Regulates and governs BC's professional engineers and geoscientists under the authority of the *Engineers and Geoscientists Act*.	Professional practice guidelines

Entity	Type of Organization	Legal Mandate and Role	Key Programs
Integrated Partnership of Regional Emergency Managers (IPREM)	Regional government	Coordinates emergency management across Metro Vancouver; inter-governmental entity.	*Joint Municipal Regional Disaster Debris Management Operational Plan* Regional temporary provision of drinking water guideline
Local governments	Municipalities, regional districts	Provides services such as clean water, sewer systems, parks and recreation, and fire protection; implements climate action through the adoption of bylaws.	Emergency management plans Emergency operation centres Land-use plans Community resilience plans

standards for alterations to existing buildings. However, Engineers and Geoscientists BC has endorsed a number of technical guidelines for the seismic retrofitting of schools. Since 2011, three separate editions of the Seismic Retrofit Guidelines have been used for the seismic retrofitting of schools. A fourth edition for schools has been completed, along with guidelines for other types of low-rise buildings.

The largest gap in the building code is a lack of specificity on standards for alterations to existing buildings.

As part of the Existing Building Renewal Strategy, the Building Safety and Standards Branch (BSSB) in BC is exploring updates to the building regulatory system. Although current efforts are specific to seismic risk and the Seismic Retrofit Guidelines (SRG), legislative and regulatory considerations may relate more broadly to retrofits in existing buildings. The Province may adopt new SRG requirements as part of the BC Building Code or as a standalone regulation for existing buildings. The SRG is currently only for 43 building types—low-rise building construction types and heights common in schools. If it is to be used more broadly, it will need to be significantly expanded.

Developing Canada-specific building vulnerability functions has been challenging given the lack of observed damage data from past Canadian earthquakes. To create an inventory of vulnerable buildings and conduct risk assessments, more detailed information on buildings is needed to better understand these vulnerabilities.

4. **Infrastructure** — There is a need for post-disaster and recovery standards for critical infrastructure and financial support to invest in replacements and upgrades. Local governments have little to no budget to do this. Some infrastructure codes do not have adequate earthquake provisions. However, Infrastructure Canada's Disaster Mitigation and Adaptation Fund (DMAF) can be leveraged to support large-scale structural projects.

   More work is needed to understand the cascading impacts on critical infrastructure, such as how hospitals,[iv] telecommunications, and the flow of supplies will be impacted by the disruption of power and transportation. Scenario development with multi-sectoral participation can be an effective approach in

[iv] Most BC hospitals run near capacity, and surge planning is often designed for a maximum of ~30 people (bus crash scenario).

ADVANCING POLICY FOR SEISMIC RETROFIT IN THE CITY OF VANCOUVER

As part of its Earthquake Preparedness Strategy, the City of Vancouver partnered with Natural Resources Canada and local experts through the City's Seismic Policy Advisory Committee to begin work to develop a comprehensive risk assessment of its 90,000 privately held buildings. This assessment pulls together earthquake modelling results with urban and community planning efforts to generate a clear and actionable strategy to understand the city's seismic risk.

This initiative, developed through the City's first resilience strategy, connects seismic risk reduction in buildings into the City's larger resilient-building efforts. The ultimate goals of this ongoing work are to develop a sophisticated understanding of risk and risk reduction costs and benefits. It is an initiative that develops seismic risk reduction targets and generates policy options, which will be evaluated by City staff, partners in the community, industry, and all levels of government. From there it will be possible to decide together how best to act to reduce risk and advance resilience in buildings.

defining and understanding the interdependencies and impacts across CI systems, the vulnerability drivers, and developing risk management scenarios.

> More work is needed to understand the cascading impacts on critical infrastructure, such as how hospitals, telecommunications, and the flow of supplies will be impacted by the disruption of power and transportation. Scenario development with multi-sectoral participation can be an effective approach in defining and understanding the interdependencies and impacts across CI systems.

5. **Response and recovery planning** — There is a lack of capacity and resources in emergency management teams at the local level to develop comprehensive response and recovery plans; existing planning is limited (most communities have at most one emergency planning coordinator responsible for entire emergency management programs).

   There is also a need for guidelines and suggested approaches in developing disaster recovery plans for all hazards, with specifics on post-earthquake recovery. FEMA's Pre-disaster Recovery Guide for Local Governments is an example of steps that can be taken by local governments and communities to support recovery following a disaster, with checklists, estimated timelinws for recovery steps and case study examples.[42]

6. **Earthquake science** — Given that few damaging quakes have been recorded in BC, there is a need to better understand where future earthquake sources are located, the frequency of ruptures, and how a fault can rupture, including the direction of rupture (propagation) and how the seismic wave travels through the ground or offshore. For offshore faults, there is a need to better understand rupture mechanisms to determine if a fault may induce damaging tsunami waves. At a given location, ground shaking can be intensified or dampened by the local site (geological and topographic characteristics), resulting in liquefaction and landslides. This knowledge of expected ground shaking is necessary to inform the design of infrastructure and buildings. High-resolution geoscience mapping both on land and offshore (marine and coastal regions) is required to determine if there are unknown active faults. This ongoing research is essential to build community resilience.

   In Canada, instruments have recorded earthquakes for the last 100 years, but modern digital data and a variety of new datasets (including GPS, precise seafloor imaging, and precise mapping using drones and satellites) are allowing for much more accurate earthquake hazard models. There is a need for ongoing paleoseismology studies to understand and assess the frequency of past earthquake events. The new earthquake early warning program will introduce new "strong motion" seismic instruments across BC to help advance knowledge of damaging earthquakes in the region.

7. **Managing financial impacts** — BC is doing well in terms of earthquake insurance uptake compared to other regions in Canada. However, gaps still exist for those who are uninsured, those who cannot afford their deductibles, or for managing a failure of the insurance sector. Despite high public awareness that BC is "earthquake country," there is a common misconception that federal or provincial funds will be available to those who are impacted by an earthquake. The Province of BC does not award financial assistance for insurable losses,[43] even if insurance is unaffordable to some. Therefore, earthquake damage is explicitly not eligible for recovery funds.[44]

OPPORTUNITY

RECOMMENDATIONS

The key recommendations for enhancing earthquake risk management in BC are listed in Table 2.

THE CHALLENGE

One of the biggest challenges that communities face is that information and mitigation plans are often focused on an individual hazard as opposed to looking at co-benefits from investments to address mitigation against the range of hazards. For example, retrofitting a building multiple times to mitigate vulnerabilities for each hazard individually could negatively impact resilience to other hazards (e.g., making the earthquake risk worse while retrofitting for flood) and is much costlier than doing the retrofits all at once in a coordinated matter. The first step to address this challenge is developing and providing communities with information on the range of hazards that a region can experience and providing case studies or examples of mitigation approaches that can be used to mitigate against a range of hazards.

Another significant challenge is for local governments to acquire appropriate resources for risk reduction efforts through provincial and federal grant programs—which, at the moment, are mostly focused on climate adaptation. The first step to address this challenge would be to provide information on the cost benefits of investing in mitigation to make communities and regions across BC more resilient to a range of hazards, including earthquakes.

Table 2: Recommendations

Recommendation	Impact	Priority Level	Capabilities Needed
Enable strategic and coordinated earthquake risk management			
1. Develop a provincial strategy and plan for a coordinated and holistic approach to reduce seismic risk in BC in alignment with the Sendai Framework.	Aligns components of earthquake risk management with different levels of governments; brings clarity on roles and responsibilities and long-term plans for reducing seismic risk in BC.	Critical	Legislation, technical, financial
2. Gather best practices and guidelines for key components of earthquake risk management at the local level.	Supports risk reduction and preparedness.	Necessary	Technical

Recommendation	Impact	Priority Level	Capabilities Needed
Advance understanding of earthquake risk, its drivers, and information sharing			
3. Gain a better understanding of interdependencies and cascading impacts of earthquakes on critical infrastructure through scenario planning.	Scenario planning brings different CI owners and providers together to discuss and understand interdependencies, cascading impacts, and capabilities for risk reduction.	Critical	Technical, financial
Effectively share data and information with users			
4. Access publicly funded risk assessment data and information from a central location.	Assists all levels of government in prioritizing hotspots and areas where mitigation will be most effective. Supports further research and analysis for advanced decisions and plans.	Critical	Technical, financial
5. Develop policy and mechanisms to share information about building hazard, risk levels, and risk reduction history at time of sale.	Better informs homeowners on how vulnerable their building may be in an earthquake.	Critical	Legislation
Use innovative communication methods and materials			
6. Bring awareness about earthquake risks and generate preparedness action by using innovative public education methodologies, including experiential methods.	Makes individuals more aware and better prepared for earthquakes.	Critical	Technical (including science of communication and human behaviour)
7. Use risk communication strategies that address known behavioural biases for earthquake risks.	Gives individuals an increased understanding of the risks associated with earthquakes and can evaluate costs and benefits of investing in risk reduction measures.	Necessary	Technical
8. Better communicate and educate stakeholders on structural vulnerability using non-technical formats.	Raises awareness and understanding for decision makers about vulnerable structures to prioritize mitigation.	Necessary	Technical
9. Provide communication briefs on earthquake hazards, including economic and public safety benefits of DRR, for politicians.	Make elected officials aware of earthquake risk and proactive measures to make communities more resilient.	Critical	Technical
Manage earthquake risk in new developments with research, policies, and programs			
10. Evolve building codes to provide design requirements to expand beyond life safety.	Increases societal resilience for faster recovery from a damaging earthquake.	Critical	Technical, legislation

Recommendation	Impact	Priority Level	Capabilities Needed
Manage earthquake risk in new developments with research, policies, and programs			
11. Address zoning and permitting in the Local Government Act to limit density of people and assets in areas exposed to damaging earthquake, flood, and landslide risks.	Limits density of people and assets in regions that are exposed to potentially damaging earthquakes, floods, and landslides.	Critical	Legislation
12. Expand the City of Vancouver's approach to engineered single-family buildings in areas exposed to potentially damaging earthquakes and increase the code for multi-family buildings.	Improves public safety and recovery rates in new buildings.	Critical	Legislation
Retrofit existing buildings with research, policies, and programs			
13. Conduct research to understand equity issues related to risk information and implementation of retrofitting programs.	Avoids accidental gentrification or inadvertent increase of risks for marginalized groups by driving up prices for safe homes.	Critical	Technical
14. Research and define design synergies between seismic retrofit, climate adaptation, and climate mitigation.	Helps buildings to withstand a changing climate and earthquakes.	Critical	Technical
15. Investigate means to apply standards to existing buildings and ensure compliance with building codes.	Helps buildings be more resilient to withstand and recover from damaging earthquakes.	Necessary	Legislation, technical, financial
16. Provide homeowners with seismic retrofit guidelines.	Informs homeowners on how to make their homes safe.	Necessary	Financial
17. Identify the locations and types of buildings most susceptible to structural damage.	Provides local authorities with information to inform structural mitigation strategies.	Critical	Technical
18. Expand existing Energy Step Code Program in BC to include seismic upgrades.	Empowers local authorities to implement and incentivize policies for energy efficiency and seismic resilience.	Recommended	Legislation
19. With financial institutions and provincial regulators, develop an incentive-based lending program based on proactive investments in mitigation and/or adaptation measures.	Provides incentives for individual property owners to invest in risk reduction measures and reduces financial liability of lending institutions.	Recommended	Financial

Recommendation	Impact	Priority Level	Capabilities Needed
Manage financial impacts			
20. With government oversight, incentivize earthquake property insurance that is risk-based and transparent (similar to the California and New Zealand insurance models).	Increase insurance uptake rates to support economic and financial recovery following an event.	Critical	Financial
21. Provide non-technical information for homeowners on the limitations of the Disaster Financial Assistance (DFA) Program for post-earthquake repairs.	Makes asset owners aware that DFA does not cover earthquake damages and they will need to purchase insurance for coverage.	Critical	Technical
Enhance post-disaster recovery planning and practices			
22. Establish neighbourhood resilience hubs across the province.	Creates social connection and a societal approach to all-hazard preparedness, mitigation, response, and recovery.	Recommended	Financial
23. Revise protocols for seismic upgrades and post-disaster refuge to allow occupants to shelter in place where the structural integrity of a building has been confirmed.	Minimizes socioeconomic disruption to individuals and businesses and accelerates post-disaster recovery.	Recommended	Financial
24. Streamline permitting and approval functions to replace and/or repair buildings damaged in an earthquake and prioritize structures critical to the recovery process.	Reduces the time to recover following a disaster event.	Necessary	Financial

RESOURCES

BC AND CANADA

1. An authoritative source of earthquake information that provides details on past earthquakes in Canada, seismic hazard values for all parts of Canada, seismograph viewers for stations, earthquake early warning, and general information on earthquakes.

Natural Resources Canada. "Earthquakes Canada." Accessed May 30, 2022. https://www.earthquakescanada.ca/.

2. The national association that proactively represents Canada's insurers. Two earthquake risk scenarios have been commissioned by the Insurance Bureau of Canada, to help inform earthquake insurance in Canada.

Insurance Bureau of Canada. "Earthquake Insurance." Accessed May 30, 2022. http://www.ibc.ca/ns/home/types-of-coverage/optional-coverage/earthquake-insurance/.

3. A collaborative project that provides and develops maps that depict shaking amplification due to local geological site conditions, liquefaction, and landslide susceptibility for communities of the Lower Mainland.

Institute for Catastrophic Loss Reduction, University of Western Ontario, and Emergency Management British Columbia. "Metro Vancouver Seismic Microzonation Project." Accessed May 30, 2022. https://metrovanmicromap.ca/.

4. An operations plan for Metro Vancouver on disaster debris management for debris generated during an earthquake in the Lower Mainland.

Integrated Partnership for Regional Emergency Managers. *Joint Municipal Regional Disaster Debris Management Operational Plan For Metro Vancouver region and members*. October 2017. http://www.metrovancouver.org/services/emergency-preparedness/Documents/2017JMRDDMPlan.pdf.

5. A best-practice example of a plain language report that provides insights on the possible consequences a damaging earthquake in the District of North Vancouver.

District of North Vancouver. *When the Ground Shakes*. North Vancouver: District of North Vancouver. Accessed May 30, 2022. https://www.dnv.org/sites/default/files/edocs/when-the-ground-shakes.pdf.

6. News reporter and CBC host provides insights from scientists, engineers, and emergency planners about earthquakes, disaster response, and resilience from BC and beyond. The book includes firsthand accounts from people who have survived deadly earthquakes, explains the science, and asks what we can do now to prepare ourselves.

Craigie, Gregor. *On Borrowed Time*. Fredericton: Goose Lane Editions, 2021.

INTERNATIONAL

7. Intended for homeowners in California, this site provides knowledge on seismic ordinances, assessments, and retrofit requirements for cities across California.

Seismic Ordinances. "Seismic Ordinances of California." Accessed May 30, 2022. https://www.seismicordinances.com/.

8. A non-profit organization that provides affordable earthquake insurance policies for Californian homeowners. The policy includes discounted premiums for homeowners that retrofit their homes.

California Earthquake Authority. "Prepare your house for an earthquake." Accessed May 30, 2022. https://www.earthquakeauthority.com/Prepare-Your-House-Earthquake-Risk.

9. An authoritative source of earthquake risk information for funding opportunities, hazard maps, building codes and standards, publications, training, and earthquake insurance for the United States.

Federal Emergency Management Agency. "Earthquake Risk." Accessed May 30, 2022. https://www.fema.gov/emergency-managers/risk-management/earthquake.

10. NDC, along with experts in the fields of construction, finance, and economics, estimated retrofit costs, researched best practices in peer cities, examined economic impacts of retrofits, and studied a comprehensive set of potential funding sources.

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11. A guide for local US governments to develop seismic retrofit incentive programs. The guide includes case studies of US cities that have promoted and implemented earthquake retrofitting, information on the use of zoning as an incentive to retrofit, local government finance options, and a description of the Unreinforced Masonry Buildings (URM) law.

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1.8 RIVERINE FLOODS

June 2022

DRRPathways.ca

RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 1 Understanding and Managing Climate and Disaster Risk: Hazard Threat*. To read all articles in the report, see DRRPathways.ca.

The Resilience Pathways Report is a project of Natural Resources Canada.

1.8 RIVERINE FLOODS

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ABOUT RIVERINE FLOODS

DESCRIPTION

Floods are among the most commonly occurring natural hazards in BC and account for the second-largest portion of disaster recovery costs annually.[1] Typically, flooding occurs from September to February during the rainy season on the coast and from May to June during snowmelt (freshet) in the mountainous regions and major river basins of the province.

BC is drained by six major rivers: the Fraser, Columbia, Peace, Skeena, Stikine, and Liard. A number of smaller rivers also feed these major rivers or drain directly to the Pacific Ocean along the mainland coast, Haida Gwaii, and Vancouver Island. Watersheds, also called drainage basins or catchments, are bounded by the heights of land. The land channels rainfall and snowmelt to creeks, streams, and rivers, and eventually to outflow points such as reservoirs, bays, and the ocean. Typically, a watershed boundary will extend beyond one administrative/municipal boundary, requiring a degree of cooperation, strategic planning and management.

BC is susceptible to major weather events, such as atmospheric rivers originating in the Pacific. As warm, moist air collides with mountain ranges, it rises and cools, often causing heavy precipitation. In the spring, as temperatures warm and the snow melts, rivers rise and additional water from heavy rainfall often causes them to spill their banks. Heavy fall and early winter precipitation on the coast can cause rivers to flood low-lying regions. Faster-moving water, especially if it has entrained materials like rocks or logs, can be more damaging and can cause erosion or avulsions, which rapidly change the course of a river. Similarly, powerful waves on the shorelines of lakes and oceans have additional energy that can cause erosion and damage in the wave zone.

FLOOD TYPES

Each flood event tends to be unique, varying in likelihood, severity, and driving factors. In addition, climate change is increasing flood risks in many ways in different regions. Sea-level rise, changes in precipitation patterns, and land-use practices can exacerbate current and future flood events. When planning for flood mitigation, it is important to understand the different types of floods we face today, as well as in the decades to come. Characteristics of different flood types in BC are described in Table 1.

FLOOD HAZARD

Flood hazards are defined by their likelihood and magnitude (Figure

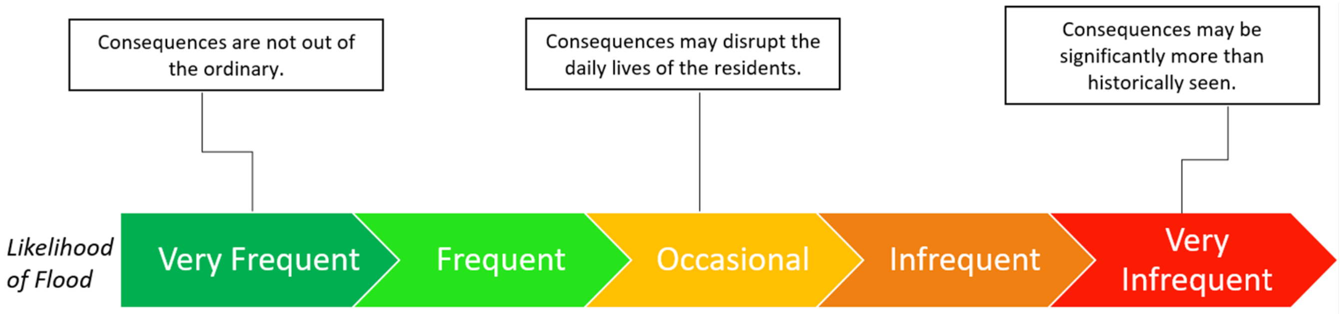
1). The magnitude can be further defined by the flood depth, velocity, and duration. Nuisance flooding in a basement is very different from moderate (>30 cm) or severe (>2m) flooding, which can cause significant to unrecoverable damage.

IMPACTS OF FLOODS

Communities, infrastructure, and buildings can be directly or indirectly impacted by floods (Figure 2). Impacts are not always just immediate; they can often persist for a number of years until the community has recovered. For instance, impacts on gas prices, food supplies, housing values, or fish populations can change over time as a result of the flood. These damages can be classified as tangible, where a dollar value can be assigned, or intangible, such as emotional stress, illness, loss of sense of community, or loss of life.

Table 1: Characteristics of different flood types (rivers and related).

Type of Floods	Description	Example in BC
Creek and river floods	Clearwater floods: high volumes of water from precipitation and/or snowmelt exceed the capacity of rivers or creeks and flow onto adjacent lands. Debris floods and debris flows: debris (soil, rocks, trees, etc.) is entrained in water flowing off steep slopes where normal channel capacity is exceeded, flowing onto adjacent land. Warning times are short, velocities are high, and entrained materials can become powerful projectiles. Ice Jam floods: these can result in higher water levels than open-water floods of comparable discharge.	In November 2021, an atmospheric river event delivered 300 mm of rain, melted an early fall snowpack, and was accompanied by strong winds. It resulted in widespread flooding and debris flows across southwestern BC.
Groundwater floods	Groundwater tables are unusually high due to higher-than-normal inflows or consistent precipitation. This can occur behind dikes as high-water levels in the river change the water gradient.	Widespread flooding in spring 2017 affected a number of communities, including First Nations communities in the Okanagan. Flooding led to high lake levels and associated high groundwater, causing evacuation from homes and spread of contamination from septic fields.
Lake floods	Water levels in lakes are higher than normal due to higher inflows and/or downstream blockages. This can be compounded by wind and waves.	In 2017, highest-water levels were recorded for Okanagan Lake and Kalamalka Lake. Record-setting rainfall combined with snowmelt saturated the ground and led to major flooding along nearby creeks, with over 1,200 docks destroyed and multiple shorelines eroded.
Dike or dam failure (anthropogenic)	Infrastructure fails and releases impounded water in an uncontrolled manner. Can also be caused by ground shaking and/or liquefaction due to an earthquake.	At Mt Polley, mine tailings from a dam breach in 2014 resulted in ~17 million m^3 of water and 8 million m^3 of tailings/materials dispersed.
Pluvial (urban drainage) floods	Heavy precipitation cannot be absorbed into natural landscapes or stormwater infrastructure, creating localized flooding.	In November 2018, heavy rains caused flooding over areas of southwestern BC, with almost 228 mm of rain; large volumes of water overwhelmed sewer systems, causing sewer backup and manhole lids to pop up.



Average Recurrence Interval (ARI)	Probability of Flooding in Each Year	Probability of Flooding over 25 Years	Probability of Flooding over 75 Years
100-yr	1%	22%	53%
200-yr	0.5%	12%	31%
500-yr	0.2%	5%	14%

Figure 1: Frequent small events pose different risks than large events that occur rarely. A 1 in 100-year flood is equivalent to a 1% annual chance or has a 22% chance of occurrence in a timeframe of a 25-year mortgage (Graphic: Natural Resources Canada).

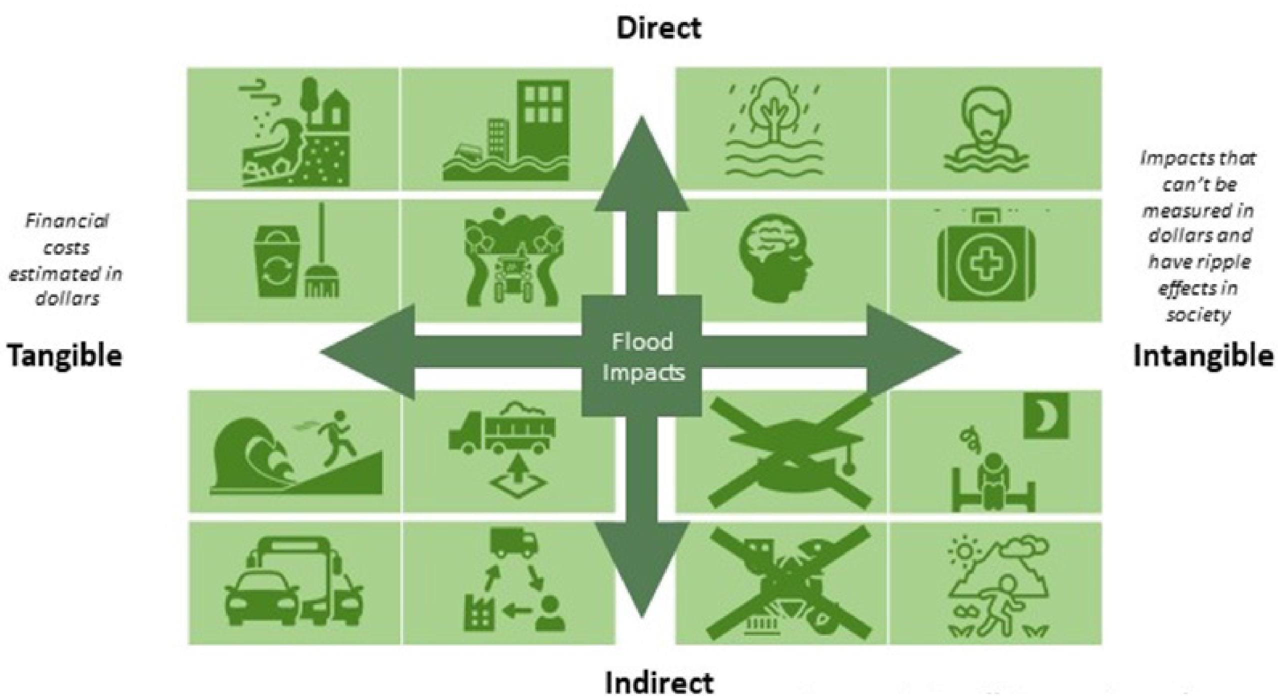


Figure 2: Communities can face a range of impacts from flooding. Adapted from the federal flood damage estimation guideline[4] (Graphic: Natural Resources Canada with icons from the Noun Project).

DISPROPORTIONATE IMPACTS OF FLOODS ON FIRST NATIONS IN BC

First Nations in BC are typically disproportionately affected by floods. BC Assembly of First Nations states: "Following the November 2021 floods and landslides, the First Nation Leadership Council called upon the provincial and federal governments to commit significant financial supports and resources to First Nations. From a pandemic to fires then to floods, First Nations have been forced to shoulder the impacts of colonial-induced climate extremes while navigating the challenges caused by COVID-19 without adequate support and resources."5 As such, the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) must be central to future flood adaptation conversations.

Infrastructure located near waterways are most at risk, such as wastewater treatment facilities. During floods, these facilities can be damaged, causing wastewater contamination downstream. Bridges, pipelines, culverts, piers, roads, rail lines, and dike structures can all experience damage during floods. Impacts to these structures can affect areas outside directly flooded areas. When floodwaters remain in contact with a building for a long time, extensive damage can occur. Damaged buildings reinhabited following a flood can lead to illnesses such as hepatitis A, salmonella, and respiratory illnesses.[2]

Fatalities from flooding are not uncommon. In 2020 alone, there were seven flood-related mortalities in BC. Long-term health effects include impacts on mental health, loss of employment, displacement and evacuation, impacts on normal life patterns, loss of valuables, and the uncertainty around recovery and who assumes the financial burden.

Recovery is unequal among people and populations, with more vulnerable individuals often facing more significant disruption and overall impacts. Floods stretch beyond the immediate crisis, and the most impacted often face systemic barriers to accessing recovery services. Despite experiencing significant impacts, communities can also support one another by providing unique empathy and collaboration.[3]

FLOODING THREAT AND PAST EVENTS

Rivers have always been lifelines for communities, figuring prominently in the history of BC. Many First Nations have stories of major flood events where people went to the highest mountains to escape flooding. Due to our climate and geography, as well as history and settlement patterns, many British Columbians must live with the risk that floods may strike and disrupt their lives. There is great variety in how floodwaters interact with communities and assets in areas at risk due to the regional and local geography, community setting, and the vulnerability of people and infrastructure (Figure 3).

More than 60 damaging flood events have been recorded since 1900 in the Canadian Disaster Database, with an estimated cost of $1 trillion. Note that costs for flood events are not well documented and are likely much higher than this value. Multiple agencies, including private insurance companies, collect flood impact data, much of which is not publicly available. Information on flood impacts allows planners to address them—allocating resources for monitoring, mitigation, and preparedness, and building resilient communities.

Canadian Disaster Database (CDD)[6] identifies some of the impacts and costs for 40 damaging flood events in BC. However, a review of historic damaging flood events in BC carried out by a research team at the Geological Survey of Canada identified 86 damaging flood events.[7] Limited information on flooding in Indigenous communities could be found in the database.

DRIVERS OF RISK

LAND COVER AND DEVELOPMENT

The type of terrain and gradient of land influence how a watershed can flood. Land cover and channel changes from aggradation are the most significant factors. From meadows to forests to asphalt streets, each surface has a different level of perviousness or

Figure 3: November 2021, Sumas Prairie flood impacts agricultural areas, roads, and buildings (Photo: Carie-Ann Lau).

inherent ability to infiltrate water into the soil. Large-scale changes to land surfaces, such as the loss of wetlands, deforestation, and forest fires, can impact land perviousness. In cities, asphalt roads, rooftops, and pavement are largely impervious—greatly limiting the infiltration of water from rainfall and causing surface runoff. With heavier rainfall events and aging infrastructure, runoff can overwhelm stormwater systems as they channel the runoff to local creeks and rivers, leading to localized flooding and contamination.

Densification in floodplains across BC has led to increased flood risk. Increasing the projected density in floodplains will increase this risk. A recent report looks at communities across Canada with greater than 10,000 people where a significant number of buildings are in the floodplain. At the top of the list is the BC community of Chilliwack, where nearly half of the buildings in the city are located in the floodplain.[8]

DIKES

There are over 200 regulated dikes in BC protecting communities and infrastructure, and hundreds of unregulated dikes. A recent report indicates that approximately 160,000 hectares of land with thousands of buildings and significant critical infrastructure are situated behind dikes in BC communities.[9] With more than a hundred different authorities that manage these structures across BC, consistent maintenance is not carried out.

During severe floods, dikes can fail due to erosion, overtopping, or seepage. When the dikes were first constructed in floodplains, their presence encouraged development behind the dikes with the perception that the area was safe for building in, or "floodproofed." But dike failure can occur without warning and can have significant impacts. Despite the high design standards for dikes, there are almost no dikes (<5%) that currently meet these standards in BC. A significant amount of work and money over many decades is needed to bring these up to standard. Ultimately, the construction of dikes in some locations has had the perverse effect of putting the community at greater risk of catastrophic flooding when the flood eventually does occur.

GOVERNANCE

In BC, floods are governed by several orders of government and multiple sectors, ranging from coordinating roles to protecting and restoring fish habitat.[10] Local governments manage land-use development, for instance, by approving subdivisions and developments, and some of these are in floodplains. A lack of publicly available information and public awareness on where flood hazards exist has contributed to increased development in floodplains across BC. Although not intended specifically for flood protection purposes, the Agricultural Land Reserve (ALR) in BC protects approximately 4.6 million hectares of agriculturally suitable land by restricting non-agricultural uses.[11] Because many floodplains overlap with productive agricultural lands, the ALR has played a significant role in preventing additional flood risk from development in floodplains over the last 50 years. However, many critical agricultural resources remain in the path of potential floods, creating the risk of flood damage to BC's agriculture industry.

A lack of publicly available information and public awareness on where flood hazards exist has contributed to increased development in floodplains across BC.

CLIMATE CHANGE

In the mountainous regions of BC, climate change is projected to result in changes to the snowpack, loss of glaciers, thawing of the alpine permafrost, and an upward movement of the treeline. With an increase in extreme rainfall events, these changes are predicted to lead to increased flooding across the province.

Quantifying the effects of climate change on floods is challenging and evolving. Recent guidance is to expect that floods are likely to increase by about 20% in BC by the end of the century, depending on the type of flood.[12] Flood types may also change from snowmelt-driven floods to less predictable, winter storm–driven floods that are likely to coincide with high ocean levels. Where rivers and oceans interact, such as in the lower Fraser River, this can amplify water levels. Where forest fires occur, flooding and sedimentation are expected to increase.

UNDERSTANDING RISK

WHAT SOURCES HELP US UNDERSTAND HAZARD AND RISK

Due to the recent devastating floods in November 2021, most people in the province and beyond are now much more aware of the potential for flood risk and the broader systemic risks associated with flooding, such as the impacts to the supply chain. Other recent flood and high-water events that have occurred throughout BC, while not as disruptive at a provincial scale as the November 2021 floods, have brought the realities of flood risk home for many people.

Although not intended specifically for flood protection purposes, the Agricultural Land Reserve (ALR) in BC protects approximately 4.6 million hectares of agriculturally suitable land by restricting non-agricultural uses.

POST-DISASTER DAMAGE ASSESSMENT AND DATA COLLECTION

Following a damaging flood event, information is collected through a number of means (Table 2). This information is predominantly collected to inform financial payouts and response activities and is not always publicly accessible.

Post-disaster information is invaluable in supporting planning efforts to understand existing gaps and capacities with current and future flood management. The Commission for Environmental Cooperation recently developed a framework for use in Canada, the United States and Mexico to evaluate the economic impacts of floods. The methodology captures the costs of direct and indirect damages and losses following a flood event and could be more widely adopted for use in capturing and sharing post-disaster event information.[13]

HAZARD ASSESSMENT

Hazard information is typically depicted by flood maps, in the form of either high-resolution engineering models for use at the building site or community scale, or low-resolution national models used for nationwide planning and insurance. To model and map flood inundation, extents, depths, and velocities, a number of datasets are needed, including high-resolution elevation data. The Province of British Columbia provides access to available open-source LiDAR (Light Detection and Ranging) datasets through a web portal, and recently flown LiDAR data coverage across the province is continually expanding.[17] Data related to flood mapping can also be found on the Open Government portal.[18]

Between 1987 and 2003,[19] regulatory maps were generated by the Province to designate a 200-year return period (0.5% annual probability) floodplain map for many rivers and lakes. These maps have been used to establish Flood Construction Levels. These legacy flood maps are mapped to a 1 in 200-year probability.

Table 2: Post-disaster data collection for floods in BC.

Title	Purpose	Data Collected	Availability (Open/Closed)	Responsible Authority
Situational Reports	A coordinated collection of impacts and assessments developed by government agencies, primarily for operational emergency response activities.	Description of the threat/event, request for assistance, impacts on critical infrastructure and communities, and actions taken,	Dissemination varies	Public Safety Canada, EMBC, and local government Emergency Operation Centres
CatIQ[14]	Combines comprehensive insured loss and exposure indices from natural and human-caused disasters.	Physical damage, personal property, and non-physical damage (additional living expenses and business interruption).	Online subscription	Catastrophe Indices and Quantification Inc.
Canadian Disaster Database[15]	Tracks significant disaster events that meet damage criteria.	Where and when a disaster occurred; number of injuries, evacuations, fatalities; and estimate of costs.	Open	Public Safety Canada
Post-disaster Building Assessment[16]	Rapidly assesses the safety of buildings and allows people to remain or return to their homes and businesses.	Initial, rapid assessment and detailed building assessment.	Closed	Local community authorities

Flood maps do not cover the entire province, and many are decades old. This is problematic as river flow and geomorphology can change over time. In 2003, flood map development was devolved to local communities. This has led to the development of a range of map qualities and formats, many of which are not easily accessible or available in a central location.

Historically, flood maps have been typically based on a single regulatory or design event, providing a limited understanding of the range of events that might occur. On some of the legacy maps, flood construction levels (FCLs) and flood setback areas are established to define where development can occur. Not all flood maps show FCLs or flood setback areas. FCLs also vary between communities.

Local governments and First Nations are responsible for but not required to develop floodplain maps. Those communities with more resources may provide online access to some of these maps. An initiative is underway to review and possibly compile flood maps developed under recent funding initiatives. Given that there are no standards for the development of flood maps, it will be challenging to integrate maps developed using differing standards. However, these maps could still be made accessible even if data sets are not fully integrated into one layer.

EXPOSURE

A National database on the physical exposure to natural hazards[20] provides information on the built environment. This dataset provides information on exposed assets—aggregate information on buildings and populations—that can be used in a risk assessment. Where more detailed, site-specific community information exists, the more detailed information should be used in the development of community-scale risk assessments.

RISK AND VULNERABILITY ASSESSMENT

Risk assessments require a comprehensive understanding of the flood hazard, exposure, and vulnerability and can be a combination of quantitative and qualitative models at a regional, community, or site-specific scale. Detailed community risk assessments are typically tailored to the individual needs of communities. For example, assessments can assist a community with: determining a return on investment of mitigation measures for use in a funding application; prioritizing areas within a community for mitigation; and helping the community understand the impact of a hazard.

Funding sources through the National Disaster Mitigation Program are currently supporting a number of flood risk assessments across BC.[21] In addition, researchers at several universities, including the University of British Columbia,[22] Simon Fraser University[23] and the University of Northern British Columbia,[24] provide a range of expertise on flood impacts and recovery.

While overland flood insurance has not historically been available in BC, since 2013 a number of insurance providers have developed national flood risk models to inform insurance policies that have been applied in BC.

CURRENT PRACTICE IN HAZARD AND RISK ASSESSMENT

Risk assessment practice puts hazard information into the context of impacts on communities and informs decision making from a risk-based perspective. Local and Indigenous governments are typically responsible for managing and conducting risk assessments and carrying out flood mitigation projects along with partners. Risk assessment tends to bridge the disciplines of engineering, community planning, and emergency management, and therefore the current practice is disparate. In BC, approximately 60 risk assessment studies have been completed to date, many of which are focused on southern BC.[25]

FLOOD MAPPING AND MODELLING

A national or provincial geospatial platform to host all publicly funded flood models and map outputs does not exist. A lack of public information is a liability to all involved with models; these should be accessible under the principle that some information is better than no information at all. Flood maps should cover multiple flood frequencies, resolutions, and precisions to provide a comprehensive system of hazard and risk assessment for various purposes. Modelling a range of flood scenarios would take into account current and future flood hazards; in addition to future population and mitigation strategies, this can provide a community with a better understanding of the range of potential flooding, from nuisance to catastrophic flooding to future flood risks. Natural Resources Canada and Public Safety Canada are tasked[26] with developing a flood mapping portal that will aim to fill this gap at the national level.

A new federal flood hazard identification and mapping program,[27] led by Natural Resources Canada with support from the provinces and territories, will build on existing initiatives to support the development of flood hazard maps in high-risk areas across Canada. These products are anticipated to be part of the proposed web portal developed by Natural Resources Canada and Public Safety Canada that provides access to information on flood risks and best practices to protect homes and communities.[28]

RISK ASSESSMENT

Few communities in BC have developed flood risk maps that indicate who and what is at risk, and a provincial-scale flood risk assessment does not exist. Such an assessment would allow for the Province to highlight areas of concern to help support allocation decisions under funding programs or to identify communities that are at high risk but are not applying to funding programs due to capacity constraints.

There is no single database of information for the province that describes the population and built environment in a way that is suitable for flood risk modelling, and there is a shortage of vulnerability curves to support quantitative flood risk assessment. Developing such a database along with high-quality flood hazard data would provide the benefits of standardization and reduce efforts required to model flood risks on a one-off basis (for example, every time a study is done by a consultant on contract to a community). Although it may also reduce the opportunity for innovation in techniques and approaches, the value of standardized data would seem to outweigh this potential drawback while still leaving room for customization and innovation to address local idiosyncrasies.

A new open-source tool, CanFlood,[29] is available to assist flood risk modellers in conducting risk assessments. Rather than focus on a single design event, this risk-based approach takes into account the vulnerability of buildings and the full range of floods that can impact a community. Outputs of the CanFlood model can provide decision makers with quantitative information to optimize mitigation options for their community. Input data on the flood hazards and exposure needs to be added to the application. The CanFlood model was recently used in a flood risk assessment for the Lower Mainland; as part of this work, flood depth damage curves were developed to assess damage to buildings specific to the Lower Mainland region, and these curves are included in the CanFlood application.

A new report commissioned by the Fraser Basin Council provides insights as to the value and approaches for risk assessment in BC.[30]

There is no single database of information for the province that describes the population and built environment in a way that is suitable for flood risk modelling, and there is a shortage of vulnerability curves to support quantitative flood risk assessment. Developing such a database along with high-quality flood hazard data would provide the benefits of standardization and reduce efforts required to model flood risks on a one-off basis.

REDUCING RISK

RISK REDUCTION PRACTICE, POLICY, AND CAPABILITIES

Historic damaging flood events have influenced policy and legislation in BC. For example, the 1948 Fraser River flood led to the development of the 1948 federal-provincial Fraser River Board and the 1953 *Dike Maintenance Act*. The 1948 Columbia River flood led indirectly to the 1961 Columbia River Treaty. At the national level, the federal National Disaster Mitigation Program was created following the 2013 Calgary and Toronto severe flood events.

A draft discussion paper on flood risk and resilience in BC was developed in 2020 as part of efforts to develop a provincial flood strategy. This paper was informed by provincial ministries, Indigenous engagement, and local and federal government engagements. Further dissemination of the report through a public engagement process has, however, been delayed as the province addresses response and recovery to communities from the November 2021 floods and incorporates the lessons learned from that event.

GOVERNANCE

Many jurisdictions in BC play a role in flood risk reduction, including government agencies, critical infrastructure owners and operators, insurance companies, businesses, individuals, and homeowners (Table 3). Provincial legislation, regulations, and policies set out requirements and guidance for communities to manage their flood risk under the *Local Government Act*, the *Emergency Program Act*, and the *Dike Maintenance Act*.

Local government plays an extensive role in flood management, including floodplain designation, land-use planning, bylaws for non-structural measures, and emergency preparedness and response. When a state of emergency is declared, a higher level of government is responsible for supporting the response. These response actions are coordinated by emergency managers through Emergency Operation Centres

Figure 4: Federal Flood Guideline Mapping Series (Graphic: Natural Resources Canada).

GUIDELINES TO SUPPORT FLOOD MAPPING

The Federal Flood Mapping Guideline Series (Figure 4) is a set of evergreen guidelines that support flood mapping activities.[31] The series includes guidance on the Flood Mapping Framework (2018), LiDAR Data Acquisition (2020), Bibliography of Best Practices and References for Flood Mitigation (2018), Case Studies of Climate Change in Floodplain Mapping (2018), Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation (2019), Federal Geomatics Guidelines for Flood Mapping (2019), and Federal Flood Damage Estimation Guidelines for Buildings and Infrastructure (2021). New guidelines are being developed for flood land use and risk assessment that will be of value to practitioners and the Province of BC.

Engineers and Geoscientists of British Columbia provide professional practice guidelines for flood assessments and flood mapping.[32]

Table 3: Organizations and industries involved in flood risk management.

Organization	Type of Organization	Legal Mandate and Roles	Key Programs
Public Safety Canada	Federal government	Emergency preparedness and response with all orders of governments; assesses capabilities and priorities for mitigation, preparedness and response; develops plans and preparedness strategies; help Canadians prepare for and recover from floods in high-risk areas.	*Federal Emergency Response Plan* National Risk Profile (flood, earthquake, and wildfire) Requests for Federal Assistance Disaster Financial Assistance Arrangements Program Emergency exercises (tabletops) Flood Insurance Program Disaster and Climate Resilience Joint Committee for BC
Infrastructure Canada	Federal government	Infrastructure standards and funding.	Disaster Mitigation Adaptation Fund Natural Infrastructure Fund[33]
Natural Resources Canada	Federal government	With provinces and territories, develops flood maps for high-risk areas, develops a portal for access to information on flood risks, develops best practice guidelines, conducts research.	Flood Hazard Identification and Mapping Program Flood Mapping Portal Flood Mapping Guidelines Series Emergency Geomatics
Indigenous Services Canada	Federal government	First Nations emergency preparedness, management, and recovery that addresses climate change, impacts, and collaborative strategies.	First Nations Emergency Preparedness, Management and Recovery First Nations Adapt program Emergency Management Assistance Program
Environment and Climate Change Canada	Federal government	Weather forecasts, climate change projections, flood forecasting.	*Climate Data Strategy* Canada Water Agency Weather monitoring upgrades Climate change strategies *Freshwater Action Plan*

Organization	Type of Organization	Legal Mandate and Roles	Key Programs
Emergency Management British Columbia	Provincial government	Lead coordinating agency for all emergency management activities in BC.	BC Disaster Mitigation Programs[34]
Forests Lands Natural Resources and Rural Development	Provincial government	Provides tools, data, and water licensing; regulates dike safety and upgrades; provides flood forecasting and warnings.	*Environmental Management Act* *Local Government Act* Flood Mitigation Guidelines *Dike Maintenance Act* *Drainage, Ditch and Dike Act* *Water Sustainability Act* *Environmental Management Act* *Flood Hazard Statutes Amendment Act* *Land Title Act* *Community Charter* *Local Government Act* *Riparian Areas Protection Act and Regulation*
Ministry of Land, Water, and Resource Stewardship	Provincial government	Sets environmental objectives; manages cumulative environmental effects; and advances environmental sustainability, economic growth, and Reconciliation with Indigenous Peoples.	*Environmental and Land use Act* *Water Sustainability Act* *Flathead area water conservation Act* *Muskwa-Ketchika Management Areas Act* *Skagit Environmental Enhancement Act* *Wildlife Act*
Ministry of Transportation and Infrastructure	Provincial government	Promotes safety and efficient movement of people and goods.	New Building Canada Fund - Small Communities Fund
Ministry of Agriculture	Provincial government	Promotes production, marketing, processing, and merchandising of agriculture and aquaculture products; supports food security and enhancement of wild fish populations.	2021 Flood Recovery Program for Food Security

Organization	Type of Organization	Legal Mandate and Roles	Key Programs
Municipal Affairs and Housing Service	Provincial government	Supports local governments and residents to build vibrant and healthy communities.	Strengthening Community Fund Integrated Transportation and Development Strategy
Union of BC Municipalities		Offers funding programs for local governments and First Nations.	Canada Community Building Fund Community Emergency Preparedness Fund
Fraser Basin Council	Non-profit	Collaborates with federal, provincial, and local governments and First Nations, the private sector, and civil society for sustainability in the Fraser Basin and across BC.	Facilitation Education on flood hazard/risks

at varying levels of government. Homeowners and businesses are responsible for managing flood risk by knowing their flood risk and being aware, and through mitigation actions such as buying flood insurance. Ultimately, private-property owners are responsible for knowing their own flood risk in real estate transactions and for flood defences of their property.

GUIDELINES

Provincial flood land-use guidelines[35] provide good guidance on land-use planning and non-structural measures, including flood construction levels and setbacks and how to treat subdivisions versus redevelopment applications. These guidelines must be considered when local governments make bylaws.

New stormwater guidelines that address green infrastructure options are under development in BC.[36] The benefits of green systems are plentiful and include improving water quality, supporting water volume control, and reducing stormwater runoff.

Guidelines for the management of flood protection works in BC were developed in 1999[37] and provide guidance on engineered dikes.

INTEGRATED FLOOD MANAGEMENT

Given the impact of repeat flood events, some communities in BC are moving towards integrated flood and land-use management planning. This approach supports a portfolio of mitigation strategies. For instance, the community of Squamish has developed an Integrated Flood Hazard Management Plan (IFHMP), which supports the development of structural and non-structural measures together.[38] The community of Grand Forks is rebuilding post-flood using a range of mitigation approaches.

LAND-USE PLANNING

Land-use planning tools are an essential component of flood risk management and should include the integration of flood considerations into community plans, guides, and strategies, including waterfront revitalization plans, major infrastructure projects, capital plans, and open space/recreation plans. Zoning bylaws and regulations can prohibit certain building types and uses allowed within flood-prone areas. For instance, the District of North Vancouver has established development permit areas for creek areas to minimize flood hazards.[39]

For local stormwater flooding in urban areas, reducing the use of impervious surfaces, limiting urban sprawl, and decreasing stormwater runoff by retaining water on site and allowing it to infiltrate (through rain gardens, infiltration trenches, green roofs, porous pavement, and more) are key. The City of Vancouver established a

REBUILDING GRAND FORKS AFTER THE FLOOD

After devastating floods in 2018, Grand Forks and outlying communities along the Kettle and Granby rivers are building back stronger using an integrative approach and a combination of mitigation strategies. These include the buyout of 130 properties in high-risk floodplain areas to create natural floodplains for the river to occupy during floods, and the construction of dikes to protect other parts of the city. High-priority roads are being raised, floodplains and riparian areas restored, and residents assisted with relocation. Grand Forks is one of the first communities in BC to establish a buyout program to purchase homes in high-risk flood areas, leaving a large area of land that can be returned to its natural state.

A risk assessment was required to apply for funding under the Disaster Mitigation and Adaptation Fund. Consultants were hired to assist the community with completion of the assessment and develop options for a plan to move forward on consultation with the community.

Rain City Strategy in 2019 to increase resilience through sustainable water management and improve natural and urban ecosystems and water quality.[40]

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Subdivision controls can limit development by preserving riparian areas, protecting open spaces, limiting development on steep slopes, reconnecting rivers to floodplains, restoring and conserving wetlands, and establishing flood bypasses and setback dikes to give the river room to expand during flood seasons.

Provincially regulated zones, such as the Agricultural Land Reserve or conservation easements, are other regulatory tools that can be used. Flood risk management guidelines for locating new infrastructure facilities set out acceptable flood thresholds for new infrastructure. Adopting a similar approach in BC would be invaluable in limiting the development of critical infrastructure in floodplains.[41]

EDUCATING AND INFLUENCING BEHAVIOUR

The public plays a crucial role in managing flood risk to their properties and saving lives with timely evacuation. A flood preparedness guide developed by PreparedBC can assist individuals in setting up an emergency plan. It provides guidance on protecting one's home and property, understanding advisories and warnings, preparing a sandbag dike, rules for evacuation, returning home after the flood, what to expect, managing mould and health risks, psychological care, and insurance.[42] Flood-ready social media content developed by Emergency Management British Columbia can be used by organizations to communicate with the public on how to prepare before, during, and after a flood.[43] For agricultural producers in floodplains, a new Farm Flood Readiness Toolkit[44] has been developed to increase awareness and understanding of flood risks, identify vulnerable areas and components on a farm, identify measures to protect farmers' properties from flooding, and create a flood preparedness plan. However, these resources may not be universally accessible, especially to vulnerable individuals.

Bulletins and maps produced by the BC River Forecast Centre on current and forecast streamflow conditions provide advisories and warnings to the public and emergency managers.[45]

MANAGING FINANCIAL IMPACTS OF FLOODS

Provincial Disaster Financial Assistance (DFA) may compensate individuals, small businesses, farms, and charitable organizations for essential uninsurable losses once a disaster is declared. To receive compensation, one must occupy the property as the principal residence (seasonal or recreational properties aren't eligible). Farms must be in development or established and owned and operated full-time by a farmer, where the majority of their income is derived from the farm. Insurance deductibles, non-essential and recreational items, and losses due to erosion and landscaping are not covered.

A separate provincial program exists for Indigenous and local governments to rebuild or replace essential public infrastructure to pre-disaster conditions. This program does not include preventative measures to guard against future damages, enhancements to projects, or eroded or damaged land except for essential access routes and the removal of debris.

When response and recovery costs exceed the provincial threshold, the DFA program receives funds from Public Safety Canada through the Disaster Financial Assistance Arrangements program. Eligible costs include evacuation, repairs, and restoration to public works, personal property, farmsteads, and small buildings. The program does not support repairs to non-primary dwellings, repairs eligible through insurance, damages to large businesses, loss of income, or economic recovery.[46]

DISASTER RECOVERY FUNDS IN BC BUDGET 2022

Following the damaging floods and wildfires of 2021, the BC 2022 budget,[47] allocated $2.1 billion to fund disaster recovery and future responses to wildfires and floods. The fund supports communities and critical infrastructure to build back better; $400 million is to be invested in 2022–2023 for Emergency Management BC to support people and communities, and $1.1 billion is for contingencies for disaster recovery costs over the next three years. (This is in addition to $5 billion allocated by the Government of Canada to help response and recovery efforts in BC.) Of the $600 million for operating and capital funds, $83 million is to be invested in a Climate Preparedness

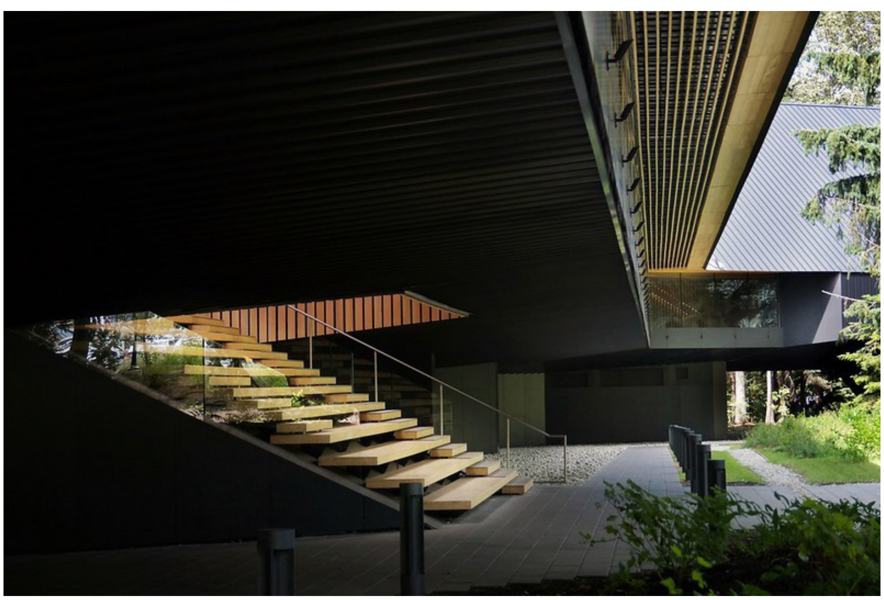

Figure 5: The Audain museum (Photo: Thomas Cartier/flickr).

FLOOD-RESISTANT STRUCTURES

Land-use planning and building design can allow us to live with water by allowing space for seasonal flooding and adapting to "having our feet wet." Approaches as diverse as parks and open spaces in floodplains, bringing in fill to build communities up beyond flood construction levels, leaving basements undeveloped, and requiring flood-resistant building design and construction are all effective means to reduce flood risks.

Elevated structures, such as the Audain museum built in the floodplain of Fitzsimmons Creek in Whistler, are elevated by one storey above grade to avoid damage from debris during a flood (Figure 5).

and Adaptation Strategy, which includes expansions to climate monitoring networks, additional capacity for the BC River Forecast Centre, the provincial floodplain mapping program, collecting building data, supporting expertise for climate risk mitigation, and climate-ready transportation networks; $30 million in grants will help safeguard BC's watersheds.

MANAGING FLOOD PROTECTION

In BC, there are more than 1,100 kilometres of regulated dikes, half of which are in the Lower Mainland.[48] A number of non-structural and small-scale infrastructure projects are currently funded under the National Disaster Mitigation Program, including projects such as decommissioning the Gardom Pond Dam in the Capital Regional District and raising a dike at the City of Fernie. The Disaster Mitigation and Adaptation Fund (DMAF) supports large-scale infrastructure projects to manage natural disasters. For example, the City of Richmond is being supported by a DMAF fund of $13.7 million to support the development of 2.6 kilometres of dike improvements and upgrade five drainage pump stations.[49]

The Adaptation, Resilience and Disaster Mitigation (ARDM) program is also funding flood mitigation infrastructure projects for individual communities (up to $10 million) and joint applications submitted by multiple communities (up to $20 million). The program has a total of $81.9 million in federal and provincial support for projects that increase structural capacity and/or natural capacity with the intent of reducing or avoiding flood damages.

MANAGING FLOOD PROTECTION DURING RESPONSE

If information and alerts are available, instant dams and berms can be installed to divert flood water and protect infrastructure. Elongated flexible tubes (known as "tiger dams" by one manufacturer) can be stacked and filled end to end with water to protect infrastructure from flooding. These have been widely used in BC as an effective means to hold back waters during a flood. For instance, the Ministry of Transportation and Infrastructure set up one of these structures during the November 2021 flood in the Sumas Prairie.[50] These reusable structures are set up quickly by trained personnel and can be used instead of sandbags to hold back the water up to a certain depth when waves, debris, and water velocity are manageable (Figure 6).

FLOOD WARNING TIMES

The amount of advance warning provided before a flood changes the impact it has on a community. With sufficient advance warning times, temporary mitigation efforts, such as sandbags and tiger dams, can lessen impacts. However, the ability to provide advance warnings depends on the type of flood and characteristics of the watershed. For some floods on larger lakes, there may be a week or a month of lead time to prepare for the event. On some larger rivers, one or two days' notice prior to flooding is the best that can be expected under ideal circumstances. However, for many small creeks and rivers, advance

Figure 6: Inflatable flexible tubes set up during the November 2021 flood (Photo: BC Ministry of Transportation/flickr).

warning time is much shorter, on the order of hours to even minutes, and in some cases, it may not be possible to get the word out in advance of flooding at all. It may be impossible to predict exactly how flood events unfold; however, it is possible to identify areas more likely to flood due to locations within floodplains as well as the condition of existing flood infrastructure. BC's system of flood watches and warnings provides some indication of elevated flood risk conditions developing and is an important public safety notification tool, but it generally cannot be used to predict the exact severity and timing of flood events at specific sites.

GAPS IN REDUCING RISK

FRAGMENTED FLOOD RISK GOVERNANCE

Many jurisdictions are involved in flood management. With flexible regulation and targets for enforcement and a lack of clear understanding of roles and responsibilities, this has led to fragmented flood risk governance.[51]

Lack of funds, staff limitations, competing priorities, and in-house expertise can vary widely between communities resulting in a lack of equity between communities to address flood risk.

Historically, the focus on flood risk has been reactive. This needs to change to focus on recovery and disaster resilience before the next flood event.

In addition, a lack of incentives for local and regional governments to manage flood risk through land-use planning and non-structural measures has led to a focus and reliance on costly structural measures.

Many jurisdictions are involved in flood management. With flexible regulation and targets for enforcement and a lack of clear understanding of roles and responsibilities, this has led to fragmented flood risk governance.

The *Local Government Act* states that "If a local government considers that flooding may occur on land, the local government may, by bylaw, designate the land as a flood plain."[52] The flexibility in the wording means that some communities may not designate areas as floodplains, especially where flood maps do not exist. When flood management occurs at the community scale, without proper engagement with neighbouring communities, management decisions upstream can have damaging effects on downstream communities.

As part of Reconciliation, strengthening and working with First Nations leadership related to flood management and compliance with the United Nations Declaration on the Rights of Indigenous Peoples needs to be prioritized. Many Indigenous communities are exposed to greater flood risks due to forced relocation in floodplains, and systems are lacking to operationalize UNDRIP.

GUIDELINES ARE LIMITED

Provincial flood guidelines are limited in scope. Guidelines are also just that—guidelines, not requirements—and there is no path for enforcement or incentives.

A historical focus on structural mitigation, including the building of dikes and dams, has tended to encourage development behind these structures, putting people, buildings, and infrastructure at risk. Dikes are costly (both financially and to local ecosystems) and need to be maintained and upgraded to withstand seismic shaking during earthquakes and prevent flooding.

There is a need for an integrated flood planning guideline that includes structural and non-structural measures, addresses climate change, land-use change, and ensures First Nations involvement. An integrated approach would allow for safe flooding in some areas to add "room for the river" and allow rivers to interact across their floodplains and create rich habitats and flood-safe communities. Measures should also address erosion protection, mitigate for multi-hazards where possible, and explore green technologies and bioengineering.

Forestry practices and related legislation and policy may not adequately address the impacts of forest harvesting on flood risks in some watersheds, such as higher-elevation forests with significant snowpack, and changes to snow dynamics and peak flows—although some uncertainties likely remain, and this is an evolving science.[53]

FUNDING IS INADEQUATE

Funding programs are often oversubscribed and limited to specific adaptation and mitigation measures. Funding programs also typically prioritize high-quality applications rather than the highest-risk areas. This leads communities without resources to complete sophisticated applications at a disadvantage. Some at-risk communities may not even apply to access these programs due to the complexities in putting together proposals and a lack of staff capacity.

There is a lack of funding programs that allow for nature-based mitigation approaches. Many of the rebuilding-focused funding programs are for structural approaches (though Infrastructure Canada has recently opened a new fund for natural infrastructure[54]). Current funding programs could lead to maladaptation by preventing the implementation of a portfolio of adaptation approaches. Historically, private and public insurance funded projects that rebuild to the pre-disaster condition. The program was revised in April 2022 to limit financial assistance to one occurrence. Future claims may not be accepted, and owners are expected to undertake mitigation measures to protect against future floods.[55]

Managed retreat (such as property buyout) is not funded, and buyout programs are difficult to implement as systems are not in place to support effective implementation and funding for land acquisition.

There is a lack of funding programs that allow for nature-based mitigation approaches. Many of the rebuilding-focused funding programs are for structural approaches.

OPPORTUNITY

RECOMMENDATIONS

Table 4 summarizes some key recommendations that can be taken to make BC more flood resilient into the future.

THE CHALLENGE

Cross-border flooding: The many jurisdictions needed to effectively work together to understand and mitigate flood risks and build resilience across jurisdictions (e.g., Nooksack River flood risks) makes this a complex issue to address. In addition, the legislation in Canada and the United States addresses risk differently, which can further complicate issues.

Intellectual property issues: Ownership of information and data limits who can access data or information. This makes modelling, and mapping flood risks a challenge. In particular, critical infrastructure owners and operators may be hesitant to share information due to security-related concerns. There is a need to address OCAP (Owner Control Access and Possession) principles[58] when handling, sharing, and working with data from Indigenous communities.

Media reports: Many media descriptions of the November 2021 floods characterized them as "unprecedented," yet many of these areas have experienced repeated, predictable, devastating floods. For example, the Nooksack River also flooded into Canada in November 1990, and experts as well as the international Nooksack River Task Force were well aware of these flood risks. Large catastrophic events have happened in the past and continue to happen in the same places. These events must be identified as anticipated, not "unprecedented" events.

Table 4: Recommendations.

Recommendation	Description of Impact	Priority Level	Capabilities Needed
Understanding Risk			
1. Complete publicly available flood maps for all flood-prone communities in BC for current and future conditions.	Areas of high flood risk are identified using a consistent approach, and inaccuracies are minimized.	Critical	Technical
2. A province-wide flood risk assessment that includes a range of mitigation scenarios and captures information on historical events.	Mitigation and adaptation reduce impacts effectively, and communities are more equitably resilient to flood risks. Post-event data and forensic data informs an understanding of future impacts and risk reduction measures.	Necessary	Technical
3. Provincial guidelines are expanded to include an integrated approach and move beyond structural mitigation, including natural approaches, land-use planning tools, and visualization tools.	Communities and practitioners have increased awareness and guidance to address a range of mitigation approaches that take into account the health of the ecosystem.	Critical	Technical
4. Mortgage lenders, appraisers, and the public are aware of flood risks, including at the time of sale, lease, or rental of a property.	Individuals and the real estate industry are aware and can adapt to and prepare for flood risks.	Critical	Technical
Risk Governance and Building Back Better			
5. Coordinate governance structures to manage, share, and update regional maps in areas prone to flood hazards; make high-level decisions about flood risk mitigation; and monitor progress and changes within the catchment area.	Supports the creation of an integrated flood management strategy. The BC DRR Hub concept note provides details on the benefits of a collaboration hub.[56]	Critical	Technical, Financial
6. Regional growth strategies, official community plans, development permit areas, zoning bylaws, floodplain regulations, subdivision bylaws, servicing bylaws, and building codes take into account natural hazard risks and consider natural infrastructure and open spaces as flood resilience tools.	Land uses and building codes consider flooding and climate change impacts.	Critical	Legislation, Technical
7. Expand strategic and comprehensive funding to allow for an integrated approach to flood risk management.	Allows funding to expand support for a variety of options, including managed retreat and nature-based solutions.	Critical	Technical, Financial

Recommendation	Description of Impact	Priority Level	Capabilities Needed
Risk Governance and Building Back Better			
8. Update dike management to include a provincial repository of dike information and assign owners to orphaned dikes.	Support dike maintenance, upgrades, and audits; streamline emergency response and recovery planning and actions; increase the public's risk awareness.	Critical	Technical, Financial
Preparedness, Response and Recovery			
9. Improve and expand flood forecasting and early warning systems.[57]	Communities and emergency responders are better prepared to respond to and cope with floods.	Critical	Technical, Financial
10. All flood-prone communities have capacities for emergency response and have flood response plans.	Communities are better prepared to manage and respond effectively to floods.	Critical	Financial

RESOURCES

BC AND CANADA

1. The Building Regional Adaptation Capacity and Expertise Program (BRACE) provides resources and tools to support professionals to develop skills, knowledge, and behaviour to adapt to climate change.

Natural Resources Canada. "Building Regional Adaptation Capacity and Expertise Program." Accessed June 17, 2022. https://www.nrcan.gc.ca/climate-change-adapting-impacts-and-reducing-emissions/building-regional-adaptation-capacity-and-expertise-program/21324.

2. A series of reports that looks at current issues, challenges, and opportunities for flood management in BC.

Fraser Basin Council. "Investigations in Support of Flood Strategy Development in BC." Accessed June 17, 2022. https://www.fraserbasin.bc.ca/BC_Flood_Investigations.html.

3. A portal that provides information on flood risk management for Fraser River flood and coastal flood hazards and risks in the Lower Mainland.

Floodwise in BC's Lower Mainland. "Your information portal on flood risk management." Accessed June 17, 2022. https://floodwise.ca/.

4. A community of practice to that supports best practices and solutions to treat the land in a shore-friendly way.

Stewardship Centre for British Columbia. “Green Shores – how it works.” Accessed June 17, 2022. https://stewardshipcentrebc.ca/green-shores-home/gs-about/how-it-works/#:~:text=Green%20Shores%20is%20Science%2DBased,transport%20processes%20and%20natural%20areas.

5. A guide to regional decision making for the Regional District of Central Okanagan on non-structural flood mitigation.

Ebbwater Consulting. *Non-structural Flood Mitigation Resource Guide*. Regional District of Central Okanagan, 2021. Accessed June 17, 2022. https://www.rdco.com/RDCO-Flood-Resource-Guide_20211216.pdf.

6. A review of the current understanding of flood buyout programs in Canada and managed retreat with lessons learned from the buyout program in Grand Forks following the 2018 floods.

Le Geyt, Melissa. “Expanding the adaptation toolbox: Exploring managed retreat in Grand Forks, BC.” MSc diss., University of Waterloo, 2022.

7. A tool to create a community disaster resilience plan for all hazards.

Justice Institute of British Columbia. “Increase Disaster Resiliency in Your Community.” Accessed July 15, 2022. https://cdrp.jibc.ca/.

INTERNATIONAL

8. Principles to achieve strategic flood management that could be applied across jurisdictions in BC.

Sayers, Paul, Gerry Galloway, Edmund Penning-Rowsell, Li Yuanyuan, Shen Fuxin, Chen Yiwei, Wen Kang, Tom Le Quesne, Lei Wang, and Yuhui Guan. “Strategic flood management: Ten ‘golden rules’ to guide a sound approach.” *International Journal of River Basin Management* 13:2 (2015): 137-151. doi:10.1080/15715124.2014.902378.

9. A public-private partnership led by the Nature Conservancy that provides resources to support an integrated and collaborative approach to enable communities and the environment to rethink floodplains.

Floodplains by Design. “Reducing risks, restoring rivers.” Accessed June 17, 2022. https://www.floodplainsbydesign.org/.

10. A resource to help property owners and buyers assess strategies to reduce flood risk. This resource is intended for decision makers in the United States, but some of the learning can be used by Canadian property owners and buyers.

Reduce Flood Risk. "Reduce your flood risk." Association of State Floodplain Managers. Accessed June 20, 2022. https://www.reducefloodrisk.org.

ENDNOTES

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[4] Natural Resources Canada, *Federal flood damage estimation guidelines for buildings and infrastructure*, General Information Product 124e (2021), doi:10.4095/327001.

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2.1 RISK MITIGATION IN CRITICAL INFRASTRUCTURE

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RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 2 Climate and Disaster Risk Management: Practice*. To read all articles in the report, see DRRPathways.ca.

The Resilience Pathways Report is a project of Natural Resources Canada.

2.1 RISK MITIGATION IN CRITICAL INFRASTRUCTURE

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COORDINATING RISK MITIGATION

NATIONAL STRATEGY FOR CRITICAL INFRASTRUCTURE

The *National Strategy for Critical Infrastructure (2009)* (the Strategy) sets out Canada's approach to strengthening the resilience of critical infrastructure (CI). The Strategy defines CI as the "processes, systems, facilities, technologies, networks, assets and services essential to the health, safety, security or economic well-being of Canadians and the effective functioning of government."[1] CI can be stand-alone or interconnected and interdependent within and across provinces, territories and national borders. Disruptions of CI could result in catastrophic loss of life and injuries, adverse economic effects, and significant harm to public confidence.

The Strategy advances coherent and complementary actions among federal, provincial, and territorial initiatives and among the ten CI sectors: energy and utilities, finance, food, transportation (Figure 1), water (Figure 2), government, information and communication technology, health, safety, and manufacturing.[2] A Lead Federal Department (LFD) is responsible for each sector and for bringing together a network of stakeholders and representatives from within each sector. The Strategy is built around three strategic objectives: 1) building partnerships among federal, provincial and territorial governments and CI sectors, 2) implementing an all-hazards risk management approach, and 3) advancing the timely sharing and protection of information among partners.[3]

Between 2018 and 2020, Public Safety Canada led an examination of the Strategy to determine if there was a need to update Canada's overall approach to CI resilience. The examination's findings recommended a renewal process, which will take place over the next three years (2021–2023).[4] The renewal of the Strategy is an opportunity to shed light on what is working well, what needs to be improved, and what our vision for the future should be, as Canada faces an evolving list of risks and threats.

1. BUILDING PARTNERSHIPS

As detailed in the *Emergency Management Framework for Canada*,[5] strengthening the resilience of CI requires complementary and coherent action by all partners to promote the most effective use of resources and execution of activities. Harmonizing approaches to strengthening the resilience of CI at all levels will enable efforts to facilitate timely and effective prevention, mitigation,

Figure 1: Trains and rail lines provide critical transportation infrastructure (Photo: Public Safety Canada).

preparedness, response and recovery measures to deal effectively with disruptions. The Strategy recognizes that each responsible jurisdiction, department and agency, as well as CI owners and operators, will take action as they deem appropriate for strengthening the resilience of CI in Canada. To be successful, however, the implementation of the Strategy requires the collaboration of federal, provincial, territorial and CI sector partners and the establishment of engagement mechanisms to facilitate this collaboration.[6]

2. IMPLEMENTING AN ALL-HAZARDS APPROACH

The Strategy promotes the application of risk management and sound business continuity planning. Risk management refers to the "continuous, proactive and systematic process to understand, manage and communicate risks, threats, vulnerabilities and interdependencies across the CI community." A comprehensive risk management process requires that federal, provincial and territorial governments collaborate with their CI partners to develop all-hazards risk analyses that take into account accidental, intentional and natural hazards. While governments promote a common approach to strengthening the resilience of CI, and share tools, lessons learned and best practices, CI stakeholders are ultimately responsible for implementing their own risk management approach given their situation.[7]

As part of the Strategy, federal, provincial and territorial governments conduct exercises and assist in the coordination of regional exercise planning across jurisdictions and with CI sectors. Exercises help partners with an assessment of their CI and recommend improvements to their plans, which ensure an effective response and recovery in the face of a CI disruption.

> A comprehensive risk management process requires that federal, provincial and territorial governments collaborate with their CI partners to develop all-hazards risk analyses that take into account accidental, intentional and natural hazards. . . . CI stakeholders are ultimately responsible for implementing their own risk management approach given their situation.

3. SHARING AND PROTECTING INFORMATION

Information sharing and information protection play a key role in collaborative efforts to strengthen the resilience of CI. Improved information sharing, within existing federal, provincial and territorial legislation and policies, enhances the timely exchange of information on risks and the overall status of critical assets, so that CI owners and operators, governments and others can assess risks and take appropriate action.[8] Information exchange is crucial before, during and after a disruption or emergency, as it enables a "common operating picture" among all levels of government and CI sectors an improved approach across the range of prevention, mitigation, preparedness, response and recovery.[9]

> Information sharing and information protection play a key role in collaborative efforts to strengthen the resilience of CI. Improved information sharing, within existing federal, provincial and territorial legislation and policies, enhances the timely exchange of information on risks and the overall status of critical assets.

Due to the many interdependencies in Canadian CI, the inappropriate release of sensitive information poses a risk for a province or local authority and Canada as a whole. There are some exemptions from disclosure for reasons of national security and public safety, existing under federal, provincial and territorial access to and freedom of information legislation.[10] A consequential amendment to the *Access to Information Act*, as part of the Government of Canada's *Emergency Management Act*, gave clear protection to sensitive information provided by CI owners and operators. Governments continue to ensure an appropriate level of protection to sensitive emergency management and CI information.[11]

THE NATIONAL CROSS SECTOR FORUM ACTION PLAN FOR CRITICAL INFRASTRUCTURE

The *National Cross Sector Forum Action Plan for Critical Infrastructure* (the Action Plan) acts as a blueprint for how the Strategy is implemented to enhance the resilience of Canada's CI. Since the publication of the Strategy in 2009, four supporting action plans (2010–2013; 2014–2017; 2018–2020; and 2021–2023) have been released, each outlining concrete steps towards advancing the three objectives set out in the Strategy.[12]

The first Action Plan (2010–2013) set out the roles and responsibilities of the federal government, provincial and territorial governments, and CI owners and operators along with action items in the areas of partnerships, risk management and information sharing.[13] Within years one and two, partners focused on the development of sector networks and the National Cross Sector Forum (NCSF) as well as improved information sharing. Initial activities in support of risk management were also undertaken at this time. During subsequent years, effective sector networks and improved information has enabled further risk management activities (e.g., development of sectoral risk profiles, guidelines for risk assessments) and emergency management planning and exercises.[14]

Public Safety Canada currently conducts all-hazard risk assessments through the physical-based Regional Resilience Assessment Program and the Canadian Cyber Security Tool and cyber assessment program. This includes working with provinces and territories to determine priority sites for physical assessment and identifying and implementing measures to increase the impact and reach of the cyber and physical programs. Public Safety Canada also produces risk assessment products based on specific hazards (flood, wildfire, earthquake, hurricane, etc.) or in response to potential or occurring emergencies with potential to disrupt CI.

To continue supporting the advancement of the Strategy's three strategic objectives until the release of the renewed national approach to CI resilience, Public Safety Canada (PS) has created the *National Cross Sector Forum 2021–2023 Action Plan for Critical Infrastructure*. The Action Plan (2021–2023) reaffirms the Government of Canada's commitments to work closely with CI sector partners, provinces and territories towards a more secure and resilient Canada. The Action Plan (2021–2023) also continues to support the three strategic objectives identified in the Strategy and builds upon progress made through past action plans, identifies new activities based on the changing threat environment, and will support a collaborative approach to enhance the security and resilience of Canada's CI.[15]

ALIGNMENT WITH THE SENDAI FRAMEWORK

The work under the Strategy and subsequent Action Plans for CI contribute to the Sendai Framework for Disaster Risk Reduction's seven global targets. The work directly contributes to (18) Target (d) and is critical for achieving Targets (a), (b), (c), and (g).

In the Sendai Framework, item 18 (d) states: "Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030."[16]

While in most clauses of the Sendai Framework CI is bundled with all other assets, one commitment is specific to CI. Item 33 (c) states: "To achieve this, it is important: . . . To promote the resilience of new and existing critical infrastructure, including water, transportation and telecommunications infrastructure, educational facilities, hospitals and other health facilities, to ensure that they remain safe, effective and operational during and after disasters in order to provide life-saving and essential services."[17]

ENGAGEMENT MECHANISMS

The following section outlines activities and action items that support the risk management principles outlined in the Strategy's strategic objectives. The purpose of the activities is to strengthen Canada's CI resilience by helping to prevent, mitigate, prepare for, respond to, and recover from disruptions. Additionally, they are designed to foster collaboration and information sharing among all levels of government, private sector partners, and allied countries.[18]

THE NATIONAL CROSS SECTOR FORUM

The Strategy and Action Plan (2010–2013) established the National Cross Sector Forum (NCSF) to maintain a comprehensive and collaborative Canadian approach to enhance the resilience of CI, by providing a standing mechanism for discussion and information exchange within and between levels of governments and CI sectors. Membership is drawn from the ten sector networks and is representative of a wide-ranging number of CI owners and operators, associations, and provincial and territorial governments.[19] Typically, one to three senior-level members of each sector network represents the CI sector at the NCSF.

The NCSF membership has developed terms of reference for the NCSF, including the designation of three chairs—the Deputy Minister of Public Safety, one industry representative, and one provincial/territorial representative. The chairs work with members to set agendas, determine the frequency of meetings and manage the business of the NCSF.[20] The Critical Infrastructure Division, Public Safety Canada, serves as the NCSF's secretariat, where the Division's staff provide strategic advice, support information sharing, develop the cross-sector risk profile, and provide general support to the NCSF.

THE MULTI-SECTOR NETWORK

The MSN provides a platform to examine Canada's CI priorities from a cross-sector and multi-jurisdictional perspective, facilitate the timely exchange of relevant information on CI risks and emerging issues, and foster cross-sector partnerships among CI owners and operators.[21] It brings together working-level representatives from each of the ten CI sectors and may also include representatives from the NCSF, LFDs, provinces and territories, and the international CI community to discuss topics related to CI resilience.

THE FEDERAL, PROVINCIAL AND TERRITORIAL CRITICAL INFRASTRUCTURE WORKING GROUP

The Federal, Provincial and Territorial Critical Infrastructure Working Group (FPT CI WG) is the primary

Figure 2: Wastewater treatment plants provide critical water infrastructure (Photo: Public Safety Canada).

mechanism for federal, provincial and territorial government collaboration on current and emerging issues facing CI sectors, including recent COVID-19 response efforts. Membership is open to all governments for participation if it meets their needs and as their resources permit. The FPT CI WG is co-chaired by a representative from Public Safety Canada and a provincial/territorial representative determined by group consensus. The co-chairs report to the Federal-Provincial-Territorial Senior Officials Responsible for Emergency Management (SOREM) on CI matters. Public Safety Canada serves as the secretariat for the FPT CI WG by organizing meetings, as identified by the co-chairs, and is responsible for preparing and distributing material.[22]

THE LEAD FEDERAL DEPARTMENTS CRITICAL INFRASTRUCTURE NETWORK (LFD CI NETWORK)

The Lead Federal Departments Critical Infrastructure Network (LFD CI Network) is a group of officials from departments leading each of the ten CI sectors, as follows:

- Energy and Utilities (Natural Resources Canada)
- Finance (Department of Finance Canada)
- Food (Agriculture and Agri-Food Canada)
- Health (Public Health Agency of Canada
- Information and Communication Technology (Innovation, Science and Economic Development Canada)

- Manufacturing (Department of National Defense)
- Manufacturing (Innovation, Science and Economic Development Canada)
- Transportation (Transport Canada)
- Government/Safety/Water (Public Safety Canada)

Through network meetings between government departments that are industry leads, the group works to strengthen their collective ability to identify and address disruptions to Canada's CI and share information with their networks of CI stakeholders.

SECTOR NETWORKS

The Strategy and first Action Plan (2010–2013) established sector networks: "national sector-specific standing fora for each of the ten CI sectors to address sectoral and regional issues, and enable information sharing on CI."[23] The sector networks reflect a partnership model that enable governments and CI sectors to undertake a range of activities (e.g., risk assessments, plans to address risks, exercises) unique to each sector. The Strategy provided a framework for the functions of the sector networks, including:

- Promotion of timely information sharing.
- Identification of issues of national, regional or sectoral concern.
- Use of subject-matter expertise from CI sectors to provide guidance on current and future challenges.
- Development of tools and best practices for strengthening the resilience of CI across the full spectrum of prevention, mitigation, preparedness, response and recovery.[24]

Working with CI partners, each LFD has facilitated the development of sector networks to meet the needs of their stakeholders.[25] Sub-sector networks have also been established to reflect the diversity of a particular sector where appropriate. Participation in these networks is voluntary. The sector networks are composed of CI owners and operators as well as national associations from CI sectors and relevant federal, provincial and territorial departments and agencies.[26]

CI GATEWAY

Public Safety Canada also engages CI partners and stakeholders through the CI Gateway—a practical online tool for facilitating information sharing across the ten CI sectors. It hosts information products such as risk management documents, best practices, lessons learned, meeting materials, standards, and event calendars to enhance situational awareness. Membership is granted to stakeholders belonging to a CI sector network and to relevant government partners. There is ongoing work to renew and modernize the GI Gateway in the coming years.[27]

CROSS-CUTTING ISSUES

SUPPLY CHAIN MANAGEMENT AND IMPACTS TO CI

Canada relies on national and international supply chains, which means that the goods and services that CI requires, from fertilizer to pharmaceuticals, can come from anywhere in the world. As a result, Canada's critical functions can be impacted by both domestic and international disruptions. A trade dispute, international conflict (e.g., 2022's Russian invasion of Ukraine), a transportation issue (e.g., 2020's Canadian National Railway blockade, 2022's blockages by the "Freedom Convoy") or other disruption in another country could impact the ability for Canada's CI to acquire important supplies.[28] Increasingly, malicious actors are leveraging supply chain vulnerabilities to conduct cyber-attacks. For example, a 2020 cyber-attack led to thousands of organizations, from the information and communications technology sector to government, downloading malware through IT management software supplied by SolarWinds. At the time of writing, the Canadian Security Establishment's (CSE) Centre for Cyber Security is warning CI organizations and suppliers to bolster their awareness and protection against Russian state-sponsored cyber threads amid the invasion of Ukraine.[29]

RANSOMWARE ATTACKS DURING COVID-19

One of the most significant threats to Canada's CI during the COVID-19 pandemic has been ransomware cyber-attacks. Ransomware attacks are those where criminals hold data or computer systems hostage in exchange for payment. CSE's Centre for Cyber Security predicted that as the pandemic continues, attacks directed against Canada will continue to target large enterprises and CI owners and operations Canadian CI is also at risk of the type of ransomware attack that recently shut down the Colonial pipeline in the US for multiple days. Health-sector organizations have also become popular ransomware targets during the COVID-19 pandemic, due to the importance of keeping health services available and reliable with zero downtime or disruption. At such a critical time, network downtime can have life-threatening consequences for patients, while increasing the likelihood that victims of such attacks will pay the ransom.[30]

THE NATIONAL STRATEGY FOR CRITICAL INFRASTRUCTURE RENEWAL

DRIVERS OF CHANGE IN CANADA'S CI ENVIRONMENT

The risk landscape facing the Canadian CI community is a complex one, characterized by a range of uncertainties and evolving threats and pressures, including environmental and climate change impacts, security (e.g., cyber, national, physical, economic, health, and foreign interference), aging CI, and economic recovery. The global pandemic health crisis has identified the need for greater focus by CI stakeholders on organizational preparedness, business continuity and management of risks posed by globally distributed supply chains that support critical infrastructure operations.[31]

Several key drivers of change were identified as part the Strategy examination: digitalization of systems and processes, environmental risks, security threats, and economic prosperity. These drivers are adding to the pressures and demands to which CI must adapt.

DIGITALIZATION OF SYSTEMS AND PROCESSES

The digitalization of systems and processes, and the ability to control CI operations remotely, continues to present new cyber security challenges. The increased use of digital systems to operate physical infrastructure has improved overall connectivity, communications, and service delivery to Canadians. However, the use of internet-enabled systems increases the likelihood and scale of both intentional and unintentional disruptions. Malicious actors continue to find new ways to

THE EXTENDED NATIONAL CROSS SECTOR FORUM (E-NCSF) ON COVID-19

In March 2020, at the onset of the pandemic, NCSF meetings were expanded to include hundreds of new participants across all ten CI sectors and began to be delivered in a virtual format. This new forum was rebranded as the Extended National Cross Sector Forum (E-NCSF) on COVID-19 in order to differentiate its activities from the "core" NCSF. The CI community used this outlet as events continued to unfold in the pandemic, to review the current status of the COVID-19 virus in Canada, update CI stakeholders on federal planning activities, and share areas of priority for CI industry owners and operators. E-NCSF meetings have included updates from the Public Health Agency of Canada, Public Safety Canada and the Government Operations Centre on various topics including supply chain and liquidity issues, personal protective equipment (PPE), testing and vaccination, guidance, and more. Representatives from each of the ten CI sectors also provide updates share common challenges and impacts to their respective sectors and supply chains during E-NCSF roundtable discussions. On average, 120–150 stakeholders attended E-NCSF meetings.

use cyber-attacks to disrupt CI and exploit Canadians.[32]

ENVIRONMENTAL AND CLIMATE CHANGE RISKS

Canada's climate is changing. The effects of global warming are apparent in many parts of the country and are anticipated to increase in the future. These shifts are significantly affecting Canada's natural environment, built infrastructure, economy, and the health of Canadians. Extreme weather events, such as floods and fires in Western Canada, continue to threaten the ability of CI to deliver services.[33]

SECURITY THREATS

Terrorism, extremism, organized criminals, and hostile state actors all pose threats to Canada's national security and CI. Foreign actors, with the support of state-level resources, are developing advanced capabilities to target CI and other public-private sector institutions, increasingly leveraging cyber systems to conduct espionage, steal intellectual property, and disrupt operations. Security concerns related to the rise of global supply chains, which CI depends on for products and services continues to pose significant concern. Supply chains are world-wide, making it difficult to identify single points of failure and rendering them vulnerable to accidental and international disruption.[34]

ECONOMIC PROSPERITY

Dependable CI drives economic growth by creating jobs, improving productivity and enabling business confidence, which fosters innovation and investment in CI. Continued investment requires customers, taxpayers and a thriving economy to fund investments, whether privately or publicly owned.[35] However, as record deficits have added to government debt at a time when aging infrastructure requires servicing, the full impact of the pandemic is yet to be seen. While recovering from the impacts of the pandemic, Canada will have to address inequitable access to infrastructure in order to allow all Canadians to prosper.

The challenge of securing and maintaining Canada's critical assets and systems in a complex and fast-changing risk landscape will require coordinated approaches between the public sector, private sector, and citizens, which in turn will foster ingenuity, promote adaptability, and ensure collaboration.[36] The National Strategy for CI renewal provides an opportunity to help bring CI communities together and equip them with a common framework for identifying and managing risks and for coordinating decision-making activities to meet collective resilience goals.

CONSULTATION

The purpose of the consultation process, as part of the Strategy renewal, is to solicit input, advice, and ideas to renew the Strategy and Canada's overall approach to CI resilience. Consultation will focus on six key areas of inquiry.

The challenge of securing and maintaining Canada's critical assets and systems in a complex and fast-changing risk landscape will require coordinated approaches between the public sector, private sector, and citizens, which in turn will foster ingenuity, promote adaptability, and ensure collaboration. The National Strategy for CI renewal provides an opportunity to help bring CI communities together and equip them with a common framework for identifying and managing risks and for coordinating decision-making activities to meet collective resilience goals.

1. FUNDAMENTAL CONCEPTS AND DEFINITIONS

Assessing the criticality of CI is not easy because criticality can be dynamic; it changes depending on the current context and situation. For example, during the COVID-19 pandemic, the federal, provincial and territorial governments published lists of essential services. These lists helped determine which businesses could remain open and access reserves of personal protective equipment (PPE), but they were not exhaustive. Criticality affects risk management, planning and preparedness efforts and helps governments respond more effectively during event state. In steady state, the concept of criticality is helpful for governments in determining supports, such as risk assessments provided at no cost to the business, and minimum standards of resilience. It could be argued that a range of key CI-related concepts and definitions are either dated, not widely agreed upon, or could be improved.[37]

2. CROSS-SECTOR INTERDEPENDENCIES AND DIGITALIZATION

CI sectors are highly interdependent, which means that sectors rely on one another to deliver the goods and services that Canadians need. The resilience of a CI sector is therefore determined not only by its own efforts to secure its operations but by the resilience of the many integrated systems that it relies on within other CI sectors. The interdependency of CI sectors means that a failure in one sector can have a domino effect on other sectors. Additionally, the growing connection of CI to the internet not only causes greater cyber security challenges but adds to the dependence of CI on the information and communications technology sector.[38] CI relies heavily on the information and communications technology sector to communicate, conduct business and connect with other sectors. An information and communications technology disruption, caused by a natural disaster, a cyber-attack, or an accident, could have far-reaching consequences (Figure 3).

Figure 3: Satellite ground systems provide critical information and communication infrastructure (Photo: Public Safety Canada).

Digitalization will continue to create greater interdependencies that will require greater coordination of risk management practices across CI sectors, as an attack on a physical-cyber system could result in a catastrophic failure in an area we previously considered unrelated to CI. The digital and interconnected nature of CI complicates interdependency analysis in such a way that will not easily be addressed by one model. A way to address this issue could be to develop new types of responses to protect CI systems and mitigate risk to ensure their resilience.[39]

3. CI SECTOR CONFIGURATION AND COLLABORATION

It can be argued that Canada's ten designated CI sectors and engagement mechanisms are in need of a review because the current sectors do not represent the full range of Canada's vital assets and systems. Exclusions of these businesses and systems from the ten CI sectors means that experts in these areas are not represented in current CI engagement forums.[40] For example, current engagement mechanisms do not include key CI representatives, like Indigenous leadership or municipal governments. Indigenous and municipal governments own and provide CI, for example, in the water sector. As previously discussed, the interdependency of CI sectors presents significant risks that can only be better understood through collaboration. A possible solution could be the reconfiguration of CI sector networks into networks grouped by function, could help to identify interdependencies and related risks, as well as facilitate cross-sector information sharing.[41]

4. CROSS-SECTOR COORDINATION, GOVERNANCE AND COMPLIANCE

Although CI is the common factor that connects many initiatives, priorities and approaches to CI and resilience often vary across various initiatives, CI sectors and regions. Although the current Strategy was developed to be the coordinating link between various domains (i.e., emergency management, national security, cyber security), other initiatives and strategies often have stronger governance, authorities, incentives and compliance mechanisms to address specific risks within a particular domain.[42] Several cross-sector CI fora exist; however, these engagement mechanisms do not have cross-sector authorities or compliance measures.

A way to address these issues could be to develop a clear framework that supports results and accountability to help ensure that a focused direction exists, that objectives are achieved for public and private sector investments, and that efforts to enhance the security and resilience of CI are measurable. Canada currently does not have a national results-based framework in place that effectively measures the collaborative, non-regulatory efforts to achieve CI objectives (as set out in the Strategy) and supporting action plans.[43]

A way to address these issues could be to develop a clear framework that supports results and accountability to help ensure that a focused direction exists, that objectives are achieved for public and private sector investments, and that efforts to enhance the security and resilience of CI are measurable. Canada currently does not have a national results-based framework in place that effectively measures the collaborative, non-regulatory efforts to achieve CI objectives (as set out in the Strategy) and supporting action plans.

5. ROLES, RESPONSIBILITIES AND SUPPORT TO CI OWNERS AND OPERATORS

Service delivery models and support available to CI owners and operators differ across Canada as well as at regional and municipal levels. The roles and responsibilities are not clearly understood across CI partners and stakeholders. Although different delivery models across regions might be needed to address the specific situation, the cluttered organizational landscape makes it difficult to advance common CI priorities and resilience goals and creates conflicting advice for CI owners and operators.[44]

6. ACADEMIC RESEARCH AND EXPERTISE TO SUPPORT RISK MANAGEMENT

Through research and expertise, academia and the scientific community play an important role in supporting various CI initiatives in an ad hoc manner. However, experts from federal, provincial and territorial emergency management, municipalities, Indigenous organizations, academia, policy think tanks and subject matter experts in cyber security, physical infrastructure, digital infrastructure, climate change, economic security, and business continuity are not regularly engaged through formal engagement mechanisms like the NCSF. To address this issue, building stronger and more formalized partnerships in the future with academia and think tanks that study issues related to CI security and resilience, infrastructure protection and digital technology could provide valuable advice to Canada's CI leadership.[45]

NEXT STEPS

The consultation process to support the renewal of the National Strategy will be launched in Spring 2022 and will seek input from a broad range of CI stakeholders, including from governments, industry, academia, and Indigenous communities.

RESOURCES

1. The *National Strategy for Critical Infrastructure* (to be read in conjunction with *National Cross Sector Forum 2021–2023 Action Plan for Critical Infrastructure*) sets out Canada's approach to strengthening the resilience of critical infrastructure:

Public Safety Canada. *National Strategy for Critical Infrastructure*. Canada: Her Majesty the Queen in Right of Canada, 2009. https://www.publicsafety.gc.ca/cnt/rsrcs/pblctns/srtg-crtcl-nfrstrctr/srtg-crtcl-nfrstrctr-eng.pdf

2. To continue advancing the objectives of the Strategy until the renewed national approach to critical infrastructure resilience, Public Safety Canada has created the Action Plan (2021–2023):

Public Safety Canada. *National Cross Sector Forum 2021–2023 Action Plan for Critical Infrastructure*. Canada: Her Majesty the Queen in Right of Canada, 2021. https://www.publicsafety.gc.ca/cnt/rsrcs/pblctns/2021-ctn-pln-crtcl-nfrstrctr/2021-ctn-pln-crtcl-nfrstrctr-en.pdf

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Photo: Neighbour Lab

2.2 SOCIAL INFRASTRUCTURE AND COMMUNITY RESILIENCE

June 2022

DRRPathways.ca

RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 2 Climate and Disaster Risk Management: Practice*. To read all articles in the report, see DRRPathways.ca.

The Resilience Pathways Report is a project of Natural Resources Canada.

2.2 SOCIAL INFRASTRUCTURE AND COMMUNITY RESILIENCE

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ABOUT SOCIAL INFRASTRUCTURE

OVERVIEW

In the wake of disasters, survivors emphasize the importance of community-based support systems, including neighbours, grassroots groups, organizations, and businesses that mobilize and deliver aid in response to the failure of basic services. These community-based assets make up networks of social infrastructure (SI) and include programs and services, physical facilities and spaces, and people—informal networks, deep relationships, knowledge, and resourcefulness that support and enable social interaction and hold social purposes.[i,1]

Networks of SI play a fundamental role in strengthening social fabric and community resilience by fostering social connections, improving equity, reducing disaster risk and vulnerability, and facilitating collective action and essential services through crises, emergency response, and recovery. SI takes a relational approach to community-building and is "predicated on practices, policies and social covenants that increase individual agency and dignity; collective resilience; and human-centred networks."[2] Still, SI is often considered to be an optional investment in government budget and capital planning cycles, rather than essential. Yet investments in SI are an underutilized mechanism for risk reduction and resilience building, despite delivering "hard-hitting, tangible impacts ensuring that all members of society can fulfil their basic needs, realize their potential, and experience a deep sense of belonging and well-being."[3]

> Networks of SI play a fundamental role in strengthening social fabric and community resilience by fostering social connections, improving equity, reducing disaster risk and vulnerability, and facilitating collective action and essential services through crises, emergency response, and recovery.

[i] *SI has also been defined as social services that serve people across lifespans, or address lifelong needs, and include physical spaces, buildings and facilities as an element (Davern et al, 2017). Sociologist Eric Klinenberg drew attention to the concept of SI among academic and mainstream audiences with his 2018 book* Palaces for the People: How SI Can Help Fight Inequality, Polarization, and the Decline of Civic Life. *He describes SI as "the physical places and organizations that shape the way people interact" (Klinenberg, 2018, p. 5), and argues that physical conditions and places are important for building social connectedness and social capital.*

Often, SI is equated with non-profit and charitable organizations, though this is not always the case. In the broadest sense of the concept, SI spaces may be owned or administered by public, non-profit, or faith-based entities, as most are, but they may even be social enterprises or commercial establishments, or even simply informal associations. Community centres, libraries, schools, healthcare centres, and parks all fall under the category of SI, yet they are typically owned and operated by government agencies. Businesses such as coffee shops, bookstores, salons and barbershops can also fall under this category, despite being for-profit, if people use them as a space for socializing. They all have a common function of bringing people together.

This article will largely focus on SI in the form of public and non-profit organizations (or social infrastructure organizations, SIOs) and their facilities because their primary purpose is to enable social connections and deliver services at the local level, and they rely in large part on public financial support, donations, and philanthropic grants, which creates particular funding challenges. The sheer number and variety of SIOs is staggering, and their decentralized locations offer unique opportunities for place-based planning. In BC, there are over 29,000 non-profit organizations that employ 86,000 people and contribute $6.7 billion to BC's economy.[4] There is also a growing discussion and collaborations around social purpose real estate (SPRE), referring to real estate or property that hosts facilities and/or open outdoor space used for social purposes. In 2009, a group of funders, investors and government bodies in BC formed the SPRE Collaborative to mitigate the effects of the real estate affordability crisis on non-profit and social enterprise organizations. SIOs compete primarily in the commercial real estate market to find land and property, and sharply increasing real estate prices, property tax values, and redevelopment pressures create significant challenges for these organizations.

ALIGNMENT WITH THE SENDAI FRAMEWORK

As of 2022, the Government of Canada, Government of British Columbia, and several municipalities (including the City of Vancouver) have adopted the *Sendai Framework for Disaster Risk Reduction 2015–2030* to guide their disaster risk reduction activities. The Sendai Framework emphasizes the criticality of civil society in disaster risk reduction and outlines an all-of-society approach under guiding principle "d."[ii] Guiding principles "f" and "i"[iii,iv] recognize the importance of understanding the local and specific characteristics of disaster risks and empowering local authorities and communities to reduce risks. Engagement and partnerships must be inclusive, accessible, and empower all people—particularly those disproportionately impacted by disasters—to participate in risk reduction efforts. SI plays a critical role in shaping civil society and in the "all-of-society" approach by elevating the needs and rights of those disproportionately impacted by disasters in risk reduction efforts. Additionally, Priority 1 of the Sendai Framework (Understanding Risk), directs governments to develop policies and practices for disaster risk management based on all dimensions of vulnerability (including socioeconomic vulnerability).

ALIGNMENT WITH INTERNATIONAL, NATIONAL, AND REGIONAL FRAMEWORKS

UN SUSTAINABLE DEVELOPMENT GOALS

Nearly all of the Sustainable Development Goals are relevant to the type of work performed by SIOs, including but not limited to the eradication of poverty, inequity,

[ii] *Principle "d" in the Sendai Framework: "Disaster risk reduction requires an all-of-society engagement and partnership. It also requires empowerment and inclusive, accessible and non-discriminatory participation, paying special attention to people disproportionately affected by disasters, especially the poorest. A gender, age, disability and cultural perspective should be integrated in all policies and practices, and women and youth leadership should be promoted. In this context, special attention should be paid to the improvement of organized voluntary work of citizens."*

[iii] *Principle "f" in the Sendai Framework: "While the enabling, guiding and coordinating role of national and federal State Governments remain essential, it is necessary to empower local authorities and local communities to reduce disaster risk, including through resources, incentives and decision-making responsibilities, as appropriate."*

[iv] *Principle "i" in the Sendai Framework: "While the drivers of disaster risk may be local, national, regional or global in scope, disaster risks have local and specific characteristics that must be understood for the determination of measures to reduce disaster risk."*

food insecurity, and improvement of health and wellbeing, sustainability, and climate action. Most if not all of these goals are addressed by various SIOs. Moreover, goals 9 and 11 have more direct implications for the physical spaces through which SIOs operate. Goal 9 calls for governments to "build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation," again demonstrating a focus on "traditional infrastructure" like transportation networks, power, and more. Yet, goal 11 recommends that governments "make cities and human settlements inclusive, safe, resilient and sustainable." While this section primarily describes the built environment of communities, including public transportation and public spaces, it also articulates the critical role of civil society and non-governmental organizations.

Increasingly, institutions and networks are recommending the integration of sustainable development goals and the Sendai Framework to holistically address risk and resilience in all of its dimensions and bolster the role of civil society or SIOs. Concurrently, "governments are beginning to recognize the value of social infrastructure—both from a pragmatic economic investment standpoint reducing health care, incarceration and demographic-ageing expenditure, and as a way of promoting a peaceful and democratic society amid increasing civil unrest."[5] Still, there is a need for a more direct focus on the physical spaces and facilities of SI because SIOs struggle to access adequate investment for this purpose.

> Smaller, locally based SIOs that have [deep-rooted] relationships in community are often left out of formal response and recovery efforts.

NATIONAL POLICY AND INVESTMENT

In the Government of Canada's *Investing in Canada* plan, SI was a key funding stream (including "investments in Indigenous communities, early learning and childcare, affordable housing, home care, and cultural and recreational infrastructure").[6] The federal government also launched the Canada Community Revitalization Fund (CCRF), a two-year, $500-million national infrastructure program providing project funding to community infrastructure projects.[7] While these funding streams are an encouraging trend, the sector has been chronically underfunded for decades, leaving major lag time in these investments' ability to producing measurable results in the strength and vitality of the sector. In addition to inadequate day-to-day funding, there is also a lack of appropriate funding and resourcing for SIOs within the disaster risk reduction sector. Funding streams to address long-term and operational funding for organizations is inadequate in the face of the expenses accrued by SIOs during disaster response and recovery. At present, only a small handful of grants are offered by philanthropic agencies and local governments to support SIOs to participate in disaster risk reduction, emergency management, and climate adaptation.

PROVINCIAL EMERGENCY MANAGEMENT POLICY AND INVESTMENT

SI is not currently a focus of existing provincial emergency management legislation. BC's *Emergency Program Act* (EPA), passed in 1993, provides the legislative framework for the management of disasters and emergencies in BC. The Province is currently updating the legislation (EPA Modernization)[8] and the proposed changes consider the role of volunteers, non-governmental organizations, and service providers. Existing agreements exist between large non-profit organizations like the Red Cross and Salvation Army. While these organizations play a crucial role in response and recovery, they typically mobilize and establish themselves within disaster-impacted communities at the onset of an emergency but are not necessarily grounded in these communities to provide regular services prior to the event. As a result, they seldom have deep-rooted relationships with local communities. Smaller, locally based SIOs that have these relationships in community are often left out of formal response and recovery efforts. Trust and relationships are critical both in reaching disaster-affected community members quickly in critical moments and addressing the needs of communities who are left out of formal response and recovery planning. While legislation plays a directive function that cannot be applied to an independent sector like SI, formal acknowledgement of the importance of place-based and embedded SIOs and their facilities could serve to promote engagement between disaster management professionals and the SI sector.

SOCIAL INFRASTRUCTURE IN DISASTER RISK REDUCTION

SOCIAL RESILIENCE AND SOCIAL VULNERABILITY

A core benefit of SI is that it plays a crucial role in risk reduction at the local level by decreasing individual and community vulnerabilities and building collective capacities and actions. Largely, technocratic approaches to Emergency Management, Disaster Risk Reduction, and Climate Adaptation focus on addressing physical exposure to hazards and physical vulnerabilities. Social vulnerability is often left out of formal Disaster Risk Reduction programs, projects, and policies, even though vulnerability underpins disaster impacts.

SI builds community resilience strengthening social capital and social cohesion, and it supports more inclusive and sustainable economic development—which is important for minimizing a community's vulnerabilities to the negative impacts of a disaster and strengthening capacities for recovery and reconstruction.[v,9,10] Local leaders and professionals increasingly appreciate the role of spaces along with social capital networks in community resilience. In reviewing the research literature on community resilience, "there has been little coordinated effort to address the complex interactions between physical, social, and economic infrastructure that enable community resilience. Instead, most studies have focused on a single hazard (often earthquakes) or specific infrastructure (e.g., health care facilities)."[11] Practitioners should focus on the ways that communities build social cohesion and address ongoing social and economic stresses in order to minimize vulnerabilities to the impacts of disasters.[12]

SIOs play a crucial role in fostering the conditions that support resilience. In many cases, SIOs form to fill gaps in government services and assist people who are systemically excluded from formal government supports. While a majority of SIOs provide direct services, they also act as advocates and conveners between government and equity-denied communities, leading to direct improvements and access to governmental services. This role of SI in addressing root causes of vulnerability and advocating for the rights and wellbeing of equity-denied and systemically marginalized communities is irreplaceable. To reduce risk and build resilience, practitioners must connect directly to work that is reducing socioeconomic vulnerability and ultimately advancing justice. SIOs are an important partner in this work. The disaster and emergency management field does not leverage the full potential of SI to contribute to more holistic and comprehensive risk assessments and risk management.

While a majority of SIOs provide direct services, they also act as advocates and conveners between government and equity-denied communities, leading to direct improvements and access to governmental services.

UNDERSTANDING AND ASSESSING RISK

Historically, risk assessments have been conducted primarily by state-defined experts and professionals, with little community involvement, and are presented as relatively objective truth. Defining and assessing risk is a process that is laden with emotion, bias, and value judgement, regardless of whether the

[v] SI allows people to come together and interact, and this is important for building social connectedness and social capital. Klinenberg (2018) draws on many other scholars to describe this connection to social capital. Latham and Layton (2019) outline the relevant literature on public space, social interactions, and SI. Aldrich and Meyer make the case for the importance of social capital networks for communities in disaster response and recovery.

NEIGHBOURHOOD HOUSES, SOCIAL CONNECTION AND COMMUNITY BUILDING

Figure 1: Neighbours attend a Resilience Walk during Emergency Preparedness Week in 2019, starting at the Mount Pleasant Neighbourhood House (Photo: Neighbour Lab).

Neighbourhood houses (NHs) focus on building community, are place-based and open to anyone, and offer many programs, services, and activities for a range of target groups (children, youth, seniors, adults, newcomers, and more). In their multi-year survey and research of NHs in Metro Vancouver, Lauer and Yan found that NHs contribute to two key aspects of community building in a neighbourhood: the development and maintenance of relationships and friendships, and the development of social capacity, which they define as the "ability to work with others to achieve shared goals." While NHs organize activities in schools, libraries, community centres and parks, their own facilities are crucial to enable their community-building role (Figure 1). NHs are found in Canada, the United Kingdom, the United States, Australia, and other places, but they are each unique as they serve the needs of local communities.

person conducting the assessment is a formal expert or a member of the public.[13] Those who define risk also determine the focus of risk reduction actions.[14] As an example, extreme heat response has historically focused on outdoor interventions like spray parks, or indoor interventions like centralized and public cooling centres. These interventions are critical but leave out socially isolated seniors and people with complex health conditions who may not be able to leave their homes to reach this supportive infrastructure. Involving SIOs in risk assessments early on allows them to inform practitioners about the specific needs of the community they serve and to guide disaster management practitioners in coming up with interventions that will best serve those who are the most vulnerable.

In addition, SI sometimes plays a direct role in reducing social vulnerabilities. Social vulnerability is a core component of hazard, risk, and vulnerability assessments, but it is often misunderstood and distilled into reductionist individual characteristics. Many practitioners in emergency management, disaster risk reduction and climate adaptation use social vulnerability indices as the primary mechanism for understanding social vulnerability. Many such indices build on the pioneering work of Susan Cutter and colleagues, who developed place-based, local-level models for measuring social vulnerability and community resilience.[15] Within these indices, which are typically based on census data, characteristics like age, gender, economic status, education, and more are used as proxies for social vulnerability so that they can be used comparatively across communities. However, indicators used in these indices do not accentuate the underlying systems at the root of social vulnerability.

Social vulnerability, at its core, is determined by systems of power—who holds power and resources, and who does not. People who face systemic oppression, exclusion, and marginalization receive labels of vulnerability based on demographic characteristics. Yet demographic characteristics are not an inherent vulnerability (e.g., being a racialized person is not a vulnerability—being a racialized person and living in a racist society is the vulnerability.)

> Social vulnerability, at its core, is determined by systems of power . . . People who face systemic oppression, exclusion, and marginalization receive labels of vulnerability based on demographic characteristics. Yet demographic characteristics are not an inherent vulnerability.

Another challenge with commonly used social vulnerability methodologies is that they do not illustrate whether people have access or proximity to community assets in their neighbourhood (organizations and facilities for social services and activities) that they can turn to for information, basic needs, and collective action during emergencies. Moreover, to date, most social vulnerability indices have not captured bonding, bridging, and linking social capital—which support adaptive capacity.[16] Reducing disaster risk and building resilience is contingent on policies, programs, and processes that address the root causes of vulnerability, not just response solutions for individual characteristics. Disasters are not just about hazards; they are, at their core, historical and political processes, and practitioners must work with communities to understand socioeconomic conditions and historical drivers of risk in order to identify the best measures to reduce risk. Tools and methodologies for capturing social vulnerability need to become more nuanced to capture not only root causes of vulnerability, but also reflect adaptive capacities so that risk reduction investments can build on strengths and address gaps.

Through the EPA Modernization, local governments are facing an increasing responsibility to conduct hazard, risk, and vulnerability assessments to inform risk reduction efforts. In recent years, federal funding was made available for local government disaster mitigation and climate adaptation efforts, including the National Disaster Mitigation Program, Municipalities for Climate Innovation Program, Disaster Mitigation and Adaptation Fund, First Nation Adapt Program, and the Community Emergency Preparedness Fund. As the obligations, responsibilities, and support for local authorities increases related to climate and disaster risk management and mitigation, they will rely on SI for effective and equitable assessment, planning, and action. This must be acknowledged and reflected in policies, legislation, and resource distribution. Governments are required by law to conduct hazard, risk, and vulnerability assessments (HRVA). Under the existing *Emergency Program Act* there is no direction to develop HRVA using participatory approaches that engage diverse stakeholders, resulting in inconsistent standards, quality, and approaches to assessing risks. At the time of writing this article, the HRVA design and process is under evaluation by Emergency Management BC; the findings and new directions could be included in the EPA Modernization.

This coincides with historical processes in which "climate adaptation and hazard mitigation take a technocratic approach, one that privileges quantitative data above people, and argues for colour-blind risk reduction."[17] Such an approach sidelines equity-denied communities in the shaping of risk narratives and the development of solutions. Communities bear the brunt of risks, despite not having created these risks themselves. SIOs can host and mediate participatory discussions about risk and the co-creation of risk reduction actions that meet the needs of communities.

> Tools and methodologies for capturing social vulnerability need to become more nuanced to capture not only root causes of vulnerability, but also reflect adaptive capacities so that risk reduction investments can build on strengths and address gaps.

Few SIOs have seen or participated in risk assessments for their own geographic areas, or developed continuity plans and long-term resilience strategies. There is increasing focus on the role of volunteer networks and social missions or community-based organizations during emergency response and disaster recovery,[18] and guides and toolkits are available for such organizations to conduct risk assessments and emergency planning and training.[19] However, there is little research on how many social-purpose organizations have completed risk assessments or undertaken resilience planning,[20] or the kinds of plans and measures these organizations adopt and their motivations for them.[21]

While there are no surveys to gather data on this topic from the SI sector in BC, this is a common challenge for organizations in the social sector in many places. They often struggle with short-term project cycle funding, securing core operational or long-term funding, and limited and overburdened staff capacity for current service needs. This makes it challenging for

RESILIENT NEIGHBOURHOODS PROGRAM IN VANCOUVER

In 2017, the City of Vancouver launched the Resilient Neighbourhoods Program, aimed at transforming the way the City and communities collectively build resilience to a range of shocks and stresses. This program focused less strictly on emergencies and emphasized that social networks and relationships matter just as much, if not more, than emergency kits. Ultimately, community resilience is "based on collaborative problem-solving, and built at the speed of trust." This pilot was run in conjunction with the development of the Resilient Vancouver Strategy. From 2017 through 2019, City staff partnered with four (SIOs) in four neighbourhoods that each received a $50,000 grant to participate.

Each partner was encouraged to identify the shocks (acute events) and stresses (chronic challenges) that were of greatest concern to their communities. These ranged from social isolation, the opioid poisoning epidemic, earthquake risk, and racism. Over the course of the pilot, SIOs, community members, and City staff held engagement events, conducted social and physical asset mapping (Figure 2), completed resilience evaluations and conversational hazard, risk, and vulnerability assessments to ground actions in relevant potential disruptions. The pilot culminated in the development of neighbourhood resilience action plans to address both shocks and stresses. From the beginning of the pilot, SPO partners raised the critical need to incorporate anti-racism and equity work, poverty reduction, food security, and social connection into emergency planning efforts. These partners innately understood that addressing disaster risk and resilience required addressing the underlying conditions that result in disproportionate and compounding impacts to communities. Moreover, these SIOs were already working to address these stresses in their day-to-day programming and had deep, trust-based relationships with equity-denied community members (those impacted by power and resource imbalances). While this program paused through the first two years of the COVID-19 pandemic, staff are re-launching the program in 2022 with lessons from the pandemic and 2021 heat dome event incorporated into a revised model.

Figure 2: Community leaders share ideas and identify neighbourhood assets in the Downtown Eastside during the Resilient Neighbourhoods Program Asset Mapping Workshop at 312 Main in 2019 (Photo: City of Vancouver).

them to devote staff and resources to general long-term planning or risk, emergency, and continuity planning. During the COVID-19 pandemic, these challenges were reflected and emphasized in *Imagine Canada*'s advocacy in response to the federal government's approach to emergency aid packages and inadequacies based on the needs of the non-profit and social sector. It included the ability to sustain facilities and operations in its call for a Sector Resilience Grant Program to provide core operating support of the full sector.[22]

ENHANCING PREPAREDNESS, RESPONSE, AND RECOVERY

EMERGENCY RESPONSE

When disasters strike, SIOs and informal groups are often the first to activate to meet community needs well before government agencies have time to mobilize formal response plans. SIOs collect and distribute supplies, mobilize volunteers, offer spaces for people to gather, and more.[23] SIOs, and the staff and volunteers who run them, have unique knowledge, skills, and trusting relationships with community members which allow them to identify and address needs via adaptable and tailored supports, particularly for equity-denied communities and those who are considered to be socially vulnerable.[24] SIOs often addresses major gaps and inequities in existing governmental response frameworks. These organizations are key partners in delivering services in an equitable, timely, and culturally appropriate way.[25]

Governments are required by law to conduct hazard, risk, and vulnerability assessments (HRVA). Under the existing Emergency Program Act there is no direction to develop HRVA using participatory approaches that engage diverse stakeholders, resulting in inconsistent standards, quality, and approaches to assessing risks.

Governments, on the other hand, have formal roles to play in emergency response, but often lack key relationships, or even basic awareness of the location and needs of vulnerable community members. Government response plans and services are often generic and inflexible, meaning they rarely meet the needs of large percentages of the population. In particular, they often fail to meet the needs of those most vulnerable. Standardized programs and support offered by government agencies in many cases do not work for equity-denied groups because they are laden with rigid bureaucratic procedures that slow down or exclude access to services, even further traumatizing disaster victims.[26] Indeed, the "need to stick to consistent procedures can serve to mask unjust actions and excuse the failure to put human rights of survivors first and foremost."[27] SIOs, on the other hand, work in hyper-local and relational ways, making them much more responsive to emerging needs during a disaster.

DISASTER RECOVERY

SIOs also play an important role in long-term disaster recovery by supporting the psychological health of survivors. SI enables people to participate in physical and psychosocial recovery. Community spaces and facilities will always be needed to host support services and community-building activities.[28] People will need places to work together to rebuild the social and economic fabric of society.[29] Still, while disasters strengthen social ties in some cases, they can also sever social networks, particularly when residents are displaced on a large scale. The loss of community ties and social cohesion is traumatizing and can be described as a secondary disaster.[30] Disasters are inherently traumatic experiences, and SI often supports and even facilitates the collective processing of trauma and healing. SIOs are also subject to displacement, but not to the same extent as individuals, which allows these organizations to do what they do best: bring together community members to connect, share, heal, celebrate, and offer ongoing services that meet basic needs.

COVID-19 RESPONSE AND COMMUNITY RESILIENCE

At onset of the COVID-19 pandemic, City of Vancouver staff gathered to begin assessing potential impacts not only of the virus itself, but of some of the unintended consequences of government restrictions. Initial direction for physical distancing triggered widespread closures of businesses, organizations, and community spaces. The closure of these spaces brought forth a secondary disaster, one in which the loss of free meal programs, public washrooms, and other amenities had devastating consequences for equity-denied communities and people already experiencing poverty, loneliness, limited mobility, and reliance on social services. Organizations that kept their facilities open were inundated and overextended.

Figure 3: Residents enjoy a Pop Up Plaza during the summer of 2020 (Photo: City of Vancouver).

To address these gaps, City staff formed a Community Resilience Branch in the Emergency Operations Centre and worked closely with SIOs to identify impacts and needs and also collaborate on solutions and build capacity to meet surging demand. SI played a critical role in delivering services like grocery hampers to low-income residents, preparing and delivering culturally appropriate meals to seniors, setting up outdoor gathering spaces like parklets, increasing access to sanitation and hygiene facilities, staging emergency shelters, providing storage space for personal protective equipment, and disseminating important messaging about health orders and guidance to people without regular or direct access to the internet (Figure 3). None of these actions would have been possible without the knowledge, relationships, and resourcefulness of SIOs.

Another key role of SIOs in the context of recovery is advocacy. Disasters expose and exacerbate our deepest pre-existing inequities, as impacts are not equally distributed among populations and communities. Government-led disaster recovery programs and policies are designed “to compensate for measurable monetary losses, with no real consideration of need, resulting in . . . the perpetuation of existing inequalities.”[31] SIOs are closer to community, both geographically and relationally by way of offering front-line services that require face-to-face interactions. They have experience navigating government and philanthropic grants, and often have relationships with government staff or elected officials. This allows them to use their positional power to advocate for unmet needs in communities. At the same time, SIOs are often subject to the same disaster impacts as the communities they serve. According to the Vantage Point *Unraveling* report on the impact of COVID-19 on non-profits across BC eight months into the pandemic, of the organizations that serve specific populations, those that serve racialized people (61%) and adults (60%) were most likely to be concerned about having to shut down.[32] Recovery support for communities and SI must address these inequities.

POLICIES IN THE MUNICIPAL CONTEXT

To date, at the local level, only two municipalities in Metro Vancouver have recent policies or strategies that focus directly on SI.

The City of Richmond’s *Building Our*

Future: A Social Development Strategy for Richmond[33] includes a strategic direction to "strengthen Richmond's SI," and the city has a Non-Profit Organization (NPO) Replacement and Accommodation Policy. Under this policy, if NPOs are displaced through development, they receive support for a temporary location or replacement space and moving costs, and they have the first right of refusal to return as a tenant in the new development. If the NPO tenant declines to return to the new development, the space is reserved for another NPO acceptable to the City of Richmond.

The City of Vancouver has two strategies that directly link resilience and SI. In 2019, the City of Vancouver approved *Resilient Vancouver*,[34] includes several objectives and actions specifically designed to reframe and transform the role of SI in disaster risk and resilience. These objectives include: "Cultivating community connections, stewardship, and pride through actions like participatory budgeting processes" (1.1); "Empowering communities to support each other during crises and recover from disasters through actions like scaling the Resilient Neighbourhoods Program and training community centre staff to support disaster preparedness" (1.2); and "Strengthening social and cultural assets and services through actions like evaluating the resilience of food assets and meal programs" (1.4). These actions signify a shift away from traditional, individualistic approaches of personal preparedness towards a more collective, socially collaborative approach.

More recently, the City of Vancouver approved its first strategy dedicated exclusively to SI. The city council approved *Spaces to Thrive: Vancouver SI Strategy Policy Framework* in December 2021. *Spaces to Thrive* takes a human rights–based approach that emphasizes addressing the needs of those most disproportionately impacted by shocks and stresses. Directions within the strategy cover a broad range of supportive policies, including: building partnerships and capacity; addressing persistent facility deficits (quality, quantity, and location); prioritizing reconciliation, equity, and resilience in supply; investing in operational funding for the health and vitality of the sector; and optimizing the SI ecosystem to improve resilience and adapt to pressures from climate change and disasters.[35]

> Government agencies can improve resilience outcomes for communities by funding and supporting comprehensive packages for SI that recognize the importance of the operational costs, staff, facilities, and physical assets that make services, programs, and social connections possible.

OPPORTUNITY

RECOMMENDATIONS

Many meaningful actions can be taken to support SI in its role contributing to community resilience and disaster risk reduction. These are presented under two key ideas, one that supports and strengthens the ongoing work of SI in communities and another that specifically identifies opportunities to integrate SI into the work of disaster risk reduction.

FUNDING FOR STABILITY, LONG-RANGE PLANNING, AND ADAPTATION

Government agencies can improve resilience outcomes for communities by funding and supporting comprehensive packages for SI that recognize the importance of the operational costs, staff, facilities, and physical assets that make services, programs, and social connections possible.

Core funding and operational grants: Many organizations have called for changes to existing philanthropic models that largely offer project-based or innovation funding. Organizations require longer-term operational grants to maintain their core programs and services and conduct long-term planning. Many SIOs are continually creating new programs to qualify for grants, while struggling to fund their existing and impactful work. An ongoing lack of operational funding prevents organizations from planning for long-term administrative costs and creates instability in programming, staffing, and even facility maintenance.

Contingency funds and flexible funding during emergencies: A dominant misrepresentation of overhead costs as excessive and unnecessary for social purpose organizations contributes to the problem of insufficient operational funding and a lack of contingency funds for these organizations. Availability of operational funding and contingency funds would allow organizations to adequately pay staff, resource ongoing programming appropriately, and proactively plan and respond to emergencies. During the pandemic, many government and philanthropic funders notified SIOs quickly that their funding would be flexible. This allowed organizations to keep their staff and adapt their programs and service delivery methods during the pandemic emergency. This lesson should inform standard approaches for flexible funding through emergencies in the future.

Capital funds and real estate tenure: In cities in BC and across Canada, sharply increasing real estate prices, property tax values, and redevelopment pressures are creating insecurity and displacement pressures for organizations owning or renting properties for social purposes. The pandemic compounded these pressures. The SPRE Collaborative's 2021 survey of the BC social purpose sector found that lack of affordable space, suitable space, and declining tenure and long-term security in terms of ownership and leasing of space are the biggest challenges the sector faces, and these challenges directly affect the quality or extent of programs and services offered.[36] Mechanisms are needed to help these organizations stay close to the people they serve.

Capital funds for resilience and adaptation: At a practical level, SI spaces are a collective investment in resilient and protective facilities and services for communities. A significant number of residential buildings in BC are not designed beyond life-safety code for earthquakes, are built in flood plains, have limited air filtration for pollutants and wildfire smoke, and are not designed for thermal safety in heat waves. As climate change increases the frequency and severity of extreme weather (like the heat dome of 2021) and BC faces persistent and significant earthquake risk, investments in SIOs offers a temporary stop-gap. SIOs need capital funding to upgrade and replace aging facilities and construct flexible-use spaces that can accommodate emergency response activities like shelters or mass feeding.

SI AS KEY PARTNER IN DISASTER RISK REDUCTION

Support for the SI sector should receive serious consideration in the modernization of BC's EPA legislation and should be considered in the renewal of Canada's *National Strategy for Critical Infrastructure* (2021–2023).[37] There should be more connections among the disaster risk and emergency management fields, the social sector, and communities. Communities and municipalities rely heavily on SIOs during disasters, and local authorities should be encouraged to seek out partnerships with SIOs in advance of disasters. There should also be clear pathways of government funding and compensation for SIOs that take on response and recovery roles.

Liability considerations for the role of SI during emergencies: Current documents on the BC EPA modernization process include consideration of civil liability protection for registered and convergent volunteers during emergencies. This could include protection from undue liability for service providers using their facilities for emergency response activities, even those that do not have a mission to engage in emergency response but that step in to fill a need in their neighborhood.

Insurance and financial backstops: SI owners and operators need accessible and reasonably affordable insurance products and services, and regulations to ensure that they do not encounter excessive cost increases, exclusions, or complete denial of insurance coverage or renewal during emergencies and disasters, as many have during the pandemic.

Incorporating SI into hazard, risk, and vulnerability assessment (HRVA) processes and comprehensive recovery plans: SIOs must be included as partners in shaping HRVAs. They are essential for developing comprehensive and relevant hazard, risk, vulnerability, and capability assessments and in supporting participatory processes that involve civil society and diverse communities. This requires a fundamental shift in what type of knowledge we elevate, and a willingness to see non-traditional and non-technical knowledge as valuable expertise. It also requires appropriate resources for SIOs to have the capacity to participate in these processes.

Communication, coordination, and collaboration in emergencies: Emergency situations involve rapidly changing conditions, logistics, required provisions, and available supports, so SIOs need to receive information and resources in a timely manner as they decide how to adapt their services and support residents. Emergencies also necessitate quick and flexible collaboration, and, often, staff of local government and philanthropic grant-making institutions will play an informal coordinating role to help SIOs and community leaders connect with each other, share resources, or identify gaps in services that need to be filled. For a lasting and supportive relationship between local authorities and SIOs, it is necessary for local authorities to ensure clear and effective support for SI across all municipal departments during emergencies. For example, though social policy departments tend to have the most direct engagement and relationships with community partners, SIOs and smaller community groups may need permits for new or temporary facilities or activities, or may need to use municipal-owned property. For this, they must deal with building permit departments that may have a different understanding of how or whether the local government should support community groups.

Governance and decision-making mechanisms for local SI networks are also important. A general lack of coordination, formal roles, and decision-making frameworks to allocate resources and aid in disasters abounds, but should be established to ensure that key emergency response services such as food provision are provided without interruption, and that appropriate facilities are kept available for use, whether by their normal operators or other operators that can step in during emergency contexts.

THE CHALLENGE

Practitioners in the fields of disaster risk reduction and resilience increasingly recognize that preventing, responding to, and recovering from disasters is not only predicated on our physical environment, but equally contingent on the strength, flexibility, and equity of our social and economic systems. To address disaster risk in all its complexity and dimensions, we need to see the social dimensions of disasters as equally valid and equally ripe for risk reduction action. The stresses that erode community resilience on a continual basis are just as critical to address as the shocks that cause acute disruptions. The challenge often seems to be that practitioners do not quite know how to do this—but social infrastructure can help. Involving social infrastructure in comprehensive disaster risk reduction efforts is a crucial step in achieving a whole-of-society approach, extending both the breadth of potential disaster risk reduction actions and the depth of these actions. Building relationships and investing in these social-purpose places opens up new knowledge, new potential plans, and new interventions to ensure that community needs are centred in immediate and long-term disaster risk reduction work.

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2. An introduction to the concept of social infrastructure and cases and evidence of how SIOs and their physical spaces strengthen social connections in communities, reduce vulnerability to disasters, and play a role during emergencies:

Klinenberg, Eric. *Palaces for the People: How SI Can Help Fight Inequality, Polarization, and the Decline of Civic Life*. New York: Penguin Random House, 2018.

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Photo: Lizz Koebel-Davidson

2.3 RISK AND RESILIENCE APPROACHES IN ELECTRICAL INFRASTRUCTURE

June 2022

DRRPathways.ca

RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 2 Climate and Disaster Risk Management: Practice*. To read all articles in the report, see DRRPathways.ca.

The Resilience Pathways Report is a project of Natural Resources Canada.

2.3 RISK AND RESILIENCE APPROACHES IN ELECTRICAL INFRASTRUCTURE

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ABOUT ELECTRICAL INFRASTRUCTURE AND UTILITIES

OVERVIEW

The generation, transmission, and distribution of electricity within BC is under the jurisdiction of the Ministry of Energy, Mines and Low Carbon Innovation. The electrical system extends beyond the provincial boundaries and is part of a larger power grid known as the Western Interconnection. BC's utilities collaborate with reliability bodies, including North American Electric Reliability Corporation (NERC), Western Electricity Coordinating Council (WECC), and Western Interstate Energy Board.

Utilities are regulated by the British Columbia Utilities Commission (BCUC) under the *Utilities Commission Act*. BCUC's mandate is to balance the interest of the consumer and the utility companies.

In BC, there are two major utilities supplying electricity: British Columbia Hydro Power and Authority (BC Hydro) and FortisBC Inc. There are also five BC municipalities that have their own utilities: City of Nelson, City of New Westminster, City of Grand Forks, City of Penticton, and District of Summerland. These municipal utilities sell electricity directly to their customers. FortisBC is a Canadian-owned, BC-based company servicing customers in the Southern Interior region. BC Hydro is a provincial Crown corporation, owned by the government and the people of BC. BC Hydro services 95% of the province's population. The Lieutenant-Governor in Council appoints the board of directors for BC Hydro and they are responsible for overseeing BC Hydro's affairs. The day-to-day management is delegated to BC Hydro's president and CEO.

BC has some of the cleanest grid-supplied electricity through generating power from hydroelectric dams. Electricity will continue to play a critical role in helping the BC Government move towards its commitment of reducing greenhouse gas emissions to 40% from 2007 levels by 2030. As a result, grid resilience and secure supply of electricity will be important to the functioning of society.

This article is a high-level overview of hazards, threats, vulnerabilities, and risks from a generic electrical utility perspective, but in order to clarify the concepts it uses examples from BC Hydro, which is the main utility in BC. Since the electricity in BC is largely generated by hydroelectric power, the electrical grid is dependent on understanding the trends in climate and hydrology at the generation level. The bulk electrical system is responsible for bringing electricity to the end-use customer. The end user not only includes residential, commercial, and industrial customers, but also neighbouring utilities to the east and south who are part of the Western Interconnection.

In today's world, where modern technologies are integrated with legacy technologies and where there is more and more reliance on remote monitoring and control, a secure telecommunication system becomes one of the important elements for a utility and the operation of its power electrical system; the power electrical system relies on a robust and secure telecommunication system designed to ensure continuity of its operation.

In the event of any catastrophic incidents, the electrical system will be a vital resource for minimizing the cascading impacts of a disaster and will be critical for providing support for emergency services, aiding in recovery, and rebuilding the province.

ALIGNMENT WITH THE SENDAI FRAMEWORK

The resilience of the utility system is directly related to (18) Target (d) of the Sendai Framework for Disaster Risk Reduction and is critical for achieving Targets (a), (b), (c), and (g).

In the Sendai Framework, item 18 (d) states: "Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030."[1]

IMPACT OF PAST HAZARD THREATS ON ELECTRICAL INFRASTRUCTURE

Electrical outages occur all year round and the causes include motor vehicle accidents, animal and tree contacts, obstructions in the wires, equipment failure, sabotage, theft, and extreme weather events. During outages, electrical service is restored by both field work and system control work. Electrical utilities have some contingencies built into the system design to ensure that as many customers are restored as quickly as possible, thus minimizing outage duration and overall disruption to customers and businesses.

Residential, commercial, and industrial customers are largely serviced by the distribution infrastructure. Distribution infrastructure includes the poles and wires that are along the highway, streets, and, in some cases, along the hillsides. These poles and wires are known as the overhead system. The overhead system is the most susceptible to weather-related hazards. Other distribution infrastructure is in underground facilities and not visible, or is placed on the sea floor. Underground infrastructure can be damaged by flooding, landslides, ground shaking, liquefaction caused by ground shaking (from an earthquake), or even improper construction methods.

Larger than the distribution system is the transmission system, which can also be damaged during storm events. If the transmission system is affected, the impact is greater since the transmission system feeds the distribution system and several very large industrial customers. To restore power to the most customers as soon as possible, alternate circuits may need to be used (where such a contingency in the system exists) and large customers could be asked to reduce their consumption or areas will need to remain out of service, resulting in a reduction of supply service.

Every year, electrical utilities prepare for winter storm season, which usually occurs from fall to spring. Wildfire season starts March 1, overlapping the winter storm season. The primary hazards resulting in outages are from windstorms, severe rain events, ice storms, and wildfires. Other hazards affecting the electrical system include avalanches, tsunamis, severe temperatures, drought, landslides, extreme inflow events, floods, and earthquakes. The demand created by high temperatures is also a factor affecting electrical service. BC's climate risk assessments evaluated the likelihood of 15 climate risk events that could occur. The greatest risks identified were wildfire, water shortage, heat wave, ocean acidification, glacier loss, river flooding, and coastal storm surge.[2]

ICE STORMS

In December 2017, Fraser Valley East had two ice storms that resulted in outages to more than 162,000

Figure 1: Ice buildup on electrical infrastructure (Photo: BC Hydro).

customers. The ice storm made conditions dangerous—icy roads, poor visibility, and fallen trees. Crews had to repair and replace equipment in the substations from the ice buildup (Figure 1).

WILDFIRES

Every year during the summer months, electrical utilities prepare to address damage from wildfires and need to assess wildfire risk when working in dry areas. Everyone in BC is required to follow the *Wildfire Act* and *Wildfire Regulation*. The legislation specifies responsibilities and obligations on fire use, wildfire prevention, wildfire control, and rehabilitation. BC Hydro and BC Wildfire Service have agreements in place where BC Hydro is exempt from regulation 6 (3) (a) *High risk activities within 300 m of forest land or grass land* if the restoration work is deemed as a "trouble call," on the condition that fire suppression equipment and a fire watcher is maintained. Trouble calls, most of which are reported outages, are identified, assessed, and dispatched for repairs by BC Hydro's Restoration Centre. The Fire Risk Management Team develops, maintains, and implements fire safety standards and resources to ensure those working in wildfire risk areas are working safely.

From 2008 to 2016, BC had an average of 1,700 wildfires each year affecting roughly 165,000 hectares of land.[3] However, beginning on July 7, 2017, BC experienced one of its worse wildfires: 1.2 million hectares were on fire and more than 65,000 people needed to leave their homes.[4] The winter preceding the 2017 wildfire season was wet and cold. In early May of 2017, Southern BC was dealing with flood conditions in Kelowna, Cache Creek, and Salmon Arm. The wet spring resulted in fertile growth throughout the province, but with no rain in June, the new growth became dry and fuel for a wildfire. The trend is that wildfires are increasing each year in numbers and severity. The following year in 2018 saw 1.35 million hectares affected by wildfires. In 2021, a provincial state of emergency was declared. The Village of Lytton burned, destroying the town. Even a large community like the City of Vernon was put on evacuation alert.

WINDSTORMS

In December 2018, the BC's South Coast (BC Hydro territory) experienced one of its worst windstorms. There were several factors that contributed to this large outage. The windstorm came after several heavy rain events; some areas experienced more than 400 mm of rainfall. As a result of over a week's worth of heavy rain, the soil in some areas was completely saturated, exposing roots and making tress with shallow roots more vulnerable. The wind also came from an atypical direction, and wind speed ranged from 85 km/h to as high as 144 km/h. Over 750,000 customers were without power (400,000 customers in the Lower Mainland and Fraser Valley and 350,000 on Vancouver Island and Gulf Islands). BC Hydro mobilized over 900 field workers, including those from other parts of the province and contractor crews from other provinces. Within 24 hours, power was restored to over 550,000 customers. The windstorm resulted in significant equipment damage (Figure 2) as well as vegetation destruction.[5]

HEAT

In late June 2021, BC experienced extreme record-breaking temperatures. Although there were only localized outages, BC Hydro confirmed a new summer peak load of over 8,300 MW. BC Hydro is a winter-peaking utility, and the new record summer peak identified that the need for cooling (requiring electricity to run cooling appliances) may change the utility's load profile.

On July 8, 2021, BC Hydro detected a bulge and oil leak in one of its submarine cables. It was suspected that the cause of the damage was due to the extreme heat. The cause remains under investigation.[6] Heat, with increased cooling loads, on overhead circuits, will result in the wires sagging. The sag can result in two circuits inadvertently touching, causing outages or power surges. The sag can also result in reducing the safe distance between people and equipment.

Repairing damage in the heat is a concern for crews; the work needs to be completed safely for both the public and the worker.

Figure 2: Fallen trees and poles during 2018 windstorm (Photos: BC Hydro).

Figure 3: Electrical infrastructure in the Sumas Prairie during November 2021 flood (Photo: Lizz Koebel-Davidson).

FLOODS

In November 2021, strong winds and heavy rainfall came in the form of an atmospheric river, caused floods and mudslides, resulting in outages to over 219,000 customers in parts of the Lower Mainland, Vancouver Island and Interior. Access to dam sites and damaged areas was at times difficult or not possible due to flooding (Figure 3).

Heavy rain also affects the reservoir levels and increased inflows in the local rivers. BC Hydro's Emergency Operations Centres engaged provincial and local agencies to provide regular updates on current and forecasted reservoir levels and dam outflows. In the storm of November 2021, flood alerts were made to Wahleach (near Hope), Alouette (near Maple Ridge), and Daisy Lake – Cheakamus (near Squamish) reservoirs.

With the increase in temperature and precipitation from climate change, there will be an increase in riverine flooding due to the higher flows.

These higher flows put transmission river crossings at risk from the damage caused to tower foundations by changing currents and debris. The lower Fraser River and the Skeena River have been impacted by the flows from spring freshets. During the 2011 freshet, BC Hydro spent $25 million repairing transmission infrastructure.

UNDERSTANDING AND REDUCING RISK

All outage events, including planned outages, are documented and tracked. The information tracked includes asset damage and extent of the outage. This information, along with scheduled maintenance inspections, is used to identify the performance of the circuits and provide reliability statistics. Maintenance inspections include overview inspections, detailed inspections, climbing or bucket inspections, vegetation patrols, infrared scanning, switch inspections, test-and-treat inspections, ground corrosion inspections, access inspections, and ad hoc inspections. The asset management aligns with ISO 55001, an industry asset management specification where the goal is to maximize the value of the physical asset over the entire life cycle of the equipment. The risk and performance of the asset are measured by looking at safety, reliability, revenue, cost, and environmental and social performance. Utilities use asset management processes, methodology and tools to ensure the system performs optimally.

EMERGENCY PLANNING PRACTICE AND CAPABILITIES (RESPONSE, PREPAREDNESS, SHORT-TERM RECOVERY)

Electrical infrastructure is a critical resource during emergencies. To ensure the safety of the public and workers, the system must be safeguarded with risk-prioritized security solutions, and operations must be prepared with well-practiced emergency response plans to support reliable and resilient infrastructure.

BC Hydro's Emergency Management Program is based on emergency response best practices such as CSA-Z1600 and meets the requirements of the provincial *Emergency Program Act* and the *Water Users' Communities Act*.[7] The program follows the resilience cycle (Figure 4) and is part of a safety framework that aligns safety processes, programs, and responsibilities of the company.

A dedicated Emergency Management Team supports, integrates, and delivers the Emergency Management Program. The team supports the development of emergency plans that identify risks and outline actions. These plans are validated through drills and exercises and improved with regular plan reviews and after-incident reviews. The team works with all business units throughout the organization, sharing learnings between groups as needed.

During larger emergency events, an Emergency Operation Centre (EOC) is activated to support response and recovery. An EOC is a central command and control facility for carrying out emergency management and ensuring continuity of operation. BC Hydro's EOC is scalable and flexible to adjust to the needs of the emergency. The role of the EOC

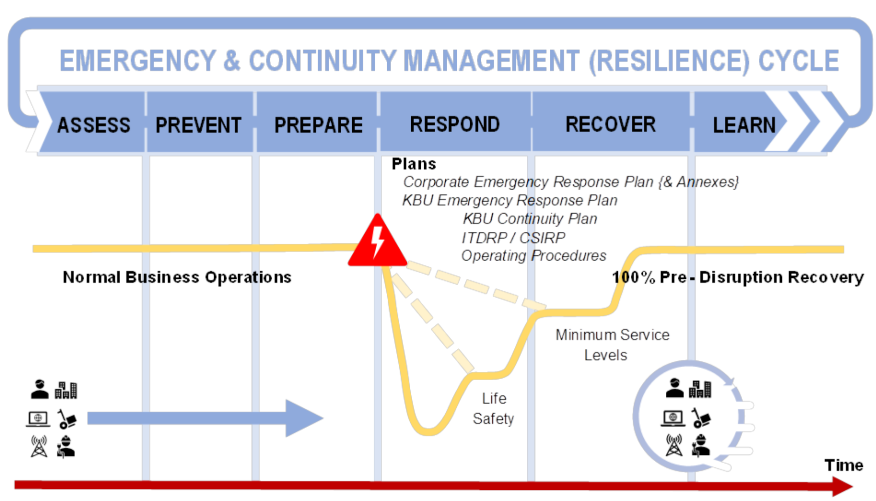

Figure 4: Emergency management resilience cycle (Graphic: BC Hydro).

Table 1: Organizations and industries involved in electrical infrastructure

Organization	Type of Organization	Legal Mandate	Role
Attorney General	Provincial government	Emergency Program Management Regulation	Coordinates government response to specific hazard event of power outage
BC Hydro	Provincial Crown corporation	Clean Energy Act	Restores electrical facilities; interrupts hydro service when threat to life or property is posed; operates and monitors its own dams safely
British Columbia Utilities Commission (BCUC)	Provincial regulator	Utilities Commission Act	Adopts reliability standards
North American Electric Reliability Corporation	Not-for-profit international self-regulation authority	US Federal Energy Regulatory Commission and Canadian governmental authorities	Enforces reliability standards
WorkSafe BC	Provincial regulator for occupational health and safety	Workers Compensation Act	Sets emergency response requirements
Canadian Dam Association	Owners, operators, regulators, consultants and suppliers interested in dams and reservoirs	Water Sustainability Act, Dam Safety Regulation	Exchanges ideas and experience in the field of dam safety, public safety, and protection of the environment
Canadian Standards Association	Accredited national standards association	Adopted as national electrical code	Designs the basis and requirements for overhead and underground line designs; National Electrical Code and equipment specifications
Ministry of Energy, Natural Resources Canada	Federal government	Interprovincial governance	Regulates the international movement of energy and energy goods; develops policies in the national interest
Institute of Electrical and Electronic Engineers Standards Association (US)	Accredited international standards association	Internationally recognized standards association	Provides global electrical system standards and equipment standards
International Electrotechnical Commission	Accredited international standards association	Internationally recognized standards association	Provides global electrical system standards and equipment standards

is to provide a strategic oversight from a central location to ensure that communication, reporting, and coordination tasks are streamlined. EOC staff are senior managers and subject matter experts that are scheduled as needed to support effective coordination internally and externally. The EOC's support increases situational awareness through coordination calls and technology, and deliverables include reporting internally and sharing information externally as needed. In addition to internal dam and power system information, the EOC accesses provincial and municipal information to ensure the awareness of risks and supports decisions to be made at the appropriate level in the organization. BC Hydro also has mutual aid agreements and logistics with the third parties, including other utilities and agencies, in the event that a situation overwhelms BC Hydro and external help is needed (Table 1).

LONG-TERM RESILIENCE PLANNING PRACTICE AND CAPABILITIES

Severe storm and heat events have happened every year since 2017 and are expected to increase in frequency due to the changing climate. The Emergency Management Program addresses current incidents, but long-term resilience planning is needed to prevent or better adapt to future events.

BC Hydro identifies climate change as an external risk. The failure to mitigate or adapt to the changing climate will result in damage to the electrical infrastructure and impact the reliability of the electrical system. BC Hydro created a Climate Change Steering Committee consisting of stakeholders across the company to provide oversight and coordination on BC Hydro's climate change adaptation process and ongoing work.[8]

Utility asset management recognizes that long-term resilience planning will rely on other methods beyond robust preventative maintenance programs—such as being ready for increased electrification, expanding existing tools, adding new technologies, incorporating non-wired alternatives, and collaborating with other parties.

MAINTENANCE PROGRAMS

There are tools used by the Asset Management Team that develop knowledge to ensure the resilience of long-term investments. Data is extracted from the preventative maintenance program, including schedules and reports. As part of the condition assessments, the degrees of inspections vary from visuals from the ground to more detailed inspections and infrared testing. Damaged equipment can also be sent for failure analysis and further study.

INCREASED ELECTRIFICATION NEEDS

For long-term resilience, electrical system planners create models from load forecasts as a driver for system reinforcements. The Future Grid Roadmap, currently in development, includes the modification of standards to integrate contemporary climate data. The Emergency Management Program addresses near-term disasters but will also provide learnings for long-term resilience.

> Electrical utilities will need to develop scenarios to acknowledge the range of uncertainty from the new realities of climate change, evolving customer needs (such as transportation), and technology advancement.

Electricity supplies only 20% of BC's energy needs. To meet the BC Government's greenhouse gas emission reduction goals for 2030, the switch from fossil fuels to electricity will be key. The success of long-term resilience planning for the electrical system is a priority for the electrical utilities. The 2021 *Integrated Resource Plan for BC Hydro* (BCH IRP)[9] includes initiatives advanced by the provincial government, such as CleanBC. The BCH IRP identifies and explains how Reconciliation with Indigenous Peoples, climate action, evolving customer needs, changing electricity consumption, and technology advancement are modifying how electrical utilities do business. Electrical utilities will need to develop scenarios to acknowledge the range of uncertainty from the new realities of climate change, evolving customer needs (such as transportation), and technology advancement. In the next five years, BC Hydro will be implementing its *Electrification Plan*[10] to increase low-carbon electrification. The *Electrification Plan* is expected to increase electrical load and decrease greenhouse gas emissions.

EXPANDING EXISTING TOOLS

There are existing tools used for design or operation that can also be used for long-term resilience planning. Designers and engineers use geographic information systems (GIS) to observe or modify the electrical system. To better inform the designer, GIS can include climate data, erosion data, and land stability information. Additional information should be added, such as wildfire fuel loading, spring runoff models, and topology.

NEW TECHNOLOGIES AND NON-WIRED ALTERNATIVES

Newer equipment, such as communicating line monitors, now have data collection and communicating capabilities that are used for fault (disruption to the system) location identification. Communicating line monitors are devices that can detect and report on a fault at the point where they are connected to the system or monitor the system during normal conditions. This information can help improve fault location and average restoration times during trouble instances by narrowing down the location of a fault or helping to predict local system overloads or voltage problems. These automated devices can be utilized to provide information beyond just location and operation for long-term resilience.

To address reliability and resilience, BC Hydro will need to examine and enhance its radial line policy to include non-wired alternatives and new technologies such as increased battery deployment. Radial lines are single-circuit distribution or transmission lines that do not have redundancy—there is no second source of supply. Non-wired alternatives include demand-side management initiatives and customer-sited new technologies.

Technology can assist with long-term resilience. BC Hydro can leverage technologies used in other jurisdictions, such as remote cameras, drones, undergrounding lines, shutting off lines during wildfire risk, and more. But with technology comes cyber security risks; with a strong cyber security system, utilizing some of these smart devices would be beneficial.

EXTERNAL COLLABORATION

BC Hydro has partnered with government, academia, and industry to understand the climate impact to its assets. In 2006, BC Hydro worked with the Province and the University of Victoria to form the Pacific Climate Impacts Consortium (PCIC), which focuses on three main themes: hydrologic impacts, regional climate impacts, and climate analysis and monitoring. The current research agreement with PCIC is for the 2019–2023 period and covers improving hydrological model simulations, investigating new climate models and analysis techniques, improving storm forecasting, and providing training and workshops.[11]

The current research agreement with PCIC is for the 2019–2023 period and covers improving hydrological model simulations, investigating new climate models and analysis techniques, improving storm forecasting, and providing training and workshops.

Utilities are involved with other organizations and communities that can contribute to long-term resilience planning. BC Hydro has a representative in the following working groups and committees: SFU Adapting to Climate Change Program Advisory Committee; Centre for Energy Advancement through Technological Innovation (CEATI) Climate Change Opportunities, Risks and Adaptation Working Group (CCORA); CEATI Transmission Line Design and Extreme Event Mitigation (TODEM), Canadian Standards Association (CSA) Codes and Standards Committee; Canadian Electric Association (CEA Climate Change Adaptation Working Group;

and the Electrical Power Research Institute (EPRI).

Utilities also have strong relationships with all levels of government, which is ideal for collaboration. Communities, especially Indigenous communities, are great partners for smaller microgrids and renewable penetration to ensure remote communities have reliable power.

The distribution infrastructure is typically built adjacent to roads, and being along a road allows for easier access for repairs by the field crews. During emergency events, roads will need to be accessible and drivable; electrical utilities cooperate with the Ministry of Transportation or local municipalities during any catastrophic events.

GAPS

The current best practice uses historical knowledge for weather and geographical information. Modern climate and environmental models should be used and mapped geospatially. Secondary hazards from climate change such as ice accretion, slope stability, and avalanches should be modelled, and these used as part of the preventative maintenance program.

Weather reporting is used to understand how to manage the near-term operations; the current equipment and systems are designed to standards based on historical temperatures. Long-term resilience planning, however, requires understanding more complex weather conditions, such as icing events, and revised thermal ratings based on future extreme conditions.

Using climate data, a vulnerability study should be initiated to understand the condition of the existing infrastructure and how to improve its long-term resilience. The study would identify which areas or regions require strengthening. Addressing the recommendations from the study will require additional resources for field verification, modelling, GIS upgrades, standard revisions, procurement resources, and capital upgrades to the system.

Using climate data, a vulnerability study should be initiated to understand the condition of the existing infrastructure and how to improve its long-term resilience. The study would identify which areas or regions require strengthening.

OPPORTUNITY

RECOMMENDATIONS

The following are recommendations to reduce risk in the sector and to ensure long-term resilience:

- Continue to develop wildfire management and methods to reduce the risk of BC Hydro infrastructure causing wildfires.
- Improve the radial line policy to include changes based on increased electrification and the integration of non-wired alternatives and new technology integration.
- Share information within the utility both in planning and responding to emergencies. Learn best practices from other departments and gather input from each area of expertise.
- Share climate change risks, impacts, adaptation, and mitigation strategies externally with other utilities. Learn from other utilities' best practices and lessons learned. The Emergency Management Team is already a part of a mutual assistance group that collaborates and shares learnings.
- Centralize the risk reduction planning. Hazards and risks do not have municipal or even provincial boundaries.
- Improve local weather and climate data. Continue to improve data collection.
- Streamline changes to allow for increased fuel switching. Work with regulators to make changes easier and beneficial to the end user.

THE CHALLENGE

Utilities are used to being the service provider; this is especially so for a Crown corporation utility. The challenge is to have the utility be the unifying source to solve future problems. If given the latitude to affect change, the utility can be a unifying link between levels of government and government entities, the end user, the community, and emergency responders. The biggest test is the change management—to accept the utility in this role. With many sectors having different rules and regulations, it would be beneficial to streamline the regulations such that there are no barriers to collaboration. The Emergency Management Team already works with 9-1-1 to improve agency-to-agency communication during events, build relationships, appreciate challenges, and identify opportunities. Having a similar type of collaboration with other organizations would be a desired end state.

Given the latitude to affect change, the utility can be a unifying link between levels of government and government entities, the end user, the community, and emergency responders.

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Photo: Province of BC/flickr

2.4 SEISMIC DESIGN OF BUILDINGS FOR FUNCTIONAL RECOVERY

June 2022

DRRPathways.ca

RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 2 Climate and Disaster Risk Management: Practice*. To read all articles in the report, see DRRPathways.ca.

The Resilience Pathways Report is a project of Natural Resources Canada.

2.4 SEISMIC DESIGN OF BUILDINGS FOR FUNCTIONAL RECOVERY

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POST-EARTHQUAKE RECOVERY OF BUILDINGS

OVERVIEW

Prompt post-earthquake recovery of buildings is an integral component of a community's seismic resilience. As defined by EERI, "functional recovery is a post-earthquake state in which capacity is sufficiently maintained or restored to support pre-earthquake functionality."[1] Functional recovery of buildings enables people to return to their homes and facilitates access to other essential functions such as schools, healthcare, and commerce.[2,3] Nevertheless, past earthquakes have highlighted that building performance is generally inadequate to ensure the seismic resilience of communities. After the Kobe earthquake in 1995, roughly 15,000 households (19% of those impacted) relied on temporary housing three years after the earthquake.[4] After the Northridge earthquake in 1994, 33% of the damaged multi-family housing units, approximately 890 buildings, took more than two years to complete repairs.[5,6] One year after the L'Aquila earthquake in 2009, only 4% of 427 buildings surveyed had completed repairs, 29% had ongoing repairs, and the remaining 67% had not yet started repairs (Figure 1).[7]

While modern seismic design codes intend to ensure life-safety in extreme earthquakes, in recent years, planners and policy makers have directed a concentrated research effort to achieve better-than-code seismic performance. Functional recovery—the performance state of a building wherein it maintains or regains the ability to perform its basic intended use—is gaining significant importance.[8] In the US, the National Institute of Standards and Technology (NIST) and the Federal Emergency Management Agency (FEMA) are developing performance objectives in terms of post-earthquake recovery times.[9,10] FEMA P-2082 has also recommended making functional recovery the primary basis for seismic design by assigning target recovery times (ranging from hours to months) to every new building, depending on the building's risk category.[11] Similarly, SPUR (San Francisco Planning and Urban Research) has identified target post-earthquake recovery times for a resilient San Francisco.[12] Despite these efforts, the efficacy of these resilience-based performance objectives is dependent on the availability of tools to assess the post-earthquake recovery time of buildings.

To expedite post-earthquake recovery, design targets in building codes should extend beyond the life-safety performance objective in extreme earthquake events to include resilience-based performance measures. These design targets and related performance measures should describe: 1) the ability to withstand earthquake loads without degradation or loss of function (i.e., robustness); and 2) the ability to regain functionality within a specified timeframe (i.e., rapidity).[13]

This article provides an overview of existing tools to estimate the post-earthquake recovery time of buildings. While the use of these tools presents a great opportunity, the importance of understanding the modelling assumptions and limitations cannot be overstated. These tools primarily serve to assess different structural and non-structural design options to enable the seismic design of buildings for enhanced performance, and to inform building owners of the expected earthquake performance as related to functional recovery. However, the results should not be regarded as hard truths, but rather as data to support effective decision making.

Figure 1 : In 2019 in L'Aquila, Italy, buildings in the historic centre were still undergoing restoration after the 2009 earthquake (Photo: Daniele Gussago/Shutterstock).

> While modern seismic design codes intend to ensure life-safety in extreme earthquakes, in recent years, planners and policy makers have directed a concentrated research effort to achieve better-than-code seismic performance. Functional recovery—the performance state of a building wherein it maintains or regains the ability to perform its basic intended use—is gaining significant importance.

Pathways to the adoption of seismic design guidelines for the functional recovery performance of buildings in British Columbia are also discussed. This includes some commentary on new provisions in the 2020 edition of the National Building Code of Canada[14] related to an enhanced performance objective of "no structural damage" for a subset of all new buildings, for lower-level earthquakes, which is a positive move towards addressing the functional recovery objectives discussed herein.[i]

ALIGNMENT WITH THE SENDAI FRAMEWORK

The Sendai Framework for Disaster Risk Reduction 2015–2030 outlines four priorities for action to prevent new and reduce existing disaster risks: 1) Understanding disaster risk; 2) Strengthening disaster risk governance to manage disaster risk; 3) Investing in disaster reduction for resilience; 4) Enhancing disaster preparedness for effective response, and to "Build Back Better" in recovery, rehabilitation and reconstruction. As previously defined, "functional recovery is a post-earthquake state in which capacity is sufficiently maintained or restored to support pre-earthquake functionality." As such, enabling the seismic design of buildings to achieve functional recovery enables people to return to their homes and facilitates access to other essential functions such as schools, healthcare, and commerce in the aftermath of a damaging earthquake. Designing buildings to achieve functional recovery performance enables disaster risk reduction by minimizing losses in lives, livelihoods, and in the economic, physical, social, cultural, and environmental assets of persons, businesses, and communities, resulting in direct alignment with the Sendai Framework for Disaster Risk Reduction.

EXISTING TOOLS TO ASSESS FUNTIONAL RECOVERY

Until recently, no tools were readily available to estimate the time required for a building that experienced damage in an earthquake to achieve a desired recovery state (e.g., functional recovery). Over the past decade, a growing number of frameworks have been developed to assess the anticipated seismic performance of buildings:

- The FEMA P-58 methodology,[15] a seismic performance assessment tool for individual buildings, translated engineering demand parameters (e.g., storey drifts and floor accelerations) obtained from structural analyses into performance metrics such as casualties, economic loss (repair costs), and repair time.

- The Resilience-based Earthquake Design initiative (REDi)[16] advanced the FEMA P-58 methodology by developing a framework to estimate the downtime of individual buildings to a defined recovery state by aggregating the repair time of damaged components, the delay time to start repairs, the effect of utility disruption, and other "impeding" factors.

- Developed more recently, TREADS[17] is a framework to probabilistically model the post-earthquake recovery of buildings and provide quantitative seismic performance measures, expressed in terms of downtime.

- Similarly, the ATC-138-3 project published a preliminary methodology to assess seismic performance in terms of the probable functional recovery time of individual buildings subjected to a damaging earthquake. The ATC methodology maps component-based damage to system-level operations, and system-level performance to tenant and building level re-occupancy and function.

- Both TREADS and ATC-138-3[18] are extensions to the FEMA P-58 methodology that conceptually implement impeding factor delay estimates as defined in REDi.

FEMA P-58

FEMA P-58 proposed a seismic performance assessment methodology for individual buildings based on the performance-based earthquake engineering framework.[19,20] The methodology employs predefined fragility functions to predict damage states in building components from structural response parameters, such as storey drift and floor acceleration. Consequence functions translate

[i] For brevity, this article focuses primarily on new building design, as enhancing the seismic performance of existing buildings to achieve functional recovery objectives presents further challenges.

these damage states into various performance metrics, such as casualties, repair costs, and repair times. Monte Carlo simulations are used to account for the high degree of uncertainty in the structural response parameters, damage state predictions, and consequence estimates.

While the repair cost estimation procedure employed in the FEMA P-58 methodology is well established, the repair time calculation only estimates the time required to achieve full recovery and does not consider any intermediate recovery states, such as re-occupancy or functional recovery. Two estimates of building repair time are provided: repair time in series (considering repairs in each floor in a building take place sequentially) and repair time in parallel (considering repair in all floors in a building occur simultaneously). The assumed workforce depends only on the building floor area and not on the extent of damage to the building, and the repair sequencing is simplified to consider repairs of only one trade at a time on a floor. While these assumptions do not provide a realistic representation of the building's repair sequencing, the series and parallel repair estimates may serve as lower or upper bounds for the expected repair time to achieve full recovery. More importantly, FEMA P-58 does not account for any possible delays prior to the initiation of repairs, such as contractor mobilization, financing, permitting, or repair design, which can be significant contributors to a building's downtime.[21]

REDi

The REDi guidelines extended the FEMA P-58 methodology and proposed a framework to estimate downtime in individual buildings to a defined recovery state. The developments include an estimate of the impeding factor delays between the occurrence of an earthquake and the start of repairs (e.g., inspection, financing, contractor mobilization, etc.), as well as estimates of utility disruption (e.g., electrical systems, water systems, etc.). The guidelines identify three post-earthquake recovery states: re-occupancy (building is safe enough to occupy), functional recovery (basic building functionality is restored), and full recovery (building is restored to its pre-earthquake condition). To identify the required repairs to achieve the desired recovery state, a repair class is assigned to each component in the building based on its extent of damage.

While the guidelines represent a significant contribution to downtime quantification, there are several limitations, such as conservative re-occupancy criteria, worker allocation, and repair sequencing. The REDi guidelines use the re-occupancy recovery state to determine if a building is safe enough to occupy—if it can be used for shelter. However, the structural and non-structural component recovery criteria suggested to achieve this recovery state seem overly conservative. According to the guidelines, repairs of almost all structural, plumbing, and HVAC components must be completed before a building can be occupied. By contrast, several researchers recommend that sheltering criteria for buildings in a post-disaster setting should consider relaxed habitability standards that allow people to stay in their own homes—even if damaged—after an earthquake, as long as the building does not pose a life-safety risk.[22,23]

To help define the order of repairs to be conducted, the REDi guidelines segregate all non-structural repair activities into groups of repair sequences. The guidelines consider that repair activities begin with the building's structural components and repair progresses only one floor at a time. The non-structural repair commences only after the entire building's structural repairs are complete. In contrast with this assumed approach, after the 1994 Northridge earthquake, contractors often repaired several floors simultaneously and performed elevator and staircase repairs in parallel with structural repairs.[24]

TREADS

TREADS (Tool for Recovery Estimation And Downtime Simulation) is a framework to probabilistically model the post-earthquake recovery of buildings and provide quantitative seismic performance measures, expressed in terms of downtime, that are useful for decision making.

Downtime estimates include the time for mobilizing resources after an earthquake and for conducting necessary repairs. The TREADS framework advances the well-established FEMA P-58 and REDi methodologies by modelling temporal building recovery trajectories to different recovery states. Analogous to safety-based US codes, which specify a threshold for the probability of collapse under a given ground motion shaking intensity (e.g., 10% or less probability of collapse under the risk-targeted maximum considered earthquake), this framework permits evaluating the probability of a building not achieving a target recovery state (e.g., shelter-in-place immediately after the earthquake), or, alternatively, the probability of not achieving a target recovery state (e.g., functional recovery), within a specified time frame.

The framework leverages the damage state predictions and component repair times obtained from the FEMA P-58 analysis to estimate building performance in terms of downtime. This process consists of five sequential steps:

1. Evaluate the extent of damage and identify the post-earthquake usability of the building, considering five distinct recovery states immediately after the earthquake: stability, shelter-in-place, re-occupancy, functional recovery, and full recovery. The shelter-in-place recovery state accounts for relaxed post-earthquake habitability standards, in contrast with the re-occupancy recovery state, which relates to pre-event habitability criteria.
2. Evaluate impeding factor delays—the various factors that may delay or impede the initiation of repair activities. These activities include the time required for building inspection, securing financing, arranging engineering services and designs, obtaining permits, mobilizing a contractor, and performing repairs to stabilize the structure or the building envelope (i.e., mitigation work to minimize aftershock collapse risk and falling debris hazard).
3. Assess the building's repair time to achieve the desired recovery state.
4. Model the building's time to recovery by using the delay time and repair time estimates, providing downtime estimates for each storey in the building. (To account for the various uncertainties within the downtime estimation procedure, the first four steps are performed for thousands of Monte Carlo simulations, resulting in thousands of downtime realizations (plausible outcomes) and recovery trajectories, each having an equal likelihood of occurrence, as illustrated in Figure 2.)
5. Link the downtime estimates to probabilistic performance measures (robustness and rapidity) that support decision making by building owners, engineers, and policy makers.

Each of the recovery states considered by TREADS represents a milestone in a building's overall recovery trajectory. To estimate downtime to achieve each of these recovery states, the framework uses the repair class concept introduced by the REDi guidelines. The damage state of each building component in each realization is tagged with a repair class, which serves to identify the recovery state hindered by the damage extent to

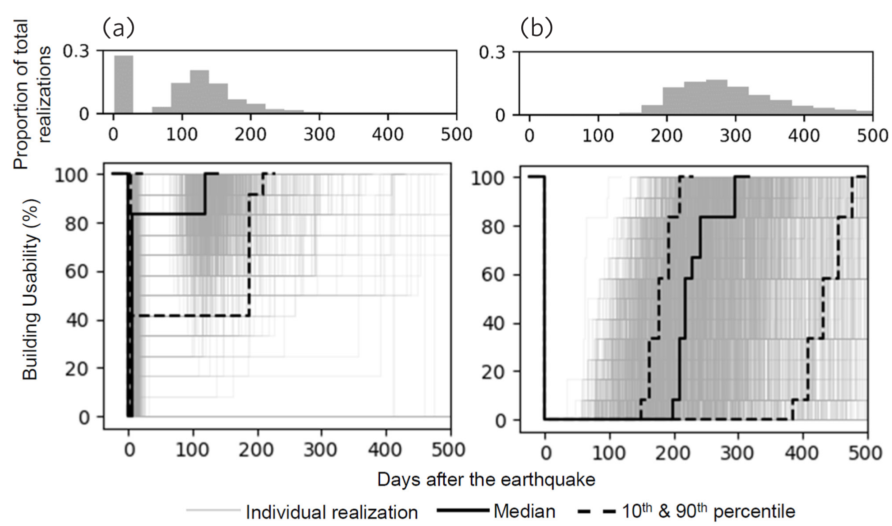

Figure 2: Recovery trajectories to (a) shelter-in-place and (b) functional recovery for 1000 realizations of building performance under ground motion shaking with a return period of 975 years (adapted from Molina Hutt et al, 2022).

the component. The post-earthquake usability is determined by identifying the recovery state achieved by the building immediately after the earthquake, before any recovery activities begin. The building condition when each of the recovery states is achieved and the associated repair class is shown in Table 1. Components that are damaged to a level that hinders achieving the building condition outlined in the table will need to be repaired before the recovery state can be achieved.

To illustrate this concept, consider a reinforced concrete shear wall building. The structure's slender shear walls are characterized by a fragility function with three distinct damage states. Damage state DS1 represents spalling of the cover with vertical cracks greater than 1/16 of an inch, which is tagged with a repair class RC3 and hinders achieving the re-occupancy recovery state. Damage state DS2 represents exposed longitudinal reinforcing and triggers an unsafe placard per the FEMA P-58 methodology, hence is tagged with a repair class RC4 and hinders achieving the shelter-in-place recovery state. Damage state DS3 represents concrete core damage or buckled/fractured reinforcing. Because this is believed to compromise the load carrying capacity of the member, it is linked to a repair class RC5 and hinders achieving the stability recovery state.

Within the proposed assessment framework, all component damage linked to a repair class equal to or greater than that associated with the desired recovery state, as indicated in Table 1, must be repaired before the recovery state in question can be achieved. To achieve functional recovery, for example, all components with repair classes RC2, RC3, RC4, and RC5 need to be repaired. If no[ii,iii] component damage hinders achieving the desired recovery state, the repair time to the recovery state in question is zero (e.g., if the maximum repair class across all structural and non-structural components is RC3, the repair time to shelter-in-place is zero).

Table 1: *Recovery state, building condition, and repair class, in descending order of criticality (adapted from Molina Hutt et al, 2022)*

Recovery State	Building Condition[ii]	Repair Class[iii]
Stability	Significant structural and non-structural damage that does not compromise the building stability	5
Shelter-in-place	Moderate structural and non-structural damage that does not threaten the safety of residents	4
Reoccupancy	Cosmetic structural and moderate non-structural damage	3
Functional recovery	Cosmetic structural and minor non-structural damage	2
Full recovery	No damage, pre-earthquake functionality maintained or restored	1

TREADS[iv] permits calculating the following outputs and resilience-based metrics: 1) the recovery trajectory of the building showing the progress of building restoration, or reconstruction, over time; 2) the robustness, or "the ability [of the building] to withstand a given level of stress or demand without suffering degradation or loss of function;"[25] 3) the rapidity, or "the capacity to meet priorities and achieve goals in a timely manner in order to contain losses and avoid future disruption;"[26] and 4) the downtime disaggregation to help prioritize design or retrofit interventions to minimize downtime.

In addition to the recovery trajectories, previously illustrated in Figure 2, sample robustness and rapidity outputs are illustrated in Figure 3. While the terms "robustness" and "rapidity" are frequently used to measure the seismic resilience of communities, within the TREADS framework, the terms measure seismic performance of individual buildings. Figure 3a illustrates the probability of not achieving the shelter-in-place

[ii] Describes the state of the building when the recovery state is achieved.

[iii] Indicates the minimum repair class that hinders achieving the corresponding recovery state.

[iv] TREADS is fully compatible with the SimCenter's (the computational modelling and simulation center of the Natural Hazards Engineering Research Infrastructure program) tool for loss assessment, PELICUN, an open-source application that implements the FEMA P-58 methodology. Thanks to this compatibility, a user can perform a complete damage, loss, and downtime assessment within a unified workflow. The TREADS framework coded in Python is available as an open-source application at the following Github repository: https://github.com/carlosmolinahutt/treads. TREADS is also available at the Python Package Index (PyPI) and can be easily installed using pip. See A. Zsarnoczay and P. Kourehpaz P, NHERI-SimCenter/pelicun: pelicun v2.5 (Version v2.5), 2021.

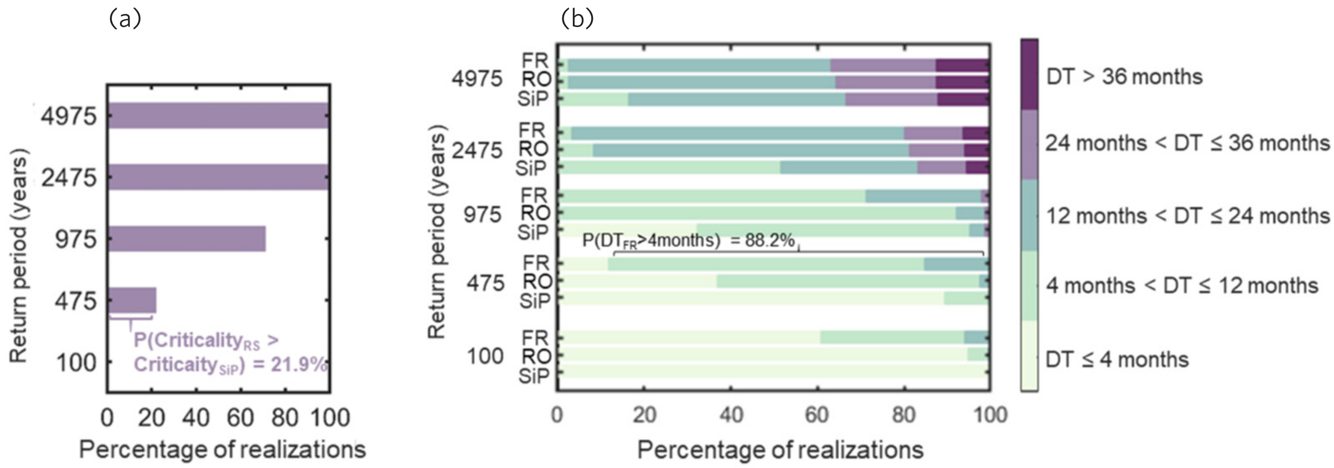

Figure 3: Sample assessment outputs under a range of hazard levels with low to high probabilities of exceedance (high to low return periods) including: (a) Robustness or the probability of not achieving the shelter-in-place recovery state immediately after the earthquake, and (b) Rapidity or the downtime to achieve functional recovery (FR), re-occupancy (RO), and shelter-in-place (SiP) recovery states within specified time frames (adapted from Molina Hutt et al, 2022).

recovery state immediately after the earthquake (ground motions representative of a range of hazard levels with low to high probabilities of exceedance). Figure 3b summarizes the downtime to achieve functional recovery (FR), re-occupancy (RO), and shelter-in-place (SiP) recovery states (also across a range of ground motion shaking intensity levels). If the building design does not conform with the desired performance measures, the framework also provides a disaggregation of downtime that highlights the components that contribute to inadequate performance, thus enabling effective design interventions.

ATC-138-3

As described in the ATC-138-3 Preliminary Report,[27] this methodology[v] for assessing functional recovery time utilizes the architecture of FEMA P-58 to explicitly quantify the loss of building function and the time to restore it. The method defines a new re-occupancy and building function module to the FEMA P-58 process, which maps component-based damage to system-level operations, and system-level performance to tenant and building level re-occupancy and function.

This new logic is implemented as a series of fault trees. In defining recovery time, the framework conceptually adopts the REDi impeding factors and certain aspects of repair scheduling proposed in the REDi guidelines and by Terzic and Yoo in 2016.[28] The recovery states tracked in this methodology are re-occupancy, functional recovery, and full functionality. While the ATC-138-3 definition of functional recovery is consistent with that employed in the TREADS framework, the ATC-138-3 definition of re-occupancy is consistent with TREADS's shelter-in-place, and full functionality in ATC-138-3 corresponds to full recovery as defined in the TREADS framework.

The general approach and logic for assessing building function is illustrated in Figure 4. First, for a building to be functional, the building must be safe to enter and re-occupy. Then, each storey of the building must be accessible, and tenants must be safe from falling and other safety hazards. Finally, tenant units within the building must be able to provide their basic intended functions within the tenant space. As illustrated in Figure 4, in "Stage 1: Building Safety," the building is evaluated for occupant safety hazards that would cause the whole building to be shut down. This check identifies whether damage

[v] *The source code associated with the ATC-138-3 methodology is freely available at https://github.com/dcook519/PBEE-Recovery. The computational algorithms have also been implemented by HB-Risk in their SP3 software modules, which are available at www.sp3risk.com.*

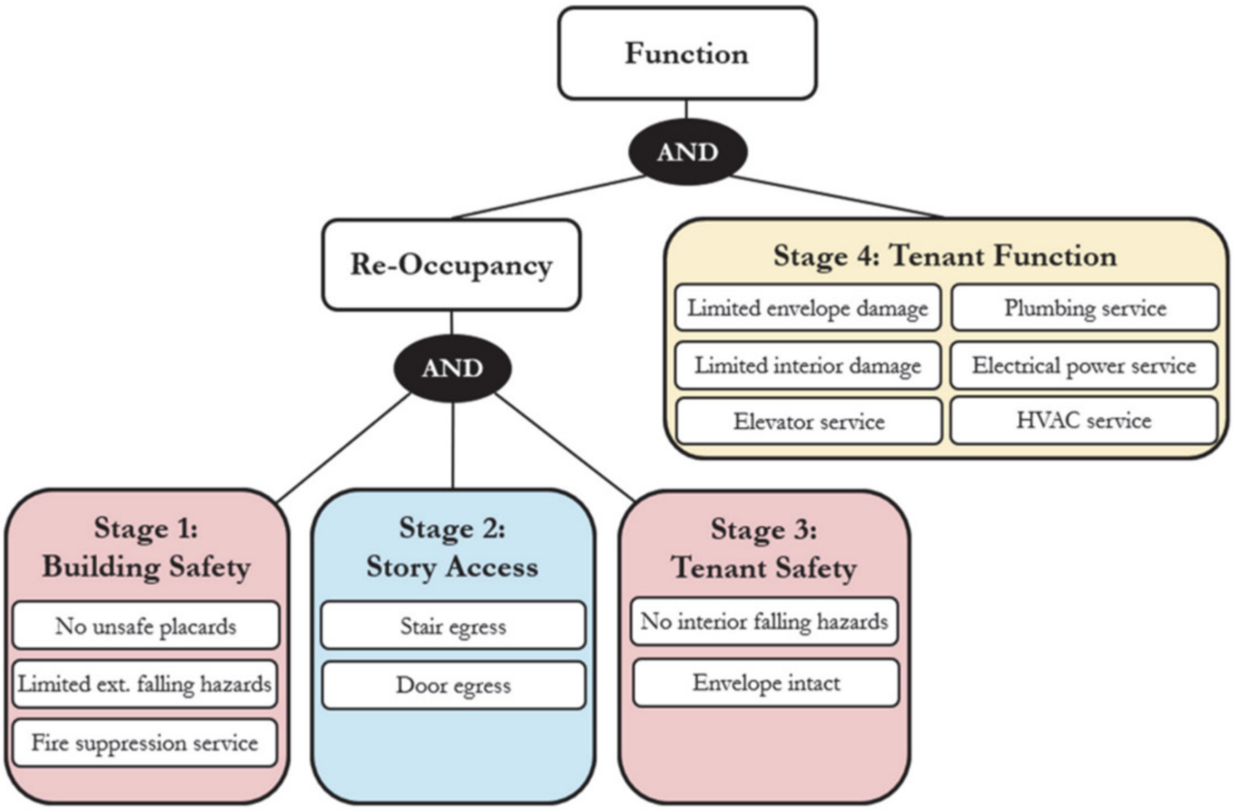

Figure 4: ATC-138-3 logic tree framework for assessing functionality (ATC-138-3, 2021).

exists that can lead the entire building to being classified as unsafe to occupy (e.g., structural safety concerns, external falling hazards). In "Stage 2: Storey Access," each storey is verified for egress and access routes, based on damage to stairways and doors. "Stage 3: Tenant Safety," identifies local safety issues, such as interior falling hazards, in tenant units within the building. Finally, "Stage 4, Tenant Function," checks whether building systems are in a condition such that the tenants can function in the space. Stages 1, 2 and 3 are required for re-occupancy of a particular space. In addition to these, Stage 4 is required for function to be restored.

As outlined in the ATC 183-3 preliminary report, the functional recovery methodology recognizes that building function may imply unique requirements for each tenant within the building, and, therefore, breaks down the building into tenant units and quantifies the functional performance of each tenant-unit individually. Building-level functional performance is quantified as the collection of the functional performance of all tenant units within the building. In each stage, component damage is related to system-level function based on a series of fault trees. These fault trees are used to define the effect that component damage has on the condition or operation of different building systems, based on assumptions as to how the condition or operation of each system affects the re-occupancy or functionality of each tenant unit. In the last stage, the function of each tenant unit is determined based on whether the performance of each system meets, or fails to meet, tenant-specific functional requirements. Figure 5 illustrates a sample fault tree employed to define the performance of the interior system in "Stage 4: Tenant Function." Similar fault trees are employed to assess other building systems, such as HVAC, electrical power, plumbing or elevators.

While the ATC-138-3 preliminary report was recently made publicly

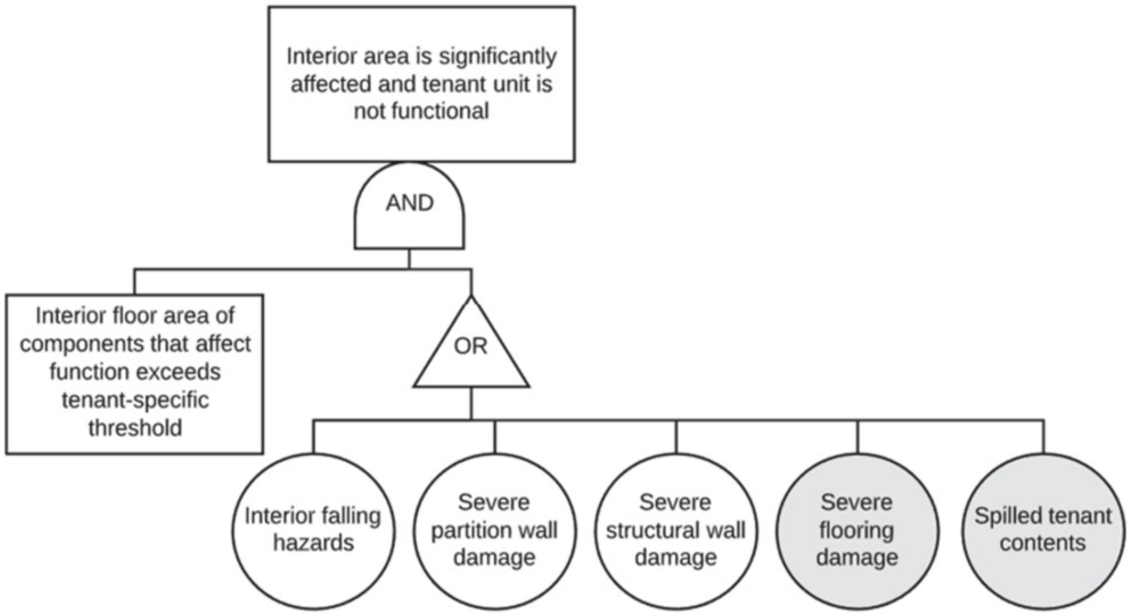

Figure 5: Fault tree defining the performance of the interior system for the Tenant Function stage (Stage 4). Gray events are not currently considered in the framework (ATC-138-3 2021).

available, to date no case studies have been published to demonstrate the implementation of the proposed framework. As new methodologies are developed, there is a clear need for comparative studies that evaluate the functional recovery performance (among other resilience-based metrics) of range of case study buildings leveraging different frameworks to enable moving towards a consensus-based approach.

OPPORTUNITY

PATHWAYS TO IMPLEMENTATION IN BC

The 2015 edition of the National Building Code of Canada,[29] adopted for the most part in the 2018 edition of the BC Building Code and the 2019 Vancouver Building By-law, is an objective-based code with varying earthquake performance objectives according to the importance category of buildings, which are set as a function of intended use and occupancy. For instance, buildings that are essential in the event of a disaster, such as hospitals, are termed "post-disaster buildings" and correspond to the highest importance category. As a result, the seismic design of these buildings includes an importance factor of 1.5. Buildings that are likely to be used as post-earthquake shelter, such as schools, have a high importance category and, in turn, an importance factor of 1.3. By contrast, buildings with a normal importance category have an importance factor of 1. The use of higher importance factors intends to achieve three things: 1) provide reduced damage to the structure; 2) provide reduced damage to elements, non-structural components and equipment (also known as operational and functional building components) and their connections; and 3) minimize residual structural drift by the requirement of reduced peak transient storey drift limits.

The design-level earthquake according to the National Building Code is equivalent to ground motion shaking with a 2% probability of exceedance in 50 years. Despite defining a single design earthquake level, the resulting performance of buildings designed according to this standard could vary widely.[vi]

[vi] This variation in performance is attributed to the large number of seismic force resisting systems available in the code with different Rd values (ductility-related force modification factors reflecting the capability of a structure to dissipate energy through reversed cyclic inelastic behavior

The implicit performance objectives of the National Building Code are to: 1) protect the life and safety of building occupants for the code-level earthquake; 2) limit building damage due to low-to-moderate levels of shaking; and 3) increase the chances of post-disaster buildings being functional and occupiable after strong ground shaking.[30] Referring back to the recovery states introduced in Table 1, and considering the range in anticipated seismic performance previously discussed, when subjected to ground motion shaking consistent with the design-level earthquake, buildings with a normal importance category are most likely to achieve stability, high importance category buildings might achieve shelter-in-place, and post-disaster buildings would likely achieve the top range of shelter-in-place nearing the re-occupancy recovery state.

The 2020 edition of the National Building Code[31] introduces additional requirements for post-disaster and high importance category buildings, as well as a subset of buildings with a normal importance category—those with heights above grade greater than 30 metres. These requirements are applicable to structures in areas of moderate to high seismicity, expressed in terms of seismic category in the new edition, and introduce additional design requirements at a lower hazard level (an earthquake more frequent than the design level, with ground motion shaking with a 5%–10% probability of exceedance in 50 years). The additional requirements include ensuring the structure and the connections of operational and functional components (OFCs) behave elastically (no structural damage and undamaged OFC connections), and also includes stricter drift limits that minimize seismic damage to non-structural components at these lower levels of ground shaking. Ultimately, these new requirements reduce the variation in anticipated seismic performance across seismic force resisting systems under the hazard levels considered (because the structure is undamaged) and would implicitly result in seismic performance consistent with the functional recovery state, previously defined in Table 1.

While these new design requirements can bring us closer to achieving desirable recovery states for selected levels of earthquakes, the evolution of codes to further address recovery states will be a slow process as new editions are updated only every five years. Therefore, code efforts should be complemented by the various frameworks presented herein. The availability of these frameworks to estimate downtime to functional recovery (or other recovery states) means that explicit consideration of these performance measures for use in building design is now a possibility. Training of all involved in the building industry on the use of these methodologies, as well as education of and outreach to the general public to enhance their understanding of earthquake risk and recovery-based objectives, is vital to improving how our buildings are designed and constructed.

The evolution of codes to further address recovery states will be a slow process as new editions are updated only every five years. Therefore, code efforts should be complemented by the various frameworks presented herein.

In BC, there may be unique pathways to the adoption of enhanced seismic design requirements to achieve functional recovery objectives. In contrast with other municipalities in BC, the City of Vancouver via the Vancouver Charter can set its own Building By-law independent from the BC Building Code, and the University of British Columbia has its own Building Regulations that do not need to comply with the BC Building Code. This independence provides an opportunity to raise the bar by enhancing earthquake design and performance requirements and serve as an example for the BC Building Code or the National Building Code of Canada, the latter of which serves as the model code for the provinces and territories. A shift from an

via expected localized damage). For example, a concrete ductile shear wall building with an Rd of 5 will have a different performance compared to a steel concentrically braced frame with an Rd of 2. While all of these systems meet the minimum requirements of the code, they perform in very different ways in terms of their anticipated ductility and damage level.

implicit to a more explicit verification of a building's seismic performance would also align with other current efforts considering a transition from objective-based to performance-based building codes.

While such shifts in our design philosophy may be foreign to some, there already are examples of projects in BC that utilized the tools presented here. For instance, the FEMA P-58 methodology is currently being used in the high-profile St. Paul's Hospital project in Vancouver, where design requirements include specific FEMA P-58 metrics (repair costs, repair times, etc.) for different levels of shaking, introduced as part of a rezoning condition.[32] The outputs of the FEMA P-58 assessment are provided to help the owner understand the expected damage state of building components on a floor-by-floor basis and the potential impacts on building occupancy and functionality. Similarly, the University of British Columbia is utilizing the REDi rating system to provide guidance to project teams in achieving resilience, and UBC has ongoing retrofit projects that aim to achieve a high resilience level of "immediate occupancy" following a major earthquake.[33]

FEMA P-58 AND REZONING ST. PAUL'S HOSPITAL

As part of the City of Vancouver's rezoning process for the new St. Paul's Hospital (Figure 6), a "Resilience Rezoning Condition" was created. This condition required the proponent to perform a climate risk assessment and a seismic assessment to inform facility design and operations with the goal of advancing likely post-disaster building functionality (and patient safety) in response to the impacts of both climate change and seismic events.

Figure 6: Concept of the new St. Paul's Hospital in Vancouver (Illustration: flickr/Province of BC).

The climate assessment followed a hybrid methodology of the PIEVC protocol, Climate Lens, ISO 31000 Risk Management, and the ICLEI BARC tool. FEMA's P-58 standard was used for the seismic assessment—a first for a hospital in Canada.

Outputs of this seismic assessment exceeded the resolution of the BC Building Code by providing proxies for the building's likely functionality (e.g., seismic damage, repair costs and repair times) following a major earthquake. This form of seismic assessment, performed during the design process of new buildings, is a potential strategy to advance high-performance buildings more broadly. The process of assessment provides design teams and developers invaluable information so that they may make performance-based design decisions to meet functionality expectations within, but also possibly above and beyond, the life-safety protection minimum requirement currently in the code.

RECOMMENDATIONS

Table 1: Recommendations

Recommendation	Description of Impact	Priority Level	Capabilities Needed
1. Train all involved in the building industry on the use of these methodologies; educate and engage with the public to enhance their understanding of earthquake risk and recovery-based objectives.	Training enables the delivery of building projects in which the expected seismic performance of buildings expressed in terms of their functional recovery is explicitly verified. Outreach results in direct demand from end-users (building owners and occupants) for buildings with enhanced seismic performance.	Critical	Technical and financial
2. Raise the bar by enhancing earthquake design and performance requirements.	The ability of the City of Vancouver and UBC to set their own bylaws independent of the BC Building Code or the National Building Code of Canada, which serves as the model code for the provinces and territories, provides a unique opportunity to raise the bar by enhancing seismic design and performance requirements.	Critical	Leadership
3. Shift from objective-based to performance-based design.	Shifting from the current implicit verification of a building's seismic performance (i.e., building meets code) to an explicit verification of performance (e.g., the building will take five days to achieve functional recovery after a major earthquake) will enhance our understanding of earthquake risk and will engage end-users (building owners and occupants) in defining the desired seismic performance of buildings.	Recommended	Technical and legislative (reflect in code)

CHALLENGES

Addressing the following three challenges will be necessary to advance the functional recovery of buildings.

1. **Cost:** The cost associated with the design of buildings to achieve enhanced seismic design requirements is a known challenge. But case studies[34] and research[35] suggest that the cost premium is small and there is a benefit to raising the bar if one were to consider costs from a lifecycle perspective as opposed to simply upfront or initial design and construction costs.

2. **Reaching a consensus-based approach:** New frameworks to evaluate downtime and functional recovery performance of buildings are just that—very new; they require a large number of assumptions and are yet to be tested or assessed against empirical data collected after major earthquakes, which allows us to check how our analysis results compare to reality. As a result, it will take time for the engineering community to embrace these new concepts and, more importantly, to reach consensus on how to conduct these assessments to ensure

consistency in our approach. The slow evolution of codes referenced in the article is in part related to this notion of the difficulty in reaching consensus.

3. **Existing buildings:** While adopting these design requirements and procedures for new building design might be challenging, applying these to existing buildings raises an even greater challenge. Existing buildings need only comply with the requirements of the code at the time they were designed and constructed. Updated editions of the building code are not applied retroactively to existing buildings. Therefore, the seismic upgrade of existing buildings could be costly and difficult to implement other than on a voluntary basis.

> Training of all involved in the building industry on the use of these methodologies, as well as education of and outreach to the general public to enhance their understanding of earthquake risk and recovery-based objectives, is vital to improving how our buildings are designed and constructed.

RESOURCES

INTERNATIONAL

1. More information on the key frameworks discussed:

FEMA P-58

FEMA. *Seismic performance assessment of buildings FEMA P-58.* Washington, DC: Federal Emergency Management Agency, 2012. https://femap58.atcouncil.org/documents/fema-p-58/24-fema-p-58-volume-1-methodology-second-edition/file.

REDi

Almufti, I. and M. Willford. "REDi™ Rating System: Resilience-based Earthquake Design Initiative for the Next Generation of Buildings." San Francisco: Arup, 2013. https://www.redi.arup.com/.

TREADS

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ATC-138

Applied Technology Council (ATC). "Methodology for Assessment of Functional Recovery Time, A Preliminary Report." *Seismic Performance Assessment of Buildings*, Volume 8. FEMA, 2021. https://femap58.atcouncil.org/documents/fema-p-58/34-atc-138-3-volume-8-methodology-for-assessment-of-functional-recovery-time/file.

2. White paper on functional recovery:

Earthquake Engineering Research Institute (EERI). "Functional Recovery: A Conceptual Framework with Policy Options." Oakland: EERI, 2019. https://www.eeri.org/images/archived/wp-content/uploads/EERI-Functional-Recovery-Conceptual-Framework-White-Paper-201912.pdf

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[6] M. C. Comerio and H. E. Blecher, "Estimating downtime from data on residential buildings after the Northridge and Loma Prieta earthquakes," *Earthquake Spectra* 26(4) (2010): 951–965.

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[8] FEMA P-2090, *Recommended Options for Improving the Built Environment for Post-Earthquake Reoccupancy and Functional Recovery Time FEMA P-2090* (Washington, DC: Federal Emergency Management Agency, 2021).

[9] 42 U.S.C. § 7705(b), "Seismic Standards," *United States Code*, 2018.

[10] Senate Bill 1768, "National Earthquake Hazards Reduction Program Reauthorization Act of 2018," 115th Congress, United States, 2018.

[11] FEMA, "NEHRP recommended seismic provisions for new buildings and other structures FEMA P-2082" (Washington, DC: Federal Emergency Management Agency, 2020).

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[13] M. Bruneau, S. E. Chang, T. Ronald, et al, "A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities," *Earthquake Spectra* 19(4) (2003): 733–752.

[14] National Research Council of Canada, *National Building Code of Canada*, Associate Committee on the National Building Code (Ottawa: NRCC, 2020).

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Photo: Johanna Wagstaffe, CBC

3.1 THE ROLE OF MEDIA IN DISASTER RISK REDUCTION

June 2022

DRRPathways.ca

RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 3 Climate and Disaster Risk Management: Enabling Action*. To read all articles in the report, see DRRPathways.ca.

The Resilience Pathways Report is a project of Natural Resources Canada.

3.1 THE ROLE OF MEDIA IN DISASTER RISK REDUCTION

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ABOUT THE MEDIA

OVERVIEW

The Canadian media plays an integral role in the resilience of British Columbians. At its very core, the media is the collection of communication outlets and tools used to deliver information to the public, delivering programming content that reflects an audience's interests and needs. Canada receives top marks for prioritizing freedom of expression and the press, which means we are steps ahead of many other countries around the world when it comes to the relationship between the public and the media. The organization Reporters Without Borders compiles an annual ranking of countries based upon the organization's assessment of their Press Freedom Index. In 2021, Canada ranked 14 out of 180.[1] The Government of Canada recognizes that "people need free media to provide them with accurate information and informed analysis to hold governments to account."[2] This has been more vital than ever in recent years following the COVID-19 pandemic and back-to-back weather disasters in BC in 2021. However, there are still hurdles and gaps when it comes to communicating important information as well as opportunities to strengthen the relationship between the audience and the media.

In Canada, the media landscape is incredibly diverse. Canadian media contains both regional and domestic coverage. Canada has several major national newspapers (print and digital) as well as several national television and radio networks. In addition, there are hundreds of local digital publications that service a hyper-local audience. The linguistic policies of the *Broadcasting Act* are followed.

For British Columbians, access to this content is channeled through television, radio, print, digital, social media, streaming services and apps. Through experience, market research, and a two-way conversation with audiences, the media understands how Canadians are accessing and consuming news. While market research continues to show accelerated trends in audiences moving towards digital and on-demand services to obtain their news, the core service of media in communicating risk, no matter the platform, remains stronger than ever.

In the context of disaster and climate risk management, the media can be thought of as a clearing agency for information. The media relays information from experts and government officials and delivers it out to the public before, during, and after a disaster (Figure 1). Canadian media is far-reaching, with the ability to connect with most of the

Figure 1: Reporter in the field (Photo: Johanna Wagstaffe, CBC) .

population either directly or indirectly through word of mouth and social media sharing capabilities. This holds enormous weight in getting a message of resilience to the public.

> The Government of Canada recognizes that "people need free media to provide them with accurate information and informed analysis to hold governments to account." This has been more vital than ever in recent years following the COVID-19 pandemic and back-to-back weather disasters in BC in 2021.

Organizations independently advise media of new risk information, and the media will independently "check in" with various organizations as pertains to news "hooks" or special projects. Our aim overall is to inform the public of immediate disaster risk, public safety information on how to navigate an unfolding crisis, the potential for risk in the future, accountability after a disaster, and what initiatives are in the works.

ALIGNMENT WITH THE SENDAI FRAMEWORK

Media is one of the stakeholder groups mentioned in the Sendai Framework with an important role as "enabler in providing support to States, in accordance with national policies, laws and regulations, in the implementation of the present Framework at local, national, regional and global levels. Their commitment, goodwill, knowledge, experience and resources will be required."[3]

More specifically, the role of media is outlined in paragraph 36(d): "Media to take an active and inclusive role at the local, national, regional and global levels in contributing to the raising of public awareness and understanding and disseminate accurate and non-sensitive disaster risk, hazard and disaster information, including on small-scale disasters, in a simple, transparent, easy-to-understand and accessible manner, in close cooperation with national authorities; adopt specific disaster risk reduction communications policies; support, as appropriate, early warning systems and life-saving protective measures; and stimulate a culture of prevention and strong community involvement in sustained public education campaigns and public consultations at all levels of society, in accordance with national practices."[4]

UNDERSTANDING AND REDUCING RISK

For decades, the media has helped deliver the message of public safety during an unfolding crisis. But the format is constantly changing—from waiting by the radio for breaking bulletins, tuning into the six o'clock evening news for updates or opening the morning newspaper for details of impact to our current landscape, to getting push notifications of alerts on our smart phones and checking twitter for live updates. Journalism across platforms and agencies has helped to connect the message from experts and decision makers to the public which, in turn, has helped make our communities more resilient.

It is the mandate of the media to provide relevant information to the public. Increasingly, individual newsrooms are making the awareness of risk, particularly as it is connected to climate change, a part of the coverage. A lot of this shift has come audience pressure as communities are increasingly impacting by extreme weather.

Individual newsrooms adhere to their own codes of conduct. The CBC's *Journalistic Standards and Practices*, for example, is available to the public and contains guidance on how to conduct fair journalism through disaster: "When a natural disaster strikes, we provide useful information and context, especially for those most directly affected. The information we provide helps the audience understand a fluid and chaotic situation, so that it can assess the impact and potential danger. We will sometimes receive conflicting information from credible sources. We may choose to report this, making clear the circumstances of the situation and citing the sources while we work to reconcile the information in light of the reality on the ground."[5]

The role of the data journalist is becoming more and more prominent in newsrooms—an important note to share with those compiling raw data, that the media is becoming more interested in source material. With access to information requests available to the public, newsrooms are dedicating more time to sifting through data and providing relevant analysis. Figure 2 is an example of journalists using publicly available data to find trends in urban sprawl in Canadian cities and create original visualizations to tell the story.[6]

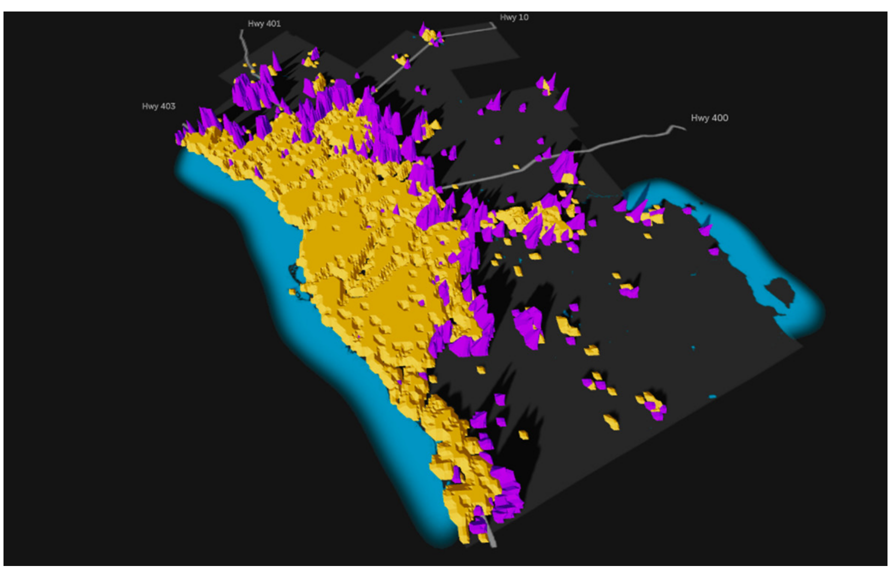

Figure 2: Journalists are visualizing data to tell a story about urban sprawl and climate change (Photo capture from work by Naël Shiab and Isabelle Bouchard).

ROLE IN DIFFERENT STAGES OF DISASTER RISK REDUCTION

Media plays a role in every stage of disaster and climate risk management and uses different approaches and tools to deliver the intended information.

Figure 3 is from a BBC Media Action Insight report in 2021 that sums up the role and tools of media across our Canadian landscape.[7]

RISK MITIGATION

Journalists can help break down complex ideas when it comes to understanding both risk information and risk management measures. This applies to scientific studies, making sure the ideas about how new information from studies may apply to individuals, as well as to finding ways to spark discussion and feedback from the public about this information. The media can help provide a platform for the work of universities and institutions when it comes to furthering our understanding of personal risk, and it can share safety recommendations, initiatives and incentives from government officials when it comes to application.[8]

The media can also invoke change. By sharing stories of individuals who have taken ownership of personal resilience, or who have put the pressure on for change from above, media can help to create a shift in the perspective of the masses. Inspiration is a powerful tool.

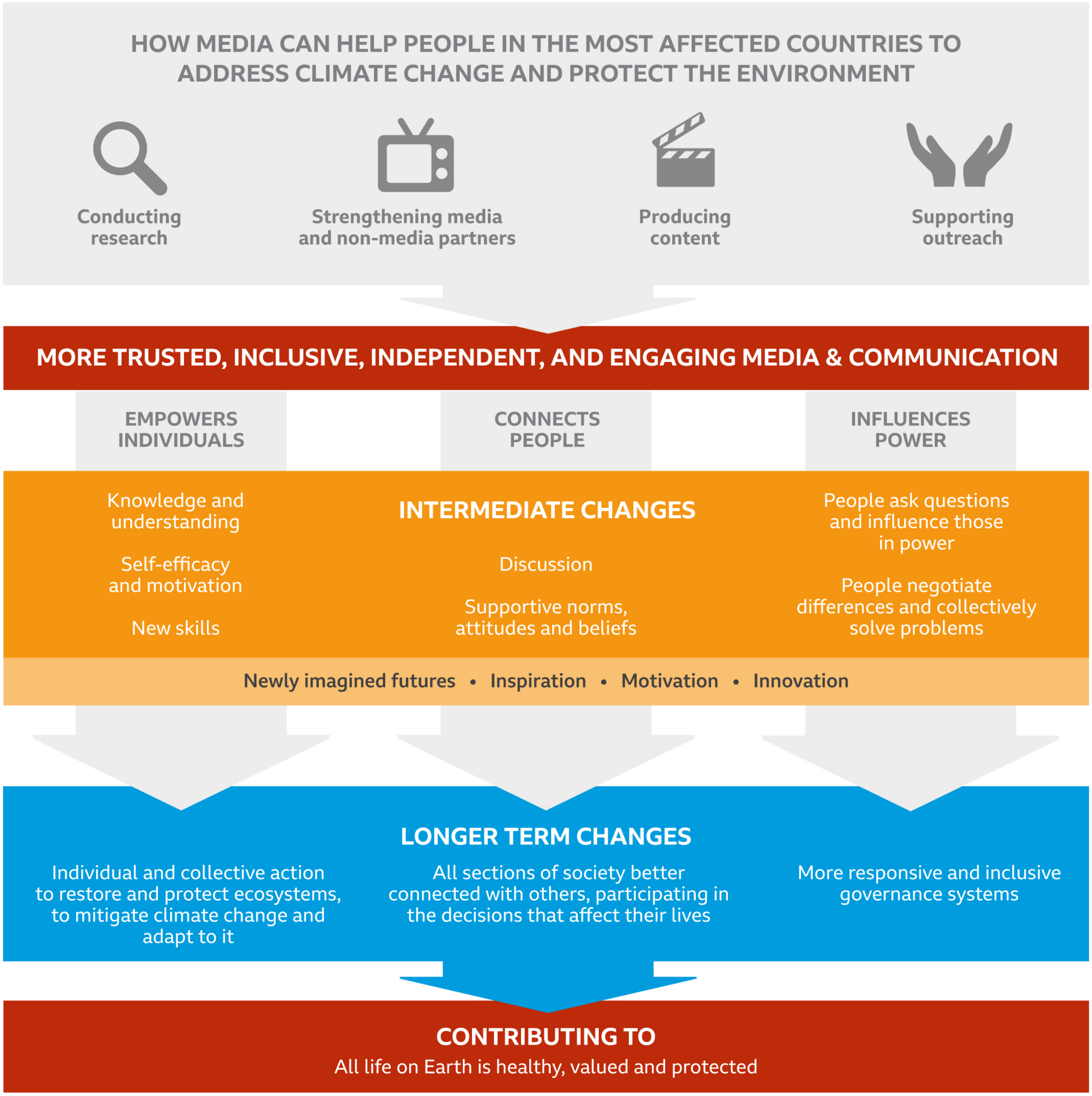

Figure 3: How media can help enable positive shifts to protect the environment and address climate change (Graphic: BBC).

Figure 4 is an artist's illustration showing how an earthquake could devastate a Vancouver elementary school. The image was created when UBC seismic engineers and psychologists wanted to test whether the image would be more effective than statistics for communicating earthquake risk. Their study demonstrated that people who viewed the image were more likely to sign a petition to fast-track seismic upgrades (77.3% compared to 68.0%) than people who only saw statistics.[9] The image and story were published by UBC News and further picked up by other news outlets.

EMERGENCY PREPAREDNESS AND RESPONSE

Arguably, the media has historically been most imperative during an unfolding crisis. Before the full roll-out of the National Public Alerting System to wireless service providers, media was the primary form of accessing life-saving information. Other methods of information dissemination are far and few between but include, in addition to word of mouth, emergency response crews going door-to-door with information, or individuals taking the initiative to set up alert systems provided by individual agencies (Environment and Climate Change Canada, for example) or Twitter alerts for accounts like @EmergencyInfoBC.

During a crisis, such as a tsunami, earthquake, wildfire, flood, or cyclone, where time is of the essence, the media has the ability to break into programming on all platforms to provide life-saving information—such as who is under the warning, the timing of events, what to do, when danger has passed, and where to go for more information. Most smartphone users will also receive automatic push notifications for breaking news events.

This is also when the media can directly connect experts and scientists to the public—offering forums, debates, town halls, and live question-and-answer sessions (Q&As) to allow the public to hear firsthand what is happening. This format has been very effective during the ongoing pandemic. For example, CBC Rundown[10] offers a live Q&A every night, taking viewers' questions, and CBC Vancouver ran a Q&A about the wildfire smoke from the 2021 fire season.[11]

RECOVERY/BUILD-BACK-BETTER

Ongoing access to information on the state of infrastructure and updates from officials on the timing and plans of recovery are part of the news reporting that will help communities

Figure 4: Artist illustration of potential earthquake damage at an elementary school in Vancouver (Photo/illustration: UBC News).

recover with resilience. Media can provide information on resources and processes for accessing support during the recovery phase. This is also where journalists hold those in power accountable by assessing how effective the flow of information was, the transparency of decision making, how much and where recovery money will be going—essentially by asking the "tough questions" to all levels of government.

AVAILABLE TOOLS

The media has the following tools available for communication flow:

Breaking news: Communication during a crisis is what many media organizations do best. The media has the ability to break into regularly scheduled television programming with warnings (tornado warnings during a non-news show, for example), issue alerts on smartphones about breaking news, turn website landing pages into breaking-news information hubs, and create radio specials in the moment.

News releases: Communications teams for various bodies that have newsroom contacts send news releases to newsrooms. Comms teams also contribute to a landing page on a publicly available webpage where the same releases all get posted. The social media presence of these bodies—university research units and think tanks, government departments, BC Avalanche, many others—also falls under this category. A recent example of a news release shared in multiple places is one from the University of Northern British Columbia, letting media know of funding for new weather stations to monitor extreme weather in the province; this news release was posted on UNBC's website and was also sent directly to our newsroom inbox.[12]

Scheduled media briefings: These are pre-organized events where experts, researchers, officials, and decision makers share information in a live event, allowing cameras and journalists to engage in a question period after the event. An example of this are the live press briefings regarding where the BC government shares updates to COVID-19 regulations.[13]

Access to events: Invitations to journalists to participate in or view training exercises or simulations. Examples of such events include Heavy Urban Search and Rescue (HUSAR) Task Force training, seismic simulation laboratories, and avalanche testing. One such event in 2020 (reported by CTV News) where media were invited to watch involved local first responders and the Canadian Armed Forces conducting training exercises for heavy urban rescue.[14]

Planned releases under embargo: Advance research is sometimes given to the newsroom ahead of a publication or announcement so that the newsroom can prepare a story in advance. This approach often leads to higher-quality journalism and wider platform release and interest. The Insurance Bureau of Canada, for example, sent an embargoed copy of their post, "Severe Weather in 2021 Caused $2.1 Billion in Insured Damage,"[15] a week ahead of time so that journalists could set up interviews and plan for stories.

In-depth project: This is an investigation into a particular topic as part of a series or documentary or enterprise journalism. The CBC Vancouver Faultline podcast[16] would be considered an in-depth project, on a topic not necessarily connected to a news hook of the day. Newspaper features can also be in-depth projects, such as the 2016 Vancouver Sun piece that reported how Vancouver's poorest residents are living in buildings at risk in an earthquake.[17]

Small events that remind, refresh audience of overall risk and strategy: A small, non-damaging local earthquake or a large earthquake somewhere else in the world can be used by media to update the audience on our current seismic hazards and preparations. For example, The Weather Network reported the small earthquake felt on Vancouver Island on December 17, 2021, and within the story are reminders of the greater risks to the region.[18]

Stories from the community: Journalists who share stories of the trials, triumphs, personal battles, and grassroots initiatives that involve risk and resilience will also share the facts of the bigger picture. Such an example are the personal stories of resilience and farmers banding together after floods in Sumas Prairie in the fall of 2021, as reported by Global News.[19]

GAPS

The media landscape and the way the public is consuming news is constantly changing, so journalists and media platforms must stay agile. Journalists have a responsibility to stay informed about emergency procedures as well as the latest risks to our communities, and to navigate the best way to get information to the public. The media also needs an open line of communication to all those involved in risk reduction and resilience, especially as messaging and information changes. However, as much as the way people are consuming news is changing, the core mission of providing facts to the public is even more important in the age of misinformation.

There is no overarching protocol for the media on how to respond to disaster, at any stage. The media has journalistic guidelines—at both federal and agency levels—but there is no specific protocol to be followed by all agencies. However, individual newsrooms have extensive emergency response protocols, which rely heavily on a list of existing of contacts. These include readily available and predetermined experts and officials who can be contacted during breaking news. Developing these relationships ahead of time is key. Often these protocols are created following an event. The 2021 Haida Gwaii earthquake, for example, initiated a detailed contacts document and procedure for the CBC Vancouver newsroom.

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OPPORTUNITY

For all phases of risk reduction and resilience, the media has the ability to:

- Quickly deliver critical information to large audiences over multiple platforms.
- Provide critical information to the public about resource services during a crisis (e.g., information about mandatory evacuations during wildfires and where to follow for updates).
- Increase public awareness about disruptions to daily life (e.g., alert the public of changes to infrastructure following the November 2021 floods).
- Reassure and calm the general population; encourage calm under times of great stress (e.g., during the ongoing COVID-19 pandemic).
- Take down paywalls during a disaster (e.g., during the first year of the pandemic, CBC offered its streaming services for free).

RECOMMENDATIONS

Additionally, there is opportunity to address existing challenges by applying the following recommendations:

1. **HIghlighting communities that are resilient.** When disaster strikes, accountability to communities and individuals who have suffered is often the main priority, which means focusing on what hasn't or still needs to be done when it comes to resilience. Positive news stories are harder to find outside the realm of personal resilience. Reframing the narrative during and after high-risk events can help with this. For example, during major flood events where some communities are hit very hard, finding stories of communities that recently undertook retrofits, upgrades or entire projects (like dikes) to protect against this kind of event would help to show the tangible side to preparation. This is exactly the kind of story that could inspire change in other communities.

   Recommendation: Work with an expert who can help find these stories. It may be hard to know whether an area would have experienced a more significant impact from an event like an earthquake, flood or heat wave without an expert with "forensic expertise." Pairing such experts with newsrooms would really help to be able to tell stories of success and resilience.

2. **Planning for telecommunication resilience and redundancy.** The majority of media organizations rely on large technological infrastructure (telecommunications) to remain in place. Most news organizations have contingency plans to outsource outside of the province but this should be regularly reviewed and updated. For example, during a major seismic event in Vancouver, broadcasting will revert to Toronto, with collaboration with ham radio operators. Most of the time, such plans only get reviewed following a disaster.

   In an emergency, major news organizations know where they are in the priority sequence of getting infrastructure back online. All news organizations, especially those that have come to provide regular updates and that a portion of the public might rely on during a disaster, need to have a contingency plan and must coordinate with emergency officials.

   Recommendation: Set up cross-media collaboration. Perhaps during urgent times, social media accounts, landing pages, radio spots and other platforms could be temporarily taken over by other organizations. Currently, collaboration (pooling resources) does sometimes happen between competing agencies during times of need. For example, CBC and Global share video during some breaking events.

3. **Staying focused on public safety.** Press briefings with a Q&A period with reporters during an unfolding crisis are critical in helping to distill information to the public. Sometimes reporters may appear aggressive and adversarial, while experts and politicians can seem hesitant to share the full picture (perhaps for fear of being misquoted) and unwilling to stray from key messages. A note that this scenario is the minority; the majority show a very positive working relationship between the two sides.

   Recommendation: Train briefing staff from other agencies. Knowing that both sides are trying to get information, perhaps there is a chance to expand on basic media training with an understanding of what makes a briefing effective for newsrooms. Formal media training does exist, but there is an opportunity at the beginning of each "season" for all parties to meet and be reminded of the risks for the season ahead and what each party wants to get out of future briefings.

   When presenters have pre-produced "simple" slides and graphics of the information they are trying to convey, either during media briefings or press releases, the story immediately has higher engagement and is easier to share across platforms. Especially when journalists are working to a deadline. Visuals have to be simple, so that organizations do not have to reproduce them in-house. These should be easy for the media to share and point people to. Reproducing slides from the COVID-19 briefings, for example, has been very time consuming. Simple is best for mass public consumption.

   Researchers can assist media by providing stills and video of actual people doing the work they are wanting to share. Again, offering additional visual or audio elements makes a story so much easier and more engaging to produce across platforms.

4. **Having more journalists with expertise.** While the topic of risk and resilience stretch across a broad range of content units (politics, community, business), reporters have historically not been assigned to this topic as a beat. Having insider contacts and relationships in the way that Capitol Hill reporters do, for example, would help drive the story with the same level of importance as other beats.

   Recommendation: More beat reports and/or regular experts. The pandemic is a great example of a situation where several high-profile epidemiologists were a regular part of programming. This built trust between the experts and the audience. As well, these experts have become an invaluable resource behind the scenes for verification, thoughts, and guidance on the science and policy. The same system could work well for resilience experts and scientists.

Newsrooms could hold public town halls to help connect agencies and information and answer questions or engage with the public. Newsroom website landing pages could help direct the public to the direct sources of information they are looking for (i.e., a place on a media platform where the Resilience Pathways report can live).

THE CHALLENGE

Getting information to the most vulnerable members of the community is the most challenging aspect of media's role in disaster risk reduction. Often the most vulnerable are also those most greatly affected by disaster and have the least access to a platform where their voices can be heard. During the 2021 heat dome, for example, most of the heat-related deaths were older people living alone, and people living in low-income housing. This is also the audience that is most difficult to reach and impact.

Having a multi-disciplinary approach with the shared goal of reaching the most vulnerable would sharpen the message for all those consuming news. At this point, telling our audience to "check in on neighbours" has not been enough and we need collaboration at all levels to find solutions; a multidisciplinary town hall could be a good first step.

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RESOURCES

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Photo: LADR Landscape Architects

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June 2022

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ROLE OF PROFESSIONAL ASSOCIATIONS

DESCRIPTION

Professional regulatory bodies and associations (referred to jointly as professional associations) govern the activities of their registrants and members with requirements for professional status and professional development, codes of conduct and ethics, standards of practice, and other guidelines, oversight, and disciplinary processes. Governance that sets and maintains standards of practice and training, including rigorous accountability for one's decisions and work, is what separates professionals from non-professionals. In an increasingly specialized world, with ever-more limited resources for government agencies, decision makers in the public, private, and not-for-profit sector increasingly look to professionals, such as foresters, biologists, agrologists, engineers, geoscientists, architects, lawyers, landscape architects, and planners to provide critical information and support for decision making about a wide range of issues. The influence of professional associations is far-reaching and well placed to play a complementary role to government as a distinct part of civil society.

It is the combination of disciplines, their independent and collective responsibility to community and public trust, and their frequent role in translating government regulation and policy into practice that make the impact of professional associations—both effective and potential—so important. Their professional (and often legislated) governance and collective expertise in a wide range of sectors provides the communities in which they live and work with expert knowledge and accountability.

Professional associations govern professional interactions with the social, natural, and built environment, making them well positioned as leaders and key advisors in disaster and climate risk management. They are nonpartisan, facilitate innovation, communication, and connection, and have a professional responsibility to ensure their members have access to and are working with current knowledge around the full continuum of risk, resilience, and recovery. Associations stimulate action from within their membership, contribute to public education and awareness, and can play a vital role in providing communities with expertise founded on established standards and accountability, ensuring community expectations of good practice and social purpose are met.

Professional associations embrace diverse types of trusted experts, creating the potential for rich dialogue around hypotheses, new and implemented ideas, and ongoing research. Collectively, professionals play critical roles in ex-ante and ex-post measures. By supporting integration of risk-informed planning and design to avoid creation of new risk or reduce existing risk, as well as supporting emergency preparedness and response, professionals play a key role in reducing potential impacts of various hazards to local infrastructure, watersheds, housing, and economies. They are the ones *doing* the "building" in "building back better," implementing nature-based solutions, and decarbonizing buildings and industrial processes (Figure 1).

> The influence of professional associations is far-reaching and well placed to play a complementary role to government as a distinct part of civil society. . . [They] govern professional interactions with the social, natural, and built environment, making them well positioned as leaders and key advisors in disaster and climate risk management.

In BC, a number of regulatory bodies and professional associations have the responsibility for self-regulating their respective professions and protecting the public interest within the scope of their professions. In February 2021, the regulatory bodies for agrologists, applied biologists, applied science technologists and technicians, engineers and geoscientists, and forest professionals transitioned to operating under the new *Professional Governance Act (PGA)* (SBC 2018, c 47), a consolidated framework that sets consistent governance structures and standards for self-regulated professions[1] including a clear directive for the regulatory bodies it governs to "serve and protect the public interest with respect to the exercise of the profession, professional governance, and the conduct of registrants in the registrants' regulated practice; and to exercise its power and discharge its

Figure 1: Professionals play a key role in reducing potential impacts of various hazards to local infrastructure, watersheds, housing, and economies; they design and approve built projects (Photo: LADR Landscape Architects).

responsibilities in the public interest."[2] The PGA also establishes a statutory Office of the Superintendent of Professional Governance (OSPG) in the Ministry of the Attorney General, responsible for administering the PGA and for ensuring that best practices for professional governance are implemented. While the PGA does not specifically address responsibility for action in the areas of disaster and climate risk, with their legislated responsibility to protect the public interest and maintain professional standards in their areas of practice, professional associations have the responsibility to promote and enhance the ability of their registrants to respond and adapt to changes in practice environments, advances in technology, and other emerging issues.

ALIGNMENT WITH THE SENDAI FRAMEWORK

In BC, most professional associations include upholding public health, safety, and welfare in their Act or mandate; this aligns with the Sendai Framework which advocates for "the substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries."[3]

Professional associations are mentioned in the Sendai Framework under "non-state stakeholders," with a critical role in managing disaster risk aligned with the "whole of society" approach, which the framework promotes. Professional associations accept responsibility for their expert role and agency in promoting sustainable development. They strengthen action at a local level through partnerships among industry and institutions, the private sector, and civil society, including mobilizing volunteers aligned with the Sendai Framework's four priorities for action.

UNDERSTANDING AND REDUCING RISK

RISK REDUCTION PRACTICE AND CAPABILITIES

For many decades, the professional associations have played a role in risk management and have responded to past events—directly as associations, and indirectly through association members and registrants. They continue to play an active role in climate and disaster risk management through a wide range of programs and activities. Professional associations do not have a mandate to collect information around post-disaster damage and loss. However, some associations provide guidance and training so registrants can carry out assessments in a post-disaster scenario. More commonly, professional responses to post-disaster damage and loss are documented and shared through a wide range of media.

PROFESSIONAL PRACTICE GUIDELINES

The guidelines developed by professional associations are discipline oriented. Examples are:

- At the time of writing, Engineers and Geoscientists BC (EGBC) is working on revising Professional Practice Guidelines on Landslide Assessments and Dam Safety Reviews. For the list of current professional practice guidelines and practice advisories from EGBC, visit www.egbc.ca/guidelines.
- EGBC in collaboration with BC Ministry of Transportation and Infrastructure created *Developing Climate Change-Resilient Designs for Highway Infrastructure in British Columbia.*[4]
- Association of BC Forest Professionals, College of Applied Biology, and EGBC coauthored *Legislated Riparian Assessments in BC.*[5]
- EGBC, in collaboration with UBC Civil Engineering Department, and commissioned by the Ministry of Education, developed *Seismic Retrofit Guidelines*[6] for the seismic assessment and retrofit of existing school buildings.

PRACTICE RESOURCES

Practice resources are developed by professional associations in collaboration with external stakeholders and partners including (and not limited to) all orders of government, non-governmental organizations and standards development organizations. Examples are:

- EGBC worked with the National Research Council on the *National Guide on Urban-Wildland Interface Fires*, and the Coastal flood risk assessment guidelines for building and infrastructure design: supporting flood resilience on Canada's coasts.[7,8]
- BC's Professional Associations Adaptation Working Group was consulted for *Low Carbon Resilience: Best Practices for Professionals*,[9] published by the Adaptation to Climate Change Team at Simon Fraser University.

CONTINUING EDUCATION AND TRAINING

Another very important function of professional associations that can be effectively leveraged to support risk management in society is their provision of continuing education and training. Additionally, many associations have developed or are developing climate-specific policies and a range of micro-credential requirements for their membership (Figure 2).

Assessments, for example, often require professionals to have micro-qualifications or advanced learning for additional competency. Flood hazard assessment reports must be prepared by a "Qualified Professional" who, for this purpose, is defined as a professional engineer or geoscientist with experience or training in geotechnical study and geohazard assessment, or in geotechnical engineering, or a person in a class prescribed by the minister under subsection 7 of the PGA. To meet the provisions of the Riparian Areas Regulation, riparian area assessments must be completed by a "Qualified Environmental Professional" who, for this purpose, is defined as an individual registered under the PGA.

Figure 2: Professionals must pursue continuing education to stay current with knowledge and practice (Photo: LADR Landscape Architects).

Association of BC Forest Professionals (ABCFP) created initiatives and partnerships around wildfires in BC. In 2019, ABCFP and BC Wildfire Service collaborated to develop and deliver training for forest professionals and others. In 2020, ABCFP hosted webinars on "Wildland Forest Fire and Fuel Management Stakeholder Engagement," and "Integrating Fire Behavior Principles in Prescribing Fuel Treatments," and the association also expanded wildfire-related practice areas to better reflect emerging areas of professional practice. ABCFP is currently engaged with UBC and BC Adaptation Learning Network initiatives to develop wildfire risk mitigation and related courseware and predictive tools for forest professionals.

COLLABORATION AND VOLUNTEERISM

Knowledge exchange within and between associations is increasing and new collaborations are continually being formed, such as risk-related committees, advisory groups, and task forces, to focus on the delivery of knowledge to members within professional associations. These activities can collectively contribute to the public's ongoing trust in professional associations and in professional associations' ability to deliver.

For example, the BC Professional Associations Adaptation Working Group (PAAWG), initiated by West Coast Environmental Law (WCEL) and formally established in 2015 by the provincial Climate Action Secretariat, has thirteen members (professional associations or organizations). When PAAWG became part of the BC Regional Adaptation Collaborative work undertaken by the Fraser Basin Council (FBC), FBC became the chair. One of PAAWG's positive outcomes is the *Joint Statement on Professional Leadership in a Changing Climate*,[10] adopted in 2016 by ABCFP, Association of Professional Biology, College of Applied Biology, Planning Institute of BC, and the BC Society of Landscape Architects.

In another example of collaboration, EGBC and BC Housing together have established a list of professional engineers with availability to respond to earthquakes and other natural disasters.

STRATEGIC FRAMEWORKS AND KNOWLEDGE MANAGEMENT

As professional liability for professional associations and their registrants increases, so too does the demand for accessible evidence-based knowledge around risk management. In response, professional associations are acting to address and reduce both their risk to exposure and the risk to society by increasing risk management and climate knowledge delivery to their membership, often through platforms open to the public. The speed at which they act is, in part, dependent on their capacity as many professional associations rely on member volunteers to do this work. Examples are:

- BC Adaptation Learning Network, established in 2019 through the support of several BC universities and professional associations, created a *Climate Adaptation Competency Framework*[11] to ensure those working in climate adaptation have expertise and abilities to perform climate adaptation job functions.
- BC Institute of Agrologists hosts a publicly accessible webpage that provides up-to-date links to educational resources around natural resource management.
- Both the BC Society of Landscape Architects (BCSLA) and EGBC have open climate portals on their websites; the BCSLA site is curated and includes nearly 1,000 resources. EGBC has released a *Climate Change Action Plan*[12] that provides a structured and proactive approach to support its registrants with managing climate impacts and reducing emissions in professional practice.

While some associations' knowledge platforms are open, communication to the public is largely the responsibility of the public sector and, to a lesser extent, private sector practitioners.

Professional associations also use their internal strategic frameworks to advance climate and risk management practice. Examples are:

- Writing "preparing for climate change" position papers that outline the association's position on disaster risk reduction, sustainability, and their plan and expectations for moving forward through the collective work of their members.
- Encouraging members to educate themselves about UNDRIP, the Truth and Reconciliation Commission, Indigenous Knowledge and culturally sacred spaces, and to commit and contribute to reconciliation.
- Establishing professional performance standards or guidelines that include risk-based approaches or updating existing standards to include risk-based approaches. Although these guidelines and advisories may have limited applicability in the world of unpredictable and ever-changing risks, they are typically developed in collaboration with multiple stakeholders and, therefore, the guidance developed is relevant and broadly applicable to multiple professional groups and situations.
- Architectural Institute of BC, in coordination with BC Housing, EGBC, and the Justice Institute of British Columbia, created a framework for their respective organizations to participate in post-disaster building assessments.

HAZARD AND RISK DATA AND INFORMATION

Disaster and climate risk information is primarily a component of continuing education that professional associations provide through knowledge sharing and resource delivery; individual associations' approaches vary somewhat. EGBC provides one example—it has an EGBC Disaster Recovery Hub (internal to operations) and integrates disaster and climate risk information to develop professional practice guidelines and training for its registrants.

Professionals with agency can use the knowledge and resources, in whole or in part, as a basis for revising and creating new policy around economics, planning, development, disaster risk mitigation, and disaster response. This, in turn, impacts all aspects of development, including land acquisition, financing, schematic design, approvals, construction, and occupancy, and ultimately influences our connection with nature, relationship with community, food and clean water security, and health; in short—our sustainability (Figure 3).

Members of professional associations use data produced by all levels of government, NGOs, and academic institutions as well as data created through their own work; they benefit greatly from open-source educational material posted to academic and research websites. It is often open-source material and member- or colleague-produced work that is posted by professional associations on the web and social media, newsletters, and magazines.

Figure 3: The knowledge professionals learn allows them to create new policy that affects all aspects of land development (Photo: LADR Landscape Architects).

Professional associations mostly use open-access information on climate and disasters. The sources include but are not limited to:

- Action on Climate Team
- Prairie Climate Centre
- Adaptation Learning Network
- Natural Resources Canada Climate Change Adaption Platform
- Climate Data Canada
- Fraser Basin Council Retooling for Climate Change
- International Panel on Climate Change
- Preparing Our Home – Sharing Circles
- Aboriginal Housing Management Association

GAPS

To fully understand climate and disaster risk and what professionals can do in managing the risk, a body of knowledge is required. This knowledge needs to be transdisciplinary, interprofessional, cross-cutting, and accessible; it needs to include Indigenous Knowledge and nature-based solutions. In this instance, accessibility includes use of a common language because community wellbeing, design, and scientific vernaculars may not be interchangeable, and if the exchange of knowledge is not clear, much may be lost in translation. The knowledge must address scale and all facets of disaster risk, including but not limited to: health, culture, economics, livelihood, food security, clean water and air, infrastructure, structure, and environment. A common repository of knowledge to hold information about hazards, risks, and responses would be useful, as would a compilation of model bylaws and policies to address these risks. Access to data, information, and methods that are paid for with the public funds should be available to all professionals for use and to build on.

There is a huge demand from professionals for resources and guidance to support nature-based approaches to disaster risk reduction (DRR), especially resources to obtain the detailed and often extensive baseline information that is necessary for nature-based methodologies. Professionals are constrained in the approaches they can recommend by their minimal capacity to obtain data relevant for specific sites in the context of project-based work. Gathering baseline and monitoring data on a regional and sub-regional level relevant for ecosystems is critical.

> A body of knowledge is required . . . [that is] transdisciplinary, interprofessional, cross-cutting, and accessible . . . Access to data, information, and methods that are paid for with the public funds should be available to all professionals for use and to build on.

Climate change adaptation and DRR have evolved separately as areas of research, policy, and practice, and there are differences in terminology, values, and interests between the two. There are very few practice resources that integrate these concepts to accelerate progress on enhancing resilience.

There is a recognized disconnect between professional associations (and, by extension, their members) and Indigenous Peoples, and between these two groups together and the rest of society. Additionally, Indigenous representation within professional associations is low. Professional associations can attempt to address the disconnect with society through outreach, but there

APPLICATION OF THE SEISMIC RETROFIT GUIDELINES TO EXISTING LOW-RISE BUILDING STOCK IN BC

In 2019, the Building and Safety Standards Branch (BSSB) of the Office of Housing and Construction Standards in the Ministry of Municipal Affairs and Housing discussed with EGBC the initiative they were undertaking to develop a building code for existing buildings that would address seismic performance. BSSB was interested in considering if the *Seismic Retrofit Guidelines (SRG)* developed for the seismic assessment and retrofit for existing school buildings could be expanded for application to various types of existing low-rise building stock (three storeys or less) in BC.

The *Seismic Retrofit Guidelines Expansion Project – Low Rise Buildings* was dovetailed with the development of SRG2020 for existing school buildings by using the same technical methodology:

- Performance-based damage prediction: performance-based earthquake damage prediction that embraces a wide range in earthquake damage (minor damage to total damage)
- High-performance tools: user-friendly access to this analytical database by practitioners through use of a rapid parametric selection process.
- Guidelines: 12 comprehensive manuals fully detail the technical procedures and the technical background for the *Seismic Retrofit Guidelines*. Technical questions on the guidelines are answered by the EGBC Technical Review Board (TRB).

In addition, The National Research Council and Natural Resources Canada were involved in the development of *SRG2020 – Low Rise Buildings and the Seismic Performance Analyzer* in order to provide an independent assessment of a mature performance-based methodology. The intent of *SRG2020 – Low Rise Buildings* is to identify common minimum evaluation and mitigation measures for the seismic performance of existing buildings.

is no clear process for such action, and it would be incomplete without interprofessional and Indigenous Peoples' collaboration. The lack of collaboration and understanding of how associations and all Indigenous people can benefit from addressing DRR cooperatively is a significant worry as, regardless of their expertise, no one group has the knowledge or capacity to effectively address the complexities of disaster risk management on their own, and building relationships takes time. DRR is a wicked problem.

> There is a recognized disconnect between professional associations (and, by extension, their members) and Indigenous Peoples. . . . Additionally, Indigenous representation within professional associations is low.

Funding is insufficient for all aspects of DRR: trying new techniques and options at all scales; enabling access to climate and DRR info; doing educational outreach; undertaking discipline/interdisciplinary/Indigenous-based DRR research; preparing action-specific guidelines, and more.

Businesses' role in DRR is largely overlooked despite being impacted by, and contributing to, the effects of DRR. Firms providing professional services are starting to be regulated under the PGA. There are three pillars to the regulation of firms: ethics, continuing professional development, and quality management. While the process of regulation enables meeting requirements of the PGA and the bylaws, more work needs to be done to understand the full extent of the role that firms could have in relation to DRR.

OPPORTUNITY

RECOMMENDATIONS

In addition to Table 1 below, it is important to mention here a list of challenges and tasks that PAAWG[i] members identified, in 2016, to assist interprofessional collaboration. Tackling the list might be a timely first step:

- Create a shared vocabulary for communicating risk broadly, cross-disciplinary communication, and developing a business case for adaptation; create a process to support development of a shared vocabulary.
- Communicate climate action as a professional obligation and to empower professionals.
- Integrate climate and DRR skills into professional practice areas.
- Create shared and experiential learning opportunities and case studies to support building on successes and learning from failures.
- Increase the effectiveness of existing tools: disseminate existing tools and learning resources more widely and evaluate uptake of existing tools; develop memorandums of understanding between professional associations to share knowledge and provide access to the data and tools behind individual associations' website login (or locate knowledge on an open-source platform).
- Provide every professional with ongoing continuing professional development (CPD) and beyond-introductory climate adaptation/DRR knowledge.
- Check on use of guidelines (enforcement); if guidelines are not in place, develop them.
- Identify basic climate change impacts and DRR courses required for association registration or, if the professional is already registered, for CPD (like an ethics course).
- Create and use effective surveys to assess member awareness and involvement.
- Recruit mentors; potentially share mentors between associations.

[i] *PAAWG exists for the purpose of interdisciplinary collaboration among, primarily, professional associations focused on natural resources.*

Table 1: Recommendations

Recommendation[13]	Description of Impact	Priority Level	Capabilities Needed
1. Develop a collaborative community of practice amongst professional associations, and between professional associations and Indigenous Peoples.	Creates a venue for interdisciplinary collaboration, knowledge sharing, and a repository for shared resources and case studies (exemplars).	Critical	Non-volunteer to facilitate discussion, training, etc.; knowledgeable participants; Indigenous participation may need separate funding.
2. Develop guidelines for the relevant professionals on nature-based solutions for climate change adaptation, disaster risk management, and resilience.	Empowers action at various scales, costs, and levels of effort; opportunity for immediate action and outreach.	Critical	Funding and technical expertise for research and development.
3. Make the connection between climate adaptation and disaster risk reduction with GHG emissions reduction more explicit in guidelines and strategic frameworks of professional associations.	Enables strategic planning around "build-back-better" and maximizes co-benefits that reduce disaster risks and emissions.	Critical	Funding for outreach; leadership.
4. Create policies or guidelines to ensure disaster and climate risk management is incorporated into rezoning and development-related applications.	Helps protect the public and brings DRR expertise to rezoning and development approval processes.	Critical	A coordinated public–private sector effort; change to development approval policies (possibly legislation).
5. Provide open-source access to all disaster and climate risk management projects, research, and strategic planning that are paid for from public funds.	Reduces cost and speeds up risk data and DRR knowledge sharing by building on work already completed.	Recommended	A managed repository and jurisdictional willingness (this could be at the provincial level, extend across several provinces, or be national).

THE CHALLENGE

In addition to the above-mentioned gaps and recommendations, there are three complex challenges that stand out:

1. What legal liability does a professional take on, and for what period, when they become involved in DRR? Public sector requests for professional liability insurance coverage are often out of step with the level of risk inherent in a project.

2. In a DRR project, how is the professional's responsibility to have "current" knowledge measured, and who does the evaluation?

3. Professionals work for a variety of clients, including climate change skeptics and those who acknowledge climate change but are unwilling to engage in risk reduction efforts, usually due to cost. Without appropriate policies, regulations, and standards, knowledgeable professionals face the ethical dilemma and professional dilemma of interacting with a client that refuses to incorporate disaster and climate risk management measures into the project.

RESOURCES

1. Website geared to professionals in BC, who work at the front line of climate adaptation, to integrate adaptation competencies into their professional practice through education, training, and networking:

Adaptation Learning Network. "Inspiring Climate Action." Accessed March 3, 2022. https://adaptationlearningnetwork.com/

2. Geared to Engineers and Geoscientists in BC, these professional practice guidelines establish the expectations and obligations of professional practice in relation to specific professional activities:

Engineers and Geoscientists BC. "Professional Practice Guidelines." Accessed March 3, 2022. https://www.egbc.ca/app/Practice-Resources/Individual-Practice/Guidelines-Advisories

3. Guidance for resource professionals developed collaboratively by the College of Applied Biology and the Association of BC Forest Professionals, focused on stewardship of species at risk in BC:

College of Applied Biology. *Managing Species at Risk in BC*. 2009. Accessed March 3, 2022. https://www.cab-bc.org/file-download/guidance-resource-professionals-managing-species-risk-bc

4. Independent report on the Professional Reliance Review to inform efforts to strengthen professional reliance in the natural resources sector:

Haddock, Mark. *Professional Reliance Review*. 2018. Accessed March 3, 2022. https://professionalgovernancebc.ca/app/uploads/sites/498/2019/05/Professional_Reliance_Review_Final_Report.pdf

5. BC guide designed to assist local government elected officials and staff, including planners, engineers, chief administrative officers, financial officers and others, to plan and act in ways that will make their communities more resilient to the impacts of climate change:

West Coast Environmental Law. "Preparing for Climate Change – An Implementation Guide for Local Governments in BC." 2012. Accessed March 3, 2022. https://www.toolkit.bc.ca/Resource/Preparing-Climate-Change-Implementation-Guide-Local-Governments-British-Columbia

6. Several titles about urban design and sustainability:

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3.3 NATIONAL DISASTER MITIGATION PROGRAM OUTCOMES IN BC

June 2022

DRRPathways.ca

RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 3 Climate and Disaster Risk Management: Enabling Action*. To read all articles in the report, see DRRPathways.ca.

The Resilience Pathways Report is a project of Natural Resources Canada.

3.3 NATIONAL DISASTER MITIGATION PROGRAM OUTCOMES IN BC

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ABOUT THE NATIONAL DISASTER MITIGATION PROGRAM (NDMP)

The National Disaster Mitigation Program (NDMP) is the foundation for informed mitigation investments that could reduce, or even negate, the effects of flood events. The NDMP fills a critical gap in Canada's ability to effectively mitigate, prepare for, respond to, and recover from flood-related events by building a body of knowledge on flood risks in Canada and investing in key flood mitigation activities. Knowledge that is up to date and accessible will not only assist governments, communities and individuals to understand flood risks and employ effective mitigation strategies to reduce the impacts of flooding but will also further discussions on developing a residential flood insurance market in Canada.

The program was established as part of the Government of Canada's commitment to building safer and more resilient communities. Budget 2014 earmarked $200 million dollars (from 2015 to 2020) to support this new program. In light of the ongoing need for risk mitigation investments in Canada and a number of provinces and territories advocating for an extension of the NDMP, the Economic and Fiscal Snapshot 2020 earmarked funding for NDMP renewal for two additional years (2020 to 2022). There are four funding streams under the NDMP:

1. **Risk Assessments** – This stream provides funding for the completion of risk assessments to inform flood risks. Risk assessments are the foundational step in disaster risk mitigation; they identify flood hazards, potential impacts, and community and infrastructure vulnerabilities as well as the overall flood risk profile for the area.

2. **Flood Mapping** – This stream provides funding for the development and/or modernization of flood maps. A flood map identifies the boundaries of a potential flood event based on type and likelihood, and it can be used to help identify the specific impacts of a flood event on structures, people and other assets.

3. **Mitigation Planning** – This stream provides funding for the development and/or modernization of mitigation plans to address flood risks. A comprehensive mitigation plan allows applicants to develop realistic and sustainable mitigation solutions by clearly outlining the plan's objectives, key activities,

expected outputs, timelines, and roles and responsibilities.

4. **Investments in Non-structural and Small-Scale Structural Mitigation Projects** – This stream provides funding for other non-structural and small-scale structural risk mitigation projects. Eligible projects would include actions such as the replacement of storm culverts, or would improve flood resilience by proactively preventing or mitigating damages and losses.

From 2015 to 2022, the NDMP funded 460 projects across Canada, including 132 in BC, and contributed to an increase of communities that undertook mitigation investments to reduce their vulnerability to disasters. The program helped small, rural communities and municipalities (median population size of recipient communities is 18,000) in mitigating the social and economic impacts of floods; it funded communities with higher representations of vulnerable populations, such as seniors and Indigenous people, and its sequential stream approach provided the prerequisites to develop a residential flood insurance market in Canada.

Flooding is the most common natural hazard affecting Canadian communities, and among the most costly.[1] Between 2008 and 2018, the Canada Disaster Database recorded 170 major disasters resulting in tens of billions of dollars in damages; of these, 108 were flood-related events, including flooding from major storms. Since 1970, the Government of Canada has paid out an estimated $8.5 billion dollars in post-disaster assistance through the federal Disaster Financial Assistance Arrangements (DFAA) to assist provinces and territories with response and recovery costs. Of these costs, 97% occurred in the past 25 years, and more than one-third occurred in the past six years alone, which indicates that disasters are increasing in both frequency and cost. This is due to the growth of population and assets. Canada's population has grown by 80% since 1970 and many of the assets are built on floodplains. The increase can also be attributed to climate change to some extent. Flooding now accounts for nearly 75% of DFAA events and two-thirds of all DFAA payments.

ALIGNMENT WITH THE SENDAI FRAMEWORK

The NDMP was informed by, and seeks to align with, the *Sendai Framework for Disaster Risk Reduction 2015–2030*, which advocates for a substantial reduction of disaster risk and losses in lives, livelihoods and health as well as in economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries. The NDMP is divided into four funding streams that seek to both address and operationalize the Sendai Framework's four action priorities.

Stream 1 (Risk Assessments) and Stream 2 (Flood Mapping) align with Sendai Framework Priority 1, *Understanding disaster risk*, by developing an understanding of disaster risk in the various dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics, and the environment. Stream 3 (Mitigation Planning) is informed by Priority 2, *Strengthening disaster risk governance to manage disaster risk*, and Priority 4, *Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation, and reconstruction*. Stream 4 (Investments in Non-structural and Small Scale Structural Mitigation Projects) directly relates to Priority 3, *Investing in disaster risk reduction for resilience*, by providing public investment in disaster risk prevention and reduction through structural and non-structural measures.

The NDMP incorporates the guiding principles of the Sendai Framework, which recognizes the shared responsibility between governments, sectors and stakeholders, through its cost-sharing mechanism with provinces and territories, in addition to recognizing the primary responsibility of the federal government in preventing and reducing disaster risk. The program empowers local authorities and communities by funding the development of resources, providing incentives, and helping to inform decision making. The NDMP further encourages stakeholder and public engagement from across society, providing eligible funds for workshops and consultations as well as national public awareness and engagement activities to advance the discussion on overland flood insurance.

NDMP'S EFFECT ON PRACTICE

The following discussion is informed by a desktop document review, interviews with NDMP recipients, and input from the Province of BC, focusing on qualitative data. The desktop document review considered corporate, policy and program documents, and public reports. Four semi-structured interviews were conducted with representatives or recipients of six NDMP projects: Okanagan Basin Water Board, Cowichan Valley Regional District, Fraser Basin Council, and Capital Regional District (note that some entities had more than one project). The cross-section of representatives included directors and project managers, providing important perspectives on outcomes and outputs of the NDMP at local and regional levels. In addition, Public Safety Canada sought input from Emergency Management BC, which works closely with the department to administer the NDMP across the province. This report seeks to fill an identified limitation in the standard national evaluation of the NDMP, which does not involve communities directly. Public Safety Canada typically works in collaboration with counterparts in provincial or territorial governments rather than the communities benefiting from NDMP project funding.

Overall, there was consensus among recipients that the NDMP projects met the objectives of being able to effectively mitigate, prepare for, respond to, and recover from flood-related events by building a body of knowledge on flood risks in Canada, and by investing in foundational flood mitigation activities. As many of the projects undertaken by recipients fell under Streams 1, 2 and 3, no direct quantitative data was collected to determine how the recipient projects have reduced the impacts of disasters on area residents. However, interviewees indicated that the work completed through NDMP projects has contributed to reducing disaster impacts and greatly improved disaster planning and mitigation (Figure 1).

NDMP projects met the objectives of being able to effectively mitigate, prepare for, respond to, and recover from flood-related events by building a body of knowledge on flood risks in Canada, and by investing in foundational flood mitigation activities.

INFORMATION PRODUCTS

A number of the recipients stated that they were satisfied with the information products (e.g., maps, reports, assessments) that were developed with NDMP funding. These information products have led to a better understanding of local and regional flood risk and have highlighted major gaps in flood management. Maps, in particular, have been incorporated into local government planning and public websites, contributing to an increase in available information at the local level, technical analysis, and informing policy decisions for a long-term flood strategy. The Capital Regional District noted the importance of translating the technical reports into more "public-friendly" material, including summary documents with key findings. These products have played an important role in informing inter-municipal networks and provincial agencies. The Cowichan Valley Regional District indicated that the outputs of the program are now informing the Province of BC's approval process for land-use products and the maintenance of infrastructure.

All of the project funding secured by the Fraser Basin Council relates to a multi-year initiative for the Lower Mainland Flood Strategy. The Fraser Basin Council noted that the hydraulic model was used by the City of Chilliwack to model dike scenarios and develop flood bylaws to reduce flood risks. Similarly, Cowichan Valley Regional District's tools have been translated into planning and development procedures, including public communications, bylaws, and permits. Okanagan Basin Water Board notes that the central Okanagan is now able to conduct non-structural flood mitigation planning based on the results of the mapping. Now that the project outputs and tools are available for long-term use, they have begun

Figure 1: Construction of a new pump station (Photo: NDMP).

to foster improved land management and building practices.

Final products were shared widely within municipalities and among government officials and staff, Chiefs and councillors, and emergency managers. The Fraser Basin Council established joint committees between managers, practitioners, and representatives from local governments as well as project specific advisory committees. The modelling and reports were made available to the public, and the Fraser Basin Council interviewee highlighted the importance of developing an executive summary, digital presentations, FAQ material, and other background documents with plain language and simplified terminology to ensure the information was accessible. All participating organizations were informed that the outputs and maps were available for their use.

STAKEHOLDER ENGAGEMENT

All six interviewees indicated that they sought to encourage and incorporate a high level of stakeholder engagement and collaboration in their NDMP projects. While the NDMP does not mandate the creation of stakeholder networks, it does encourage the use of new and existing networks to accommodate the project needs. For example, the Fraser Basin Council noted challenges in capacity and technical expertise that made the ability to participate in this particular project challenging, so it set up data-sharing agreements to manage and track the use of GIS maps and modelling.

All of the recipients interviewed recognized the work accomplished to date to engage First Nations, though they also acknowledged the ongoing need for continuous engagement. Indigenous input through workshops, stakeholder committees, and working group meetings has informed priorities and the direction of the projects. For example, the Fraser Basin Council helped establish an emergency planning secretariat based on a community member's suggestion, which was then led by an Indigenous organization to support and promote Indigenous engagement for the Lower Mainland Flood Strategy. The Okanagan Basin Water Board noted that local Indigenous communities contributed to the knowledge base of historical flooding in the region.

The Capital Regional District indicated that involving the public, elected officials, and municipal staff in its NDMP projects raised the public profile of flood preparedness. Local elected officials and municipal staff learned that they have the responsibility to prepare for, and build the capacity for, flood events and emergencies. The project highlighted impacts of potential flood events and prompted policy decisions.

REGIONAL SCALE, FUNDING, AND FOCUS

A key advantage of the NDMP is that it provides an opportunity for communities to receive funding for regional projects and tools. The Fraser Basin Council and Capital

Regional District highlighted the importance of regional cooperation in the development of these types of projects, as it can be helpful to smaller communities that may not have the resources—including funds, staff, and project management expertise—to complete substantial mitigation work independently. NDMP funding enables a regional scope to help develop context-driven tools within local areas and facilitate greater relationship building between municipalities and communities. This helps to create knowledge and foster long-term strategic planning, which is important as emergency management staff are often preoccupied with other incidents or events.

> The Fraser Basin Council and Capital Regional District highlighted the importance of regional cooperation in the development of [NDMP-funded] projects, as it can be helpful to smaller communities that may not have the resources . . . to complete substantial mitigation work independently.

The majority of the projects that were managed by the interviewees for this report fell into the Stream 1 and 2 categories, which may affect the responses received. For example, while NDMP funding informed planning efforts as a result of the assessment and mapping stages, it is difficult to determine the value of reduced disaster-related financial liabilities for municipal, provincial or federal governments (the objective of the NDMP).[2] However, the recipients overwhelmingly stated that their projects contributed towards reducing financial liabilities, as these projects triggered policy work and decision making at the municipal level which is effecting changes to future developments and spin-off projects.

NDMP recipients emphasized that the focus of the NDMP on flood-related disaster and mitigation planning and the integrated approach to flood risk management (i.e., the varied funding streams and breadth of eligible projects) was positive. However, they also called for an all-hazards approach to the program to recognize disasters beyond floods. The recipients acknowledged alternative funding sources,[3] such as the UBCM Community Emergency Preparedness Fund or the Disaster Mitigation and Adaptation Fund from Infrastructure Canada. Even so, the NDMP was noted as possessing numerous advantages, such as being better suited to the proposed projects and possessing a larger pool of available funding. In addition, it was noted that as a result of provincial caps, current funding earmarked for risk mitigation at the provincial level is not sufficient. Nearly all recipients interviewed asserted that they would have been unable to complete their respective projects without funds through the NDMP, given the lack of a comparable alternative. Interviewees further stated that they hoped to receive future NDMP funding to continue the work funded to date.

INDIGENOUS PARTICIPATION

Program recipients present at each interview highlighted the importance of Indigenous participation and input into the plans. The Fraser Basin Council indicated that their flood planning efforts were greatly informed by Indigenous and non-Indigenous local governments. One of the biggest gaps noted in the mapping products produced was the lack of information pertaining to First Nations sites of interest; these includes land, treaties, buildings, assets, traditional fishing sites, erosion areas, and cultural and sacred sites. As a result, the potential sensitivity of mapping a number of these areas, the lack of publicly available data, and the need to obtain consent from First Nations created a complex and challenging situation for project managers.

The Fraser Basin Council risk assessment included categories related to social vulnerabilities based on census data but acknowledged not seeking out other vulnerable populations in addition to Indigenous communities. The Capital Regional District indicated that discussions are ongoing to address the needs of transient populations, Elders, and seniors.

The potential sensitivity of mapping First Nations sites of interest, the lack of publicly available data, and the need to obtain consent from First Nations created a complex and challenging situation for project managers.

OPPORTUNITY

Interviews with NDMP recipients identified many similar opportunities and challenges. Some of these were included in the 2019 *Evaluation of the National Disaster Mitigation Program,*[4] but many were findings that are specific to local and regional perspectives (Table 1).

PROGRAM CHALLENGES AND RECOMMENDATIONS

Overall, the program recipients interviewed had positive feedback to share regarding NDMP funding and the outcomes of their projects. Many emphasized the collaborative nature of the work and sharing of joint successes. Despite the sometimes ambitious nature of these projects, overall project management has proceeded smoothly, though it was noted that this may be due to the organizations interviewed having greater capacity than some smaller communities. Recipients acknowledged, though, that as the impacts of climate change continue to be felt, there will be an increased demand for disaster and climate risk mitigation funding.

Many recipients disclosed that the NDMP timelines were challenging to meet, especially given the complexity of the projects, requirement for stakeholder input, and numerous COVID-19 complications causing delays. Recipients further indicated that the limited number of consulting firms available to undertake risk mitigation work contributed to sometimes lengthy delays, as there can be more projects than technical consultants available. Consultant firms often work on multiple NDMP projects with the same deadline for deliverables, which causes timeline issues due to lack of capacity. Other issues identified include a delay in receiving GeoBC LiDAR data, which resulted in projects using existing LiDAR, rather than waiting for the 2019 data to become available. Challenging site conditions, such as high river levels, also caused surveying delays; hydraulic modelling was then delayed due to river surveys having not been completed. Finally, permitting challenges impeded progress and result in structural project delays.

A number of general project administration challenges were identified by recipients for future consideration. One interviewee requested that the program look to minimize or lessen the burden of proof for applicants. For example, is it necessary to provide evidence that climate change will impact the west coast, or can it now be considered common knowledge? Another area of concern was identified by Emergency Management BC, which indicated that Request for Proposals templates often resulted in higher actual costs than were estimated in the proposals, creating requests for downward scope amendment at a later date. Other recipients echoed that their proposals had underestimated the complexity and cost of the projects and noted that there was also a lack of clarity and definition for each eligible expense category in the budget. There was a desire for further standardization and guidance in terminology and methodology, to ensure regional, national and international alignment; this includes improving the sharing of information, plans, and strategies across jurisdictions.

To fully realize the disaster reduction goals of the Sendai Framework, the Government of Canada should consider broadening NDMP eligibility to reflect an all-hazards approach.

As part of this project, NDMP recipients spoke candidly of the benefits and challenges of obtaining federal funding, proposing numerous programmatic tweaks that would improve program administration. It was acknowledged, however, that a key limitation of the NDMP is that, to date, it only funds mitigation for flood-related risks. And while the Disaster Mitigation and Adaptation Fund (DMAF) funds structural and natural infrastructure projects to increase the resilience of communities that are impacted by hazards triggered by climate change, to more fully realize the disaster reduction goals of the Sendai Framework, the Government of Canada should consider broadening NDMP eligibility to reflect an all-hazards approach.

Following the NDMP's 2019 *Evaluation* recommendations, future mitigation programming will be considering interplays between hazards to increase resilience in Canadian communities and reduce the overall disaster risk to individuals and their homes.

Table 1: Recommendations

Recommendation	Description of Impact
1. Simplify project administration: • Lessen the burden of proof for applicants (i.e., on providing evidence that climate change will impact the West Coast). • Adjust templates to ensure they better reflect the complexity and cost of projects. • Standardize guidance and terminology.	Reduces the amount of time and number of resources or capacity recipients need to dedicate to the application process.
2. Adapt timelines to ensure they can be met by recipients.	Increases the maximum number of eligible recipients applying to NDMP.
3. Broaden NDMP eligibility to reflect an all-hazards approach.	Enables recipients to apply for mitigation funding to address other hazards, such as wildfires.
4. Increase disaster and climate risk mitigation funding.	Reduces the impacts of climate change being felt by communities.

ENDNOTES

[1] Public Safety Canada, "Evaluation of the National Disaster Mitigation Program (2019)," https://www.publicsafety.gc.ca/cnt/rsrcs/pblctns/vltn-ntnl-dsstr-mtgtn-prgrm-2019/index-en.aspx

[2] As part of the Canadian Safety and Security Program 2018 Call for Proposals, an *Adaptation Project Return on Investment Toolkit* is in development to help city officials evaluate the dollar amount of disaster risk reduction by assessing natural hazard impacts to economic, social, environmental, and cultural assets. https://aecom.com/wp-content/uploads/2021/07/SUSTAINABILITY-PROJECTS.pdf

[3] Government of British Columbia, "Emergency management financial supports," https://www2.gov.bc.ca/gov/content/safety/emergency-management/local-emergency-programs/financial

[4] Public Safety Canada, *Evaluation*.

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3.4 OPEN DISASTER RISK REDUCTION DATA PLATFORM

June 2022

DRRPathways.ca

RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 3 Climate and Disaster Risk Management: Enabling Action*. To read all articles in the report, see DRRPathways.ca.

The Resilience Pathways Report is a project of Natural Resources Canada.

3.4

OPEN DISASTER RISK REDUCTION DATA PLATFORM

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ABOUT THE OPENDRR PLATFORM

The Open Disaster Risk Reduction Platform (OpenDRR Platform) aims to provide tools to share hazard and risk data such that users can investigate, assess, and mitigate earthquake disasters. It is specifically aimed at policy makers, risk analysts, private and public institutions, and citizens, to facilitate decision making prior to a crisis. The platform is under development and is intended to be launched in the fall of 2022.

Developed by Natural Resources Canada (NRCan) to support with delivery of a national assessment of earthquake risks, the OpenDRR Platform is middleware between hazard or risk modelling platforms like OpenQuake and end users who need to understand and evaluate risk to make investment and policy decisions. The end-user interface will operate as a web application using standard web browsers in desktop, tablet, or hand-held device environments.

Development and execution of hazard and risk assessment models is a separate process, outside of the OpenDRR system. OpenDRR receives output from these models as input, using one or more interfaces and interchange formats based on existing standards or on specifications developed by the implementation team if no standards meet the requirements.

The high-level goals for OpenDRR are:

- Support open and collaborative development, using science outputs
- Provide centralized access to the science outputs
- Provide tools and applications to engage users, transfer information, and support decision making with respect to mitigating risk
- Improve the efficiency of disseminating risk assessments results

RISK MANAGEMENT

OpenDRR provides access to datasets that help improve understanding of the earthquake risks in Canada through a variety of industry accepted standards and best practices for geospatial data dissemination. The multichannel approach, which includes application programming interfaces (APIs), web applications, and dashboards, serves to reduce barriers to the reuse of project assets. By reducing the barriers for all stakeholders to access, explore, and visualize earthquake risk information, the platform ensures that timely access to authoritative information about earthquake risk can be utilized to build disaster resilience.

Emergency response planners will have at their disposal a suite of data products, as well as supporting web applications, that can be readily used in emergency planning. Two key elements of Open DRR are purpose-built to serve the community: 1) a dashboard that is highly customizable and allows individuals and organizations to create public or private spaces where they can query and intuitively visualize all available data; and 2) a purpose-built application, called RiskProfiler, that seeks to communicate the key messages relating to earthquake risks without any technical capacity on the part of the user.

> [OpenDRR's] multichannel approach . . . [reduces] the barriers for all stakeholders to access, explore, and visualize earthquake risk information . . . to build disaster resilience.

These elements will allow an emergency manager to obtain information about potential impacts from earthquake scenarios, such as anticipated demands on the healthcare system, disruption to housing, or financial impacts.

This information can be used to develop emergency response plans and training exercises. Emergency managers, for example, will be able to use the platform to build resilience into response plans by working with healthcare planners to expand hospital surge capacity. As well, OpenDRR will provide decision makers and the general public with comprehensive dynamic map visualization (showing earthquake scenarios) for all regions in Canada. This will give information, for example, on which construction types are most at risk and may therefore be in need of seismic retrofitting so as to prevent building collapse in the event of an earthquake.

The platform will support more efficient delivery of NRCan risk assessments over time while providing a place for ongoing contribution to NRCan's risk models, and it will address the current paucity of mechanisms by which to access seismic risk information. While existing applications like GeoBC's Common Operating Picture[1] provide situational awareness after an event occurs, OpenDRR will provide comprehensive, public, nationwide information about seismic risk that can be used for preparedness and mitigation.

PLATFORM DEVELOPMENT

Early stages of OpenDRR data platform development were part of the DRR Pathways project of NRCan, contributing to two objectives of the project: "Enhancing understanding of disaster risk" and "Strengthening risk governance through knowledge exchange and community engagement."

The initial requirement focused on earthquake risk, but with a desire to include other natural hazard types (e.g., landslides, wildfires, flooding, tsunami). The decision was made to focus on earthquake risk and bring in additional hazards when the platform was more mature. Earthquake risk data and information in OpenDRR does not include secondary perils like aftershocks, landslide, liquefaction, or tsunami. Data is provided for all populated regions of Canada.

The scale and scope of the data involved in the project necessitated an approach that not only streamlined the production of science-based outputs, but also provided for a high degree of collaboration across many disciplines (e.g., policy, technology, and science) and stakeholders (e.g., provincial and municipal).

Decision-support requirements were well understood at the outset. A comprehensive set of requirements for a multitude of stakeholders was developed.[2] The diversity of the stakeholders and their specific needs necessitated a multichannel approach since a single application (ex: only API) was deemed to be insufficient to serve all use cases effectively.

With development led by the Government of Canada, the platform had to comply with requirements for publishing science outputs, including standardized metadata, open data, support for both official languages, accessibility, and compliance with scientific integrity and publication policies. The scientific integrity and publishing requirements were particularly problematic as they have traditionally pushed the science and development behind closed doors. To comply with policy while supporting the objectives of the project, a balanced approach that prioritizes openness and transparency is needed.

The generation of science outputs is becoming increasingly reliant on software to automate processing, quality control, and publishing. Considerable attention was paid to alignment with best practices for Open Science.[3] As such, OpenDRR adopted FAIR Principles[4] (findability, accessibility, interoperability, and reuse of digital assets), which emphasize machine-actionability of data, and R5 Principles[5] (re-runnable (R1), repeatable (R2), reproducible (R3), reusable (R4), replicable (R5)), which describe ideal characteristics of software code that is released as a scientific output.

ALIGNMENT WITH THE SENDAI FRAMEWORK

OpenDRR supports Canada to achieve the first priority for action: understanding risk. Risk indicators provided on the platform also align with targets established by Sendai to support end users to develop resilience strategies that are aligned with this global framework. It allows practitioners to understand the current seismic risk facing Canadians and to explore ways in which that risk could be lessened, and by how much.

PLATFORM DESIGN

SOURCE DATA

Source data for this project includes the National Human Settlement Layer (physical exposure and social fabric), the National Seismic Risk Model for Canada (CanadaSRM, probabilistic), Canada's National Earthquake Scenario Catalogue (deterministic), and boundary geometries adapted from 2020 Statistics Canada, 2016 Census – Boundary files. The National Human Settlement layer includes a social vulnerability component that addresses the challenges posed to disadvantaged groups and help end users understand how they can create more equitable strategies to benefit the most vulnerable members of society.

TECHNOLOGY STACK

The OpenDRR technology stack (Figure 1) is made up of four main components: 1) Data Processing Pipeline, 2) GitHub, 3) Applications, and 4) Federal Geospatial Platform.

DATA PROCESSING PIPELINE

The OpenDRR data processing pipeline (Figure 2) is responsible for extracting, transforming, and loading data. It consists of several open-source technologies, namely PostgreSQL with PostGIS extension, and Python.

OPENDRR GITHUB

GitHub[6] was chosen as the platform (Figure 3) to support the development of the science outputs and related software, documentation, and tools. While well known in the software development community, it is relatively lesser utilized in the science community. However, the core functions of GitHub (e.g., versioning, repositories) were recognized to be beneficial by key contributors.

Where possible, runnable code is available to ensure transparency in the science. For example, an interested party could clone a repository and replicate a particular output, such as a dataset or even the entirety of the OpenDRR infrastructure. GitHub makes heavy use of containerization and infrastructure as code technologies for rapid deployment on personal computing devices or the cloud.

Built-in features of GitHub, such as continuous integration and deployment, community building, websites, peer review, and secure workspaces, are tools for achieving an open and collaborative approach to science, one that seeks to build consensus and drive engagement throughout its lifecycle.

Fortunately, GitHub provides many of the statistics that feed key performance indicators, such as visitor count, number and type of downloads, and number of followers, to name a few. These will help contributors and stakeholders measure impact, sentiment, and reuse of project assets over time.

GitHub also provides robust auditing, allowing project leads to follow up on contributions as required—for example, to determine what changes were made and by whom. This functionality helps to support integrity in the science carried out on the platform and allows users from outside of the core project team to comment or contribute safely.

APPLICATIONS

Due to the diversity of use cases and user profiles for the information products (e.g., maps, visualizations), it was clear that a single solution would not be sufficient. It was determined

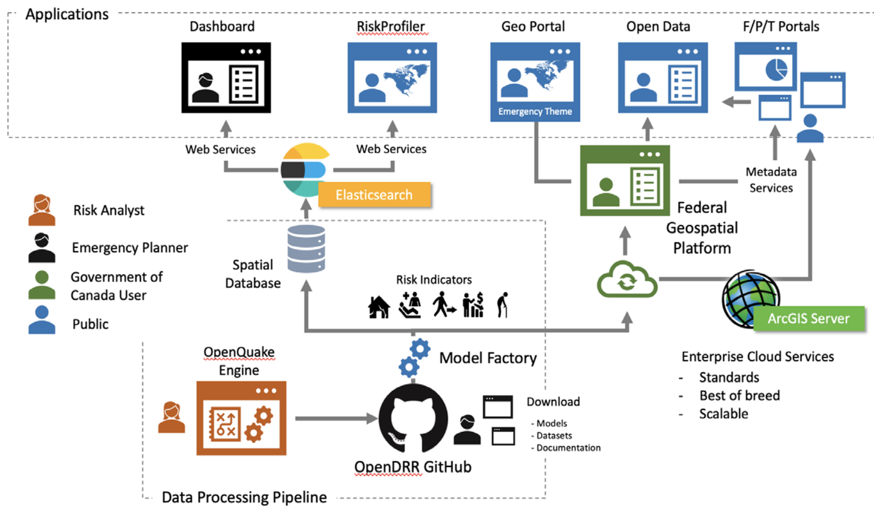

Figure 1: OpenDRR architecture overview.

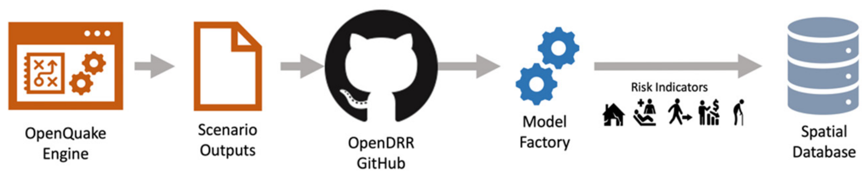

Figure 2: Data processing pipeline.

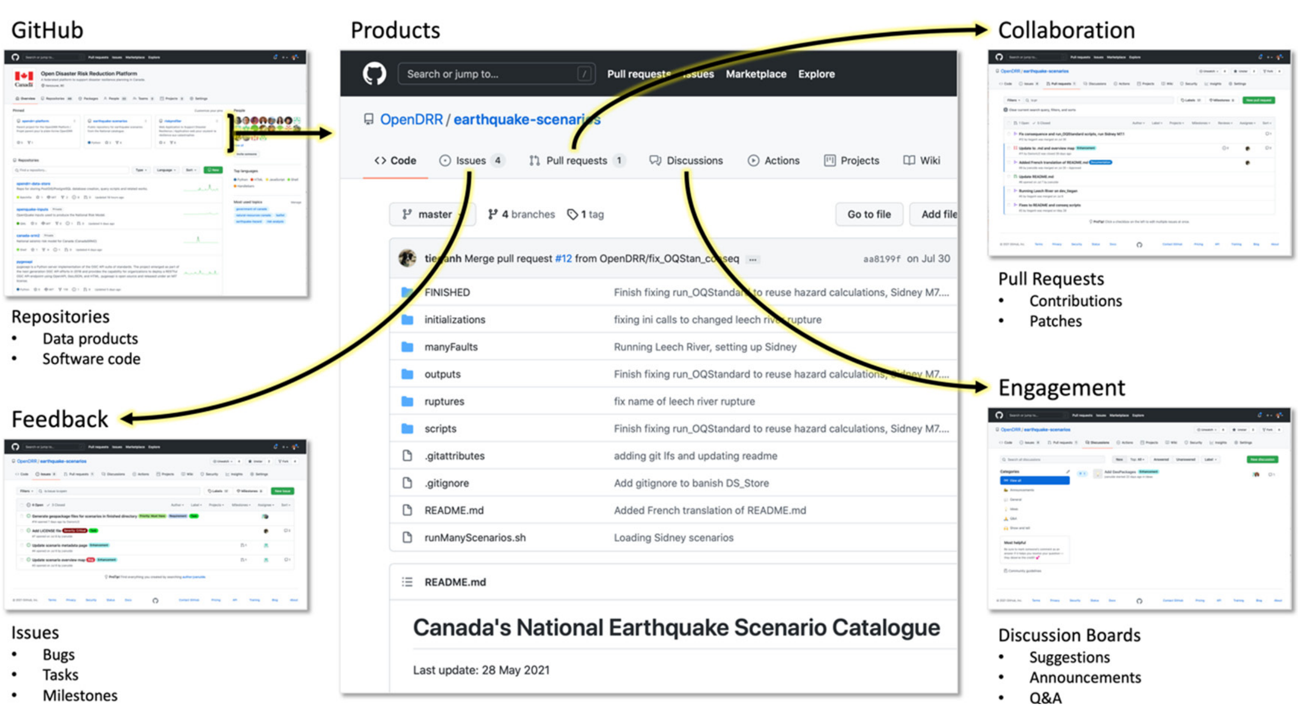

Figure 3: OpenDRR GitHub.

that a purpose-built web application (RiskProfiler) and a dashboard (Kibana) would be required to meet the needs of all users.

RiskProfiler Web Application

RiskProfiler (Figure 4) aims to provide planners and emergency managers with information on earthquake risks. This includes deterministic and probabilistic earthquake risk assessment results at a neighbourhood scale, across Canada. The scenarios are organized into a library that users can filter based on a variety of properties (e.g., location, magnitude). The library will grow over time to include more than one hundred deterministic scenarios covering the highest risk regions across Canada.

> RiskProfiler aims to provide planners and emergency managers with information on earthquake risks. This includes deterministic and probabilistic earthquake risk assessment results at a neighbourhood scale, across Canada. . . . Scenario properties can be adjusted to indicate how structural mitigation (retrofit) can affect loss.

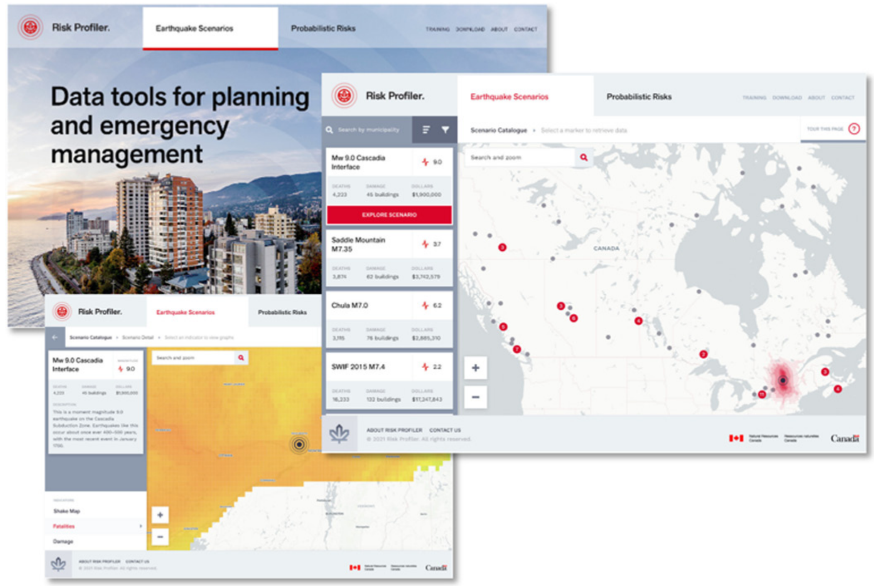

Figure 4: RiskProfiler.

The scenarios and associated risk information are intended to support emergency planning. Users are provided with a variety of visualizations that express the nature of the risk and the impacts that it may have on a community. These impacts are quantified, and in many cases, scenario properties can be adjusted to indicate how structural mitigation (retrofit) can affect loss. For example, the location and number of damaged buildings can be viewed for current conditions, or a toggle can be used to view the same metric if all buildings were brought up to modern design levels.

Kibana Dashboard Application

The Kibana Dashboard (Figure 5) is intended to support a more specific or sophisticated use case than that of RiskProfiler.

The dashboard allows users to customize workspaces where they can collaborate with others on data visualizations and reports. The entirety of available data in OpenDRR is available to dashboard users. The data is identical to what is available via OpenDRR's APIs. Users can add or link additional datasets to combine the DRR Pathway's project data with their own. For example, users could integrate risk assessment datasets provided through the OpenDRR Platform with their own linear infrastructure data to visualize the intersection between seismic risk to buildings and the existing road network.

Users can create reports, data visualizations, and maps for an area of interest. Visualizations can be exported and embedded in presentations and websites. Kibana can also be used as a platform to develop complex queries that can

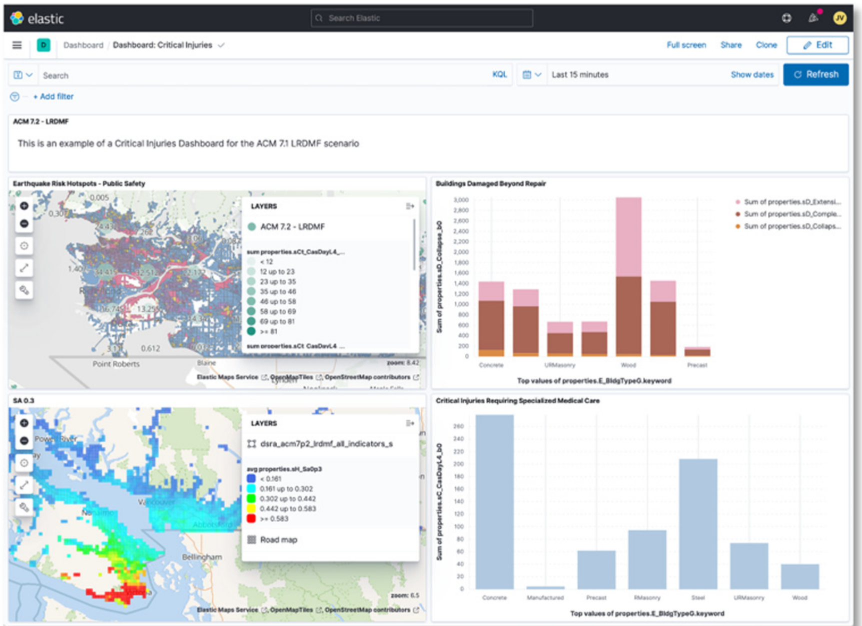

Figure 5: Kibana dashboard.

be sent directly to the Elasticsearch API. This is the first of such platforms to be made available to the public containing multi-scale risk data. It will be most useful to users who have one-off use cases, for example, those tasked with developing financial or insurance policy for a specific area.

FEDERAL GEOSPATIAL PLATFORM

The Federal Geospatial Platform (FGP) is a Government of Canada catalogue of geospatial data. The FGP provides enterprise-grade geospatial infrastructure and support services to facilitate the dissemination of data. OpenDRR datasets are hosted on the FGP and made available publicly via Esri REST services for organizations that utilize Esri-based tools and applications.

OPPORTUNITY

RECOMMENDATIONS

ADDITIONAL NATURAL HAZARD TYPES

Time will be needed to further build relationships with other federal partners who hold expertise in each of the other hazards. With this in mind, the decision was made to focus on earthquake risk and bring in additional hazards (e.g., landslides, wildfires, flooding, tsunami) when the platform is more mature.

There are several ways in which additional hazards can be added. They can be integrated fully or partially depending on the nature of the data and the capacity of the responsible party. For example, at the most basic level, a repository could be set up for each hazard type and the datasets, stored as release assets, could be easily propagated to the dissemination infrastructure by way of existing processes. A more advanced approach would be to generate the datasets from within the platform as it currently done for earthquakes; this would require a fair amount of scripting (e.g., Python, Shell) to achieve, but would not be impossible.

ENGAGEMENT

To engage the public more effectively and efficiently respond to queries about the science, the project will leverage the Discussions module in GitHub. The Discussions module can support FAQs, general discussions, feedback collection, or any other type of engagement. Outside of GitHub, the primary researcher would typically have to respond to queries on an ad hoc basis—a time-consuming but necessary task. The Discussions module could reduce the level of effort to support science hosted in repositories.

Other opportunities to engage with the user community will be explored as time and resources permit.

CHALLENGES

WORKING IN THE OPEN

Working in the open is standard practice in the software community, but this is not the case in the scientific community. Despite many science-based institutions promulgating FAIR and Open Science, they struggle to fully adapt to the very principles upon which these are based. Instead of working in the open from the outset, science continues to be carried out behind closed doors until such time that a final product is formally published. In part, this is a natural outcome of the way that the scientific community is structured—it is undesirable from a scientist's perspective to release to the public results which have not been reviewed. This is doubly true in the field of natural hazard and risk research, where outcomes may have direct tangible effects on the assets or safety of community members.

The science-based organization under which the OpenDRR platform is being developed decided to take a more liberal approach, open by default but closed where required. Internal policies regarding Open Science were not yet fully developed, therefore the approach was to do much of the science modelling and development in private repositories until peer review could be completed. It is expected that such work will be carried out in the open once Government of Canada policies and practices around Open Science are mature.

While not ideal, the OpenDRR did demonstrate that peer-review of science using GitHub was tractable. Transparency in the science that informs government policy is an important part of any democracy, and so the platform will continue to aspire to a future where policy-driven decisions are supported by data that is aligned with the principles of FAIR and Open Science.

CONTINUOUS INTEGRATION

It was readily apparent early in the development process that automation would be beneficial. In software development, continuous integration is a technology that integrates subsystems into larger systems on some predetermined event (e.g., tests have completed successfully for an update such as a bug fix). In the case of OpenDRR, continuous integration is used for software integration and data integration.

When new datasets are added and/or models are updated, automated tasks are run to deploy new services, downloadable assets, and metadata. This saves a significant amount of effort and reduces the amount of time it takes to make these assets available to the community.

In the case of OpenDRR software code, continuous integration scripts are used to prepare and publish containerized solutions, generate database scripts, generate configuration files, and run tests. Deploying systems into the cloud via continuous integration is in active development and is expected to further reduce the level of effort required to deploy the software stack.

SOFTWARE DEVELOPMENT LIFECYCLE

The intersection of science delivery and software development has traditionally been carried out independent of each other; that is, the science is completed and then the system is developed. With a very ambitious delivery schedule, it was decided to do both in parallel.

The Pathways OpenDRR development utilized the scrum process with two-week iterations. Tasks were assigned to each iteration and reported on every two weeks. The complexity of the products being developed necessitated a tight coupling of the raw science outputs with custom software and continuous integration processes.

This tight coupling presented several challenges. It was immediately apparent that a high degree of flexibility would need to be designed into the software to accommodate constantly changing data schemas. As well, the development of the science outputs moved at a much slower pace as it required collaboration with other scientists and peer reviews. The two-week iteration cycle resulted in too much overhead on the development of the science outputs, and therefore engagement with the science staff suffered.

GITHUB

The use of GitHub as a platform for the development of the science outputs was well received and uptake was high. The core concepts of GitHub were well understood, and the distributed nature of the platform proved to be a benefit during the COVID-19 pandemic, which saw most project participants working remotely, often disconnected from the enterprise network. Fine-grain control over access to repositories and associated assets was a critical factor in the success of the platform to support Open Science.

The 100-megabyte file size restriction imposed by the GitHub platform was an issue for some repositories. Thankfully, GitHub provides an alternative storage called "Git Large File Storage" (Git LFS) which was enabled on many repositories. Bandwidth quotas for Git LFS were exceeded. GitHub provides 1 GB of free storage and 1GB per month of free bandwidth. Additional costs were incurred to increase the quotas.

To mitigate the potential of increasing costs for managing large files, a strategy of including datasets and files in the release assets of a repository was adopted. GitHub allows for release assets (e.g., files, datasets) up to 2 GB to be stored and disseminated at no cost.

RESOURCES OR SIMILAR PROJECTS

As part of the requirements gathering exercise for the OpenDRR Platform a review of National and International risk portals, technologies and tools were reviewed and documented.[7] Descriptions and links are provided and can be found in Section 5.2 of *A Federated OpenDRR Platform to Support Disaster Resilience Planning in Canada: High Level Requirements – Risk Management Platforms*.

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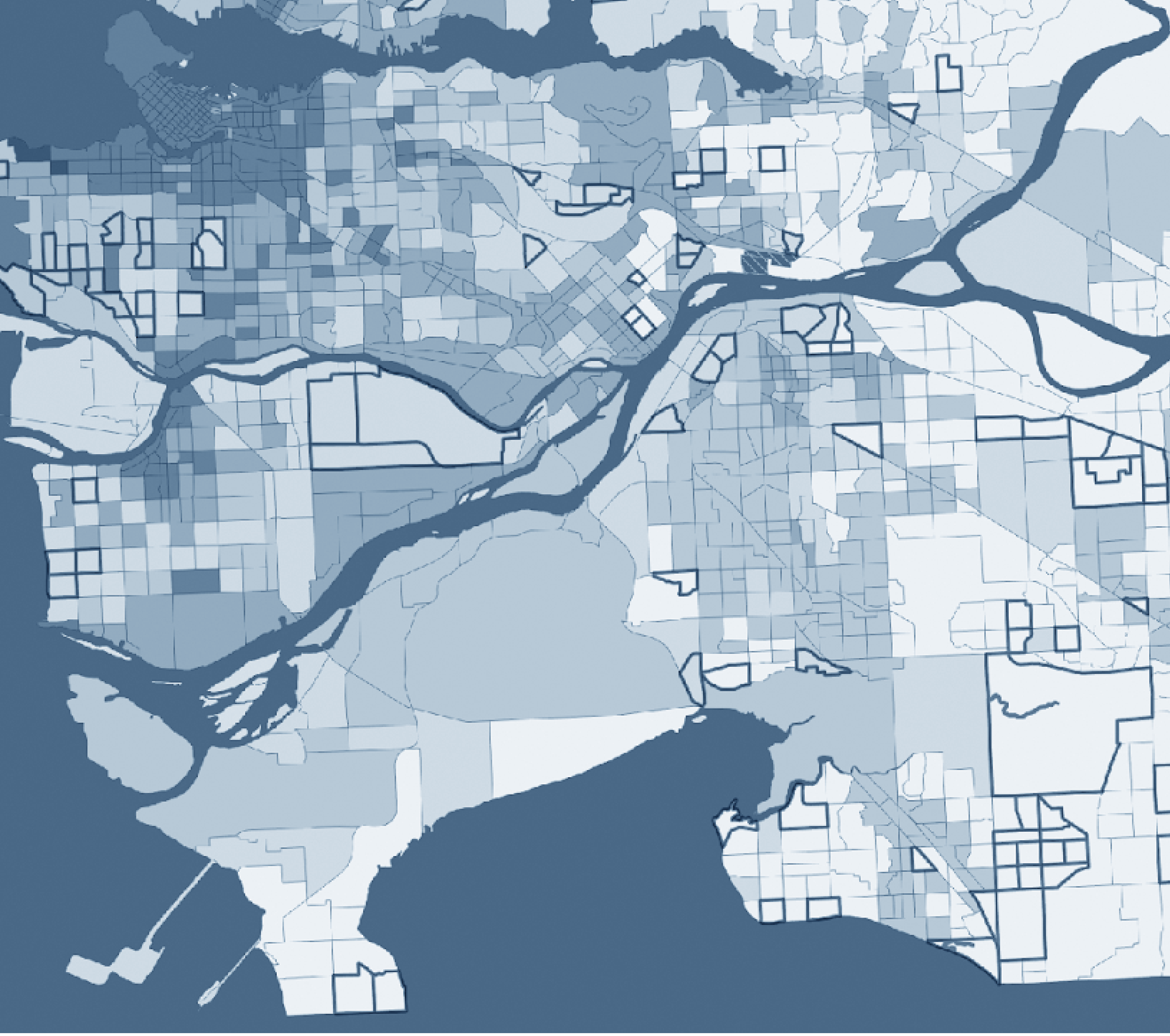

4.1 RISK DYNAMICS MODELLING IN METRO VANCOUVER

June 2022

DRRPathways.ca

RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

This article is part of the Resilience Pathways Report. The report has the following objectives: a) to share knowledge about existing practices and recent advances in understanding and managing disaster and climate risk in BC, including some information on relevant federal programs, and b) to provide insights on gaps and recommendations that will help build pathways to resilience in BC.

This article belongs to *Chapter 4 Climate and Disaster Risk Management: Research*. To read all articles in the report, see DRRPathways.ca.

The Resilience Pathways Report is a project of Natural Resources Canada.

4.1 RISK DYNAMICS MODELLING IN METRO VANCOUVER

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MODELLING NEIGHBOURHOOD EARTHQUAKE RISK DYNAMICS

Risk dynamics pertain to how the potential for disaster losses in urban areas may change over decadal timeframes. Disaster risk will transform over time in relation to factors such as population growth, land-use change, new construction, building code improvements, and changing social vulnerabilities. As time passes, the overall risk may increase or decrease, some types of losses may become more prominent, and the location of risk "hot spots" may shift. Efforts to anticipate future risk must consider not only shifts in numerous individual factors but also their layered interactions.

Similar natural hazard events can cause different degrees and patterns of loss depending on the moment they strike within a community's history.[1,2] Loss model results for today's conditions may present an inaccurate and even misleading portrayal of potential losses in future years. If disaster mitigation policies and plans are made without accounting for future risk increases, they may be unduly conservative and skewed in the direction of current-day conditions.

Understanding how neighbourhoods change over time, and the implications related to earthquake impacts, can help land use planners identify areas of high concentration of potential future risk that could be mitigated through planning and policy changes. As well, understanding the increased population displacement and the trends across the region in the event of a future earthquake can allow emergency preparedness planners at different levels of government to better plan for significant large-scale responses in different parts of the country.

ALIGNMENT WITH THE SENDAI FRAMEWORK

At the Third United Nations World Conference on Disaster Risk Reduction in 2015, delegates adopted the Sendai Framework for Disaster Risk Reduction 2015–2030. This framework identifies four priorities and seven key targets for policy actions to reduce disaster losses and the costs associated with disasters. Our project addresses two of the four action priorities identified under the framework: *understanding disaster risk* and *investing in disaster risk reduction for resilience*. This work also addresses several targets of the Sendai Framework, including *reducing the number of people potentially affected by hazard risk*, *reducing direct economic and service losses*, and *helping to create local risk reduction and recovery strategies*.

ESTIMATING FUTURE RISK IN METRO VANCOUVER

Our team partnered with colleagues from Metro Vancouver and the Geological Survey of Canada at Natural Resources Canada (NRCan) to better understand how seismic risk may change across the Metro Vancouver region over the coming decades, focusing on the effects of anticipated changes in population and the built environment. We drew on Metro Vancouver's long-range population and housing forecasts and NRCan's seismic hazard impact assessment results for different earthquake scenarios to develop a simplified Risk Dynamics Model for the region.

Metro Vancouver is a rapidly growing and changing region, encompassing 21 municipalities, one Electoral Area, and one Treaty First Nation. The region is active from a natural hazard perspective, vulnerable to a broad spectrum of seismic, flood, and weather events. The regional population of Metro Vancouver is expected to grow from 2.2 million in 2006 to 3.4 million by 2041, an increase of approximately 55%. *Metro Vancouver 2040*, the region's regional growth strategy adopted in 2011, identifies numerous priority issues, including responding to climate change impacts and natural hazard risks, especially earthquakes, floods, and slope instability.[3]
Metro Vancouver's regional growth projections were updated in 2019, providing a better understanding of how and where growth is expected to occur in the coming decades.

Past studies[4,5,6,7] have explored how similar disaster events occurring within the region could have very different impacts on society depending on when the event occurs in the region's development as structures are replaced, building codes change, and the population continues to rise. It is further noted that the development strategies (e.g., compact, status quo, or sprawled development) employed to accommodate that growth can affect how hazard impacts manifest. Recently updated earthquake scenarios developed by Geological Survey of Canada[8] allow us new insights into how earthquake shaking and its associated impacts may be distributed across the Metro Vancouver region.

To determine how the built environment in Metro Vancouver has changed historically, and how it is likely to change in the future, we first needed to establish a baseline set of neighbourhood archetypes. With this, we could explore how neighbourhoods in the region have changed over the past decade and estimate how they are likely to change in the decades to come. Using regional growth projections, we were then able to explore how a specific earthquake scenario may affect the region today and in the future. This process is summarized in Figure 1 and described in more detail in the following sections.

Similar disaster events occurring within the region could have very different impacts on society depending on when the event occurs in the region's development as structures are replaced, building codes change, and the population continues to rise. It is further noted that the development strategies (e.g., compact, status quo, or sprawled development) employed to accommodate that growth can affect how hazard impacts manifest.

STEP 1: UNDERSTANDING HOW NEIGHBOURHOODS CHANGE OVER TIME

To understand how the Metro Vancouver region's seismic risk is likely to change, we must first understand how neighbourhoods in the region have changed historically. This required establishing neighbourhood archetypes and examining how these archetypes have changed in the region over time. Census dissemination areas (DAs)

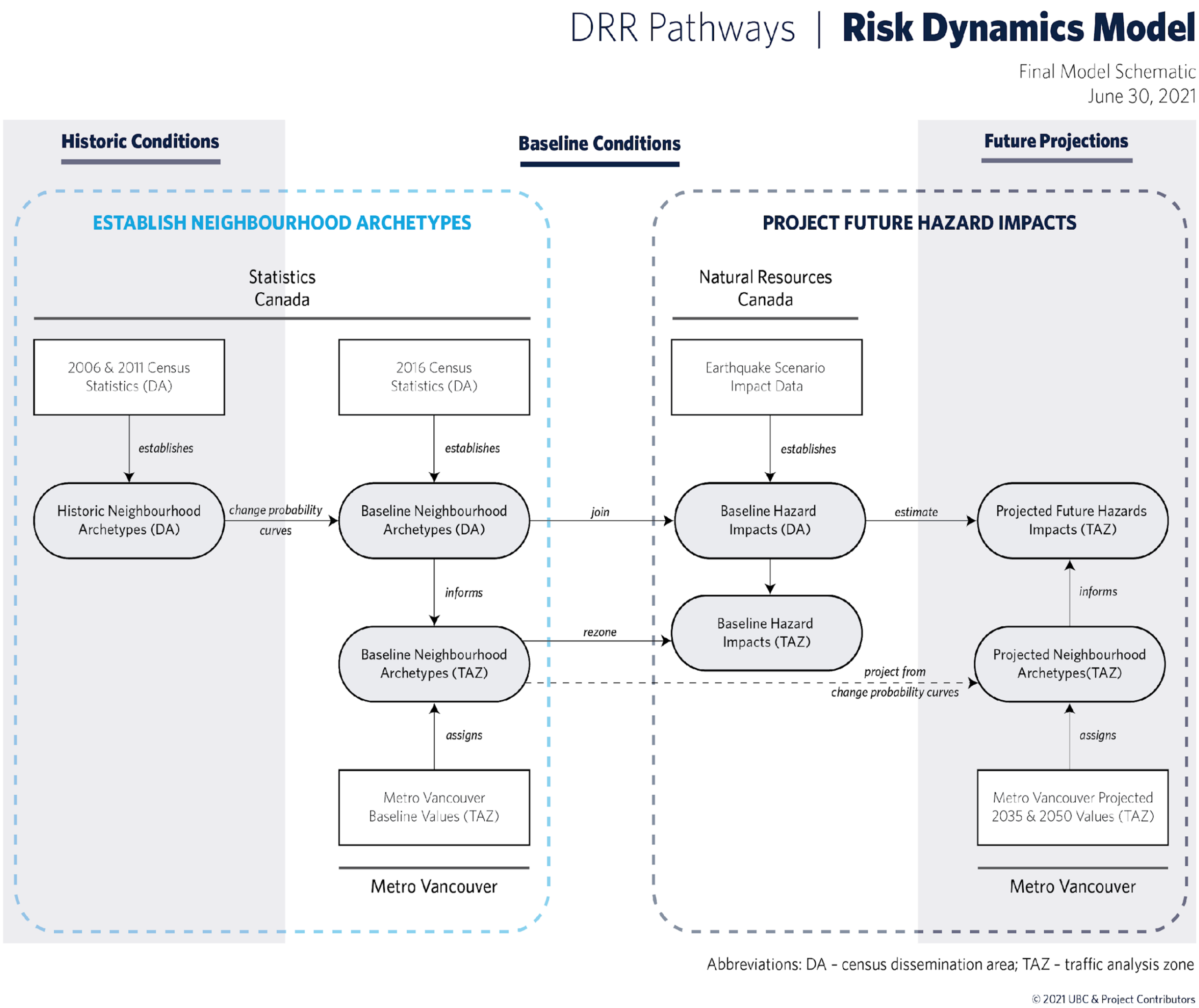

Figure 1: The Risk Dynamics Model for Metro Vancouver Future Hazards Impact Projections.

created by Statistics Canada were used as our unit of analysis and act as a proxy for neighbourhoods. DAs are small, relatively stable geographic units with an average population between 400 and 700 persons. In high-density urban areas, DAs tend to cover an area of a couple of city blocks, while in suburban and rural areas, DAs can cover much larger areas.[9] There are 1,562 dissemination areas in the Metro Vancouver region.

Neighbourhood archetypes were established using a series of cluster analyses to classify each DA by dwelling density, building type, and building age using data from Statistics Canada's *2016 Census of Population*. After careful review, we established a set of seven archetypes (Table 1) that we felt best matched with the types of neighbourhoods we see throughout Metro Vancouver, based on their most prominent characteristics. Figure 2 shows the distribution of these archetypes for the western portion of the Metro Vancouver region.

To determine how archetypes change over time in the region, we applied these same archetypes to the 2006 and 2011 censuses and established the probabilities that given archetypes would change over time and which archetypes they were most likely to become. With this understanding, it became possible to estimate how neighbourhoods are likely to change over the next few decades.

Table 1: The seven archetypes used to describe neighbourhoods in the Metro Vancouver region

Archetype	Description	Number of DAs
Older Single Detached	Neighbourhoods of predominantly single-detached dwellings, built largely prior to 1980.	732
Newer Single Detached	Neighbourhoods of predominantly single-detached dwellings, built largely after 1980.	528
Mixed Single and Multifamily	Neighbourhoods with a balanced mix of single-detached and multifamily dwellings.	691
Older Multifamily	Neighbourhoods of predominantly multifamily dwellings, built largely prior to 1980.	503
Newer Multifamily	Neighbourhoods of predominantly multifamily dwellings, built largely after 1980.	659
Medium Density Apartments	Neighbourhoods of predominantly medium-density apartments of at least five storeys.	232
High Density Apartments	Neighbourhoods of predominantly high-density apartments of at least five storeys.	101

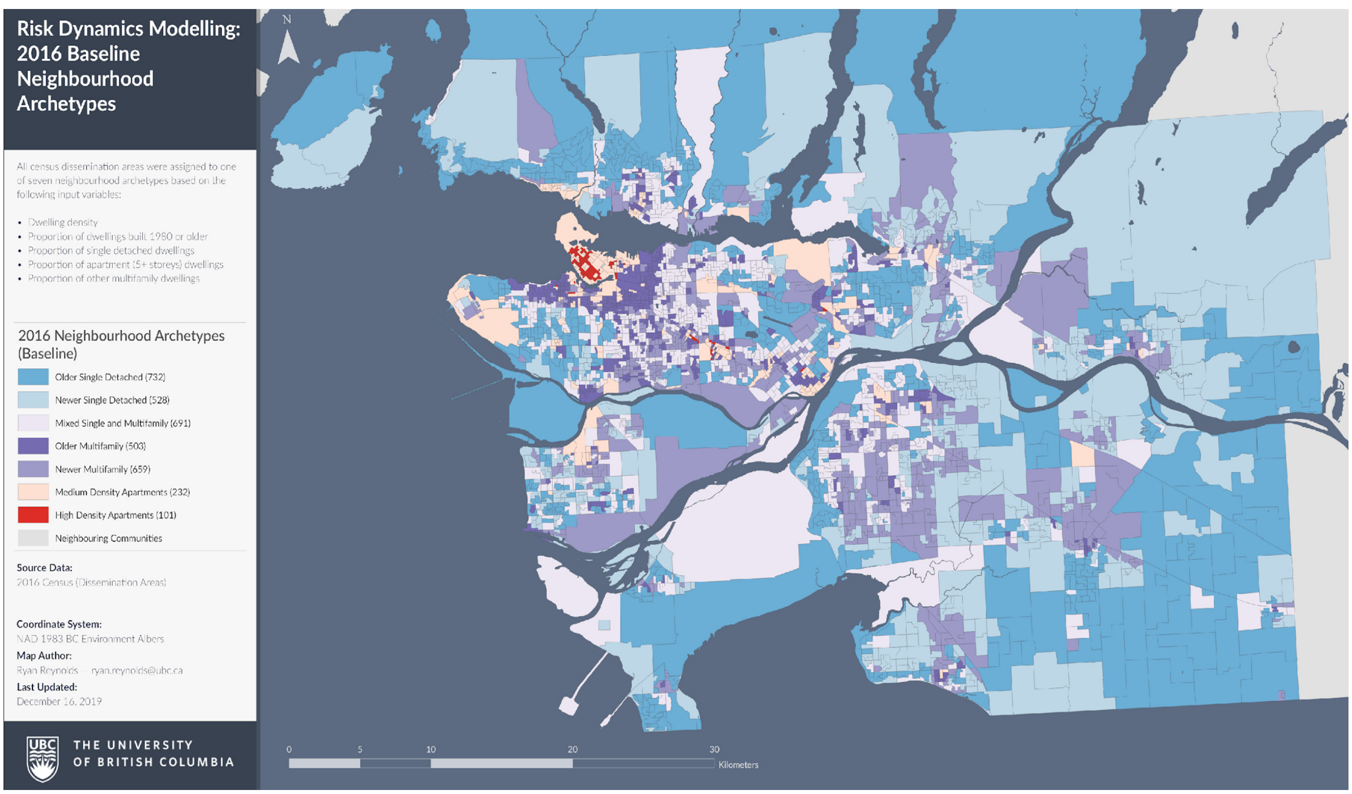

Figure 2: Map showing the distribution of the seven neighbourhood archetypes across Metro Vancouver[i].

[i] *Full-sized project maps are available for this project, Risk Dynamics Modelling, at DRRPathways.ca.*

STEP 2: ESTIMATING FUTURE NEIGHBOURHOOD CHANGES

Metro Vancouver has been working to understand how growth and development are likely to occur in the region over the next several decades. They have developed growth projections for 2035 and 2050 as part of their Metro 2050 strategy.[10] Baseline data for 2016 was also available as part of this work to allow for comparison with recent values. The projections provide information on future estimated population sizes, dwelling counts, and employment counts at the scale of traffic analysis zones (TAZs). As TAZ and DA boundaries do not align, we classified the TAZ data from 2016 using areal weighted interpolation from the neighbourhood archetypes for 2016 created earlier. This resulted in baseline archetypes for each of the 1,561 TAZs in the Metro Vancouver region.

Using the change probability curves established previously and our new baseline neighbourhood archetypes, we were able to estimate the most likely neighbourhood changes across the region for 2035. Figure 3 shows the baseline archetypes (2016) and projected future archetypes (2035) for side-by-side comparison. In total, 106 of the 1,561 TAZ units were estimated to change type between 2016 and 2035 (changing neighbourhood archetypes shown with black outlines).

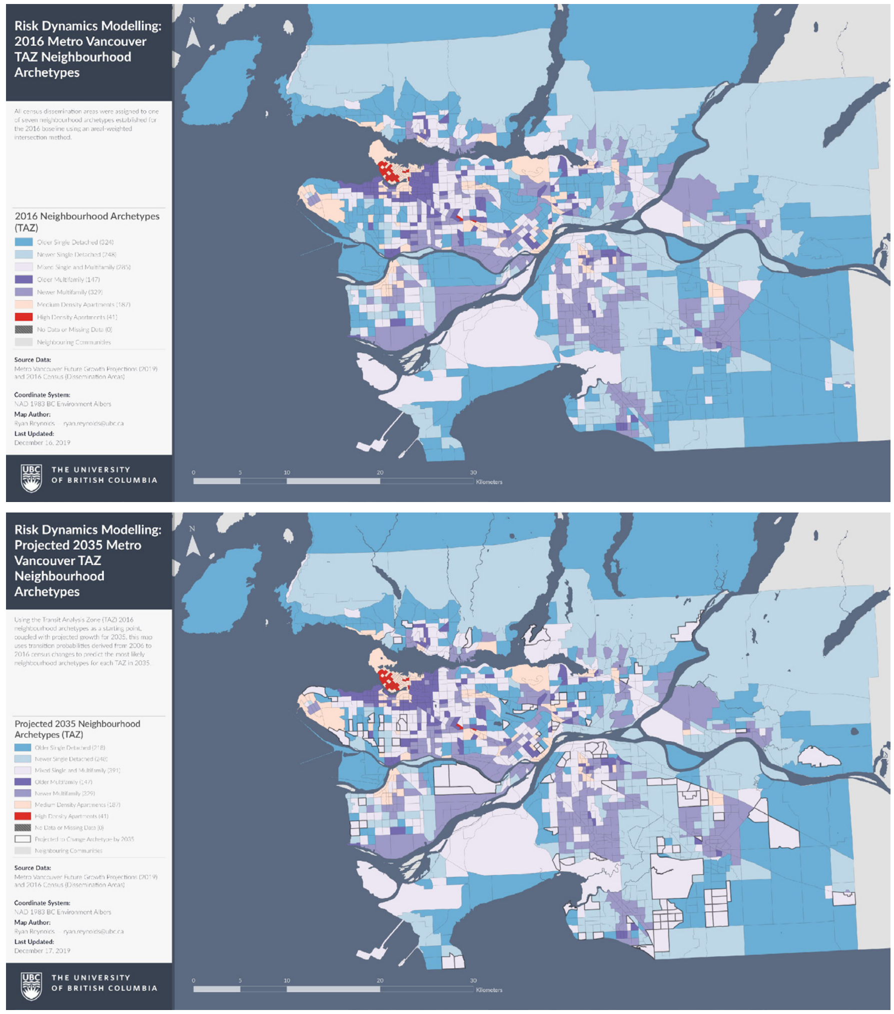

Figure 3: 2016 baseline neighbourhood archetypes and 2035 projected neighbourhood archetypes at the scale of traffic analysis zones.

STEP 3: ESTIMATING SEISMIC RISK

Our colleagues at NRCan have recently developed several updated earthquake scenarios with associated risk assessments for the Metro Vancouver region. For this study, we opted to use a simulated magnitude 7.3 event centred on the Georgia Strait between Vancouver Island and the BC Lower Mainland. The highest peak ground acceleration (PGA) for this scenario is concentrated along the northwest corner of the region and decreases south and east (Figure 4).

Baseline hazard impacts were provided by NRCan for this scenario at the level of settlement areas (SAs), which are the occupied built-up areas located within DAs. NRCan's assessments include several physical and social impact metrics for each SA unit. For the purposes of this study, we opted to use the percentage of the population displaced for three or more days as our impact metric. Nighttime

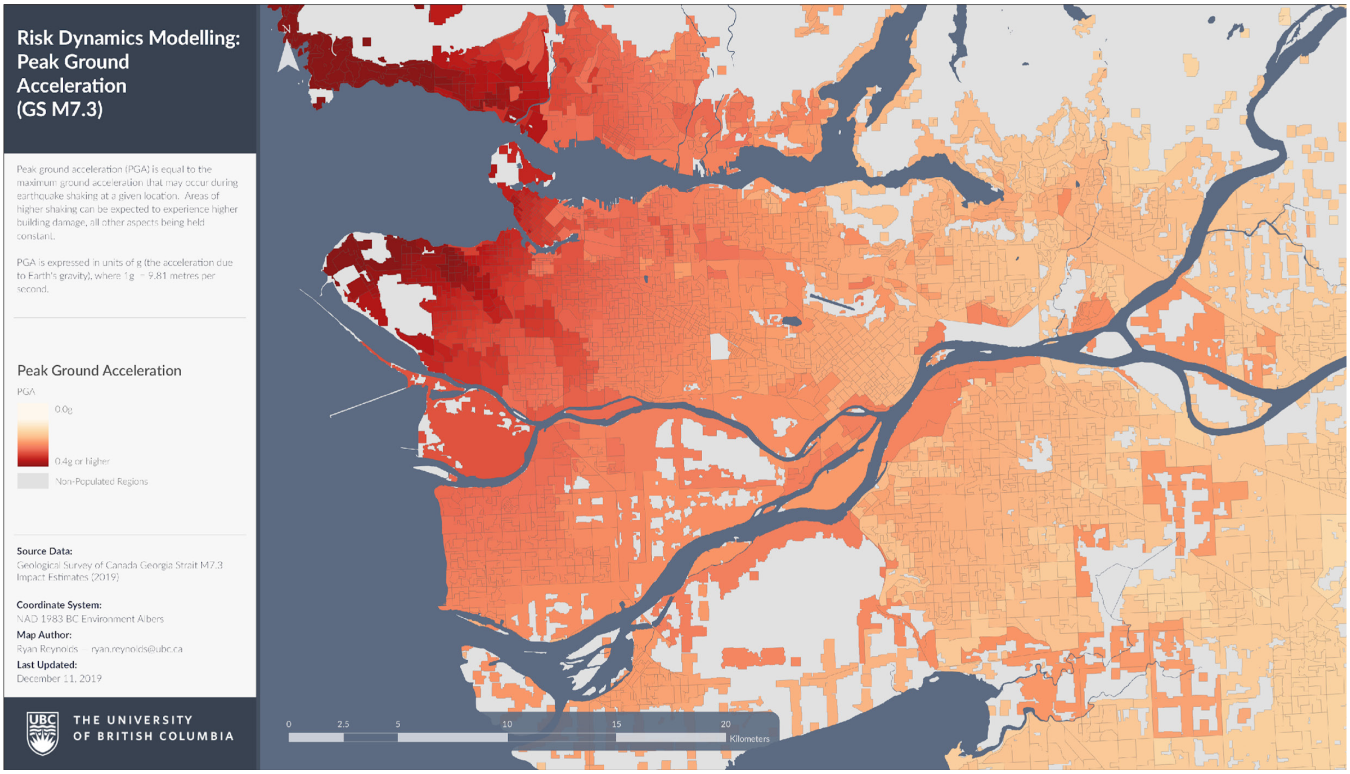

Figure 4: Map of peak ground acceleration in Metro Vancouver region for Georgia Strait M7.3 Scenario (Source Data: Geological Survey of Canada).

population estimates were used when calculating displaced populations.

At this point we needed to convert hazard impact values from the original SA level to the final TAZ level of our neighbourhoods. This was accomplished by establishing a set of neighbourhood fragility curves to establish a probabilistic relationship between PGA and population displacement. Fragility curves were developed empirically for each of the seven neighbourhood archetypes using NRCan's original source data. Examples for the "older multifamily" and "newer multifamily" neighbourhood archetypes are compared in Figure 5.

STEP 4: ESTIMATING FUTURE RISK FOR TRAFFIC ANALYSIS ZONES

Finally, we estimated the risk for a hypothetical M7.3 earthquake occurring in 2035 using NRCan's Georgia Strait scenario. Displaced population results were obtained by applying the neighbourhood fragility curves to the urban development projections for 2035 from Metro Vancouver's growth projection data. Table 2 compares the estimated displaced populations for the 2016 baseline and 2035 projected populations for the same scenario. Displaced population is expected to grow by 43,000 people to 176,000. Figure 6 shows the expected distribution of displaced populations throughout the western portion of the Metro Vancouver region.

ADAPTING THIS APPROACH BEYOND METRO VANCOUVER

The approach developed as part of this project should be transferable to locations outside of the Metro Vancouver region; it should be possible for researchers and practitioners exploring risk dynamics elsewhere in Canada to undertake such a project where appropriate data is available. However, there are several issues that may make this process difficult, discussed in the Challenges section, below.

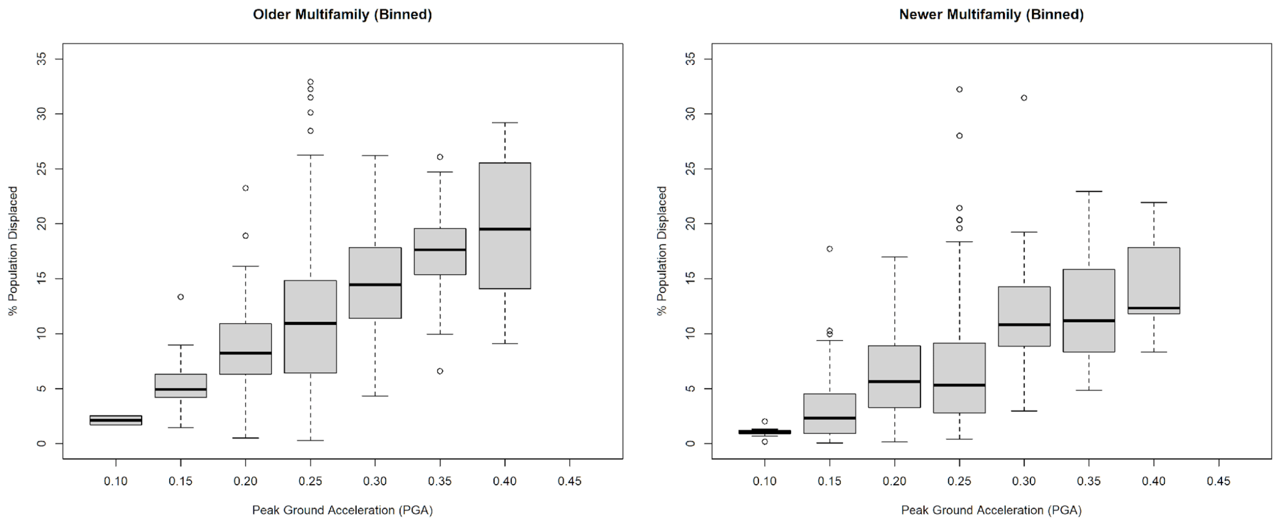

Figure 5: Peak ground acceleration (PGA) and population displacement percentage for "older multifamily" and "newer multifamily" neighbourhood archetypes.

Table 2: Projected population displacements for M7.3 Georgia Strait earthquake scenario

	2016	2035	Change
Population[ii]	2,580,000	3,370,000	787,000
Displaced Population	133,000	176,000	43,000
	5.15%	5.22%	

OPPORTUNITY

RECOMMENDATIONS

Cities are continually changing. Similar natural hazard events can cause different degrees and patterns of loss if they strike at different moments in a community's history. A community's hazard risk landscape—whether from earthquakes, floods, wildfires, or any other natural hazard—changes over time as the community changes and grows.

Building this understanding into community development planning can help identify and better characterize the effectiveness of different risk reduction strategies and help select development strategies that take changing risk into account. The approach we have described is just one of many and we have identified several areas for improvement to our approach, which can be found in our technical report on the DRR Pathways website.[11]

CHALLENGES

There are three main challenges facing anyone developing a risk dynamics model:

1. **Data Availability:** This project was only possible because the underlying seismic risk, hazard impact assessment, and growth projection data were recently updated by our project partners. Similar hazard and growth data would be required for any other location seeking to develop a local risk dynamics model.

[ii] *Population values represent 25 of 35 Metro Vancouver municipalities.*

2. **Expertise:** Our approach requires an understanding of several statistical and geospatial analysis processes, including cluster analysis, probability curves, and areal weighted interpolation. While this skill set should be available within most medium and large municipalities, smaller municipalities and Indigenous communities may need to use consultants.

3. **Geographical Scale:** We opted to use census dissemination area (DA) and traffic analysis zone (TAZ) units to act as our proxy for neighbourhoods. These units were most appropriate to the questions we were seeking to answer; however, dissemination areas can vary significantly in size, from a few blocks to entire communities. In communities made up by a single DA, it would be necessary to find alternate data.

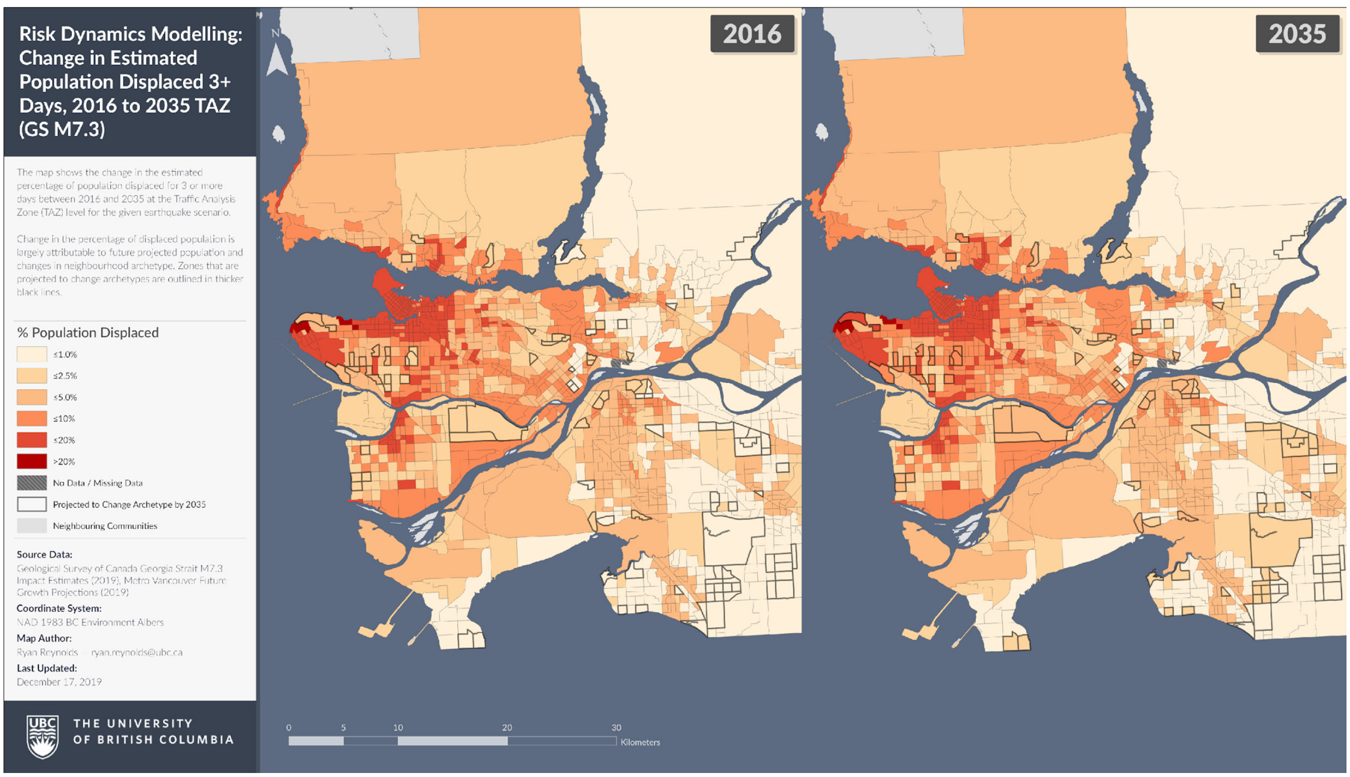

Figure 6: Map comparing estimated population displacements for M7.3 Georgia Strait scenario for 2016 and 2035 at the scale of traffic analysis zones.

RESOURCES

BC AND CANADA

1. Study exploring whether natural hazard risks for urban areas are growing over time, comparing 1971 to 2006.

Chang, S. E., M. Gregorian, K. Pathman, L. Yumagulova, and W. Tse. "Urban growth and long-term change in natural hazard risk." *Environment and Planning A* 44, no. 4 (2012): 989–1008.

2. Study exploring the effects of three different urban development patterns on future earthquake and coastal flooding risk in the City of Vancouver in 2041:

Chang, S. E., J. Z. K. Yip, and W. Tse. "Effects of urban development on future multi-hazards risk: The case of Vancouver, Canada." *Natural Resources* 98, no. 1 (2019): 251–265. https://doi.org/0.1177/0309132519895305

INTERNATIONAL

3. Report exploring the drivers of disaster risk, vulnerability, and how effective policy decisions can lead to a more resilient future:

Global Facility for Disaster Reduction and Recovery (CFDRR). "The making of a riskier future: How our decisions are shaping future disaster risk." Global Facility for Disaster Reduction and Recovery, (2016). Accessed December 10, 2021. https://www.gfdrr.org/sites/default/files/publication/Riskier%20Future.pdf

4. Study exploring ways to identify and project the risk dynamics of built-up areas in three Asian megacities:

Sarica, G. M., Zhu, T., and Pan, T. C. "Spatio-temporal dynamics in seismic exposure of Asian megacities: past, present and future." *Environmental Research Letters* 15, no. 9 (2020): 094092. https://iopscience.iop.org/article/10.1088/1748-9326/ababc7/meta

5. Study from North Carolina exploring how hurricane risk changes with time due to changes in the types and conditions of buildings:

Jain, V. K., and Davidson, R. A. "Forecasting changes in the hurricane wind vulnerability of a regional inventory of wood-frame houses." *Journal of Infrastructure Systems* 13, no. 1 (2007): 31-42. https://www.cs.rice.edu/~devika/evac/papers/Regional%20risk%20forecasting.pdf

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[6] Gizem M. Sarica, Tinger Zhu, and Tso-Chien Pan, "Spatio-temporal dynamics in seismic exposure of Asian megacities: Past, present, and future," *Environmental Research Letters* 15, no. 9 (2020): 094092, https://doi.org/10.1088/1748-9326/ababc7

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Photo: Mike W./flickr

4.2 NEIGHBOURHOOD SOCIAL VULNERABILITY IN VANCOUVER

June 2022

DRRPathways.ca

RESILIENCE PATHWAYS

CO-CREATING NEW KNOWLEDGE FOR UNDERSTANDING RISK AND RESILIENCE IN BC

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ABOUT NEIGHBOURHOOD SOCIAL VULNERABILITY

The physical damage and societal impacts of natural hazards are rarely distributed evenly across space, through time, or within affected populations.[1, 2] Experience from past disasters demonstrates that some portions of the population are inherently more susceptible to the impacts of disasters due to a mix of the physical, geographic, social, or economic traits intrinsic to these groups.[3] Socially vulnerable populations are often more profoundly impacted during disaster events and generally experience a slower post-disaster recovery process following significant disaster events than their less vulnerable neighbours.[4]

Similarly, many factors influence vulnerability to hazards at the neighbourhood level. Some are physical, such as the neighbourhood's location and exposure to the hazard, the potential environmental and structural impacts, and the likely disruption to critical infrastructure services. Other factors are social, relating to characteristics of residents such as income or housing tenure that may influence their propensity to suffer losses and experience difficulty recovering from disasters (Figure 1).

While a considerable body of research and practice has focused on the physical and built environment aspects of disasters, the *social aspects* of disasters have been less well established in Canada until recently. While there are generally agreed-upon measures of physical vulnerability for buildings, critical infrastructure, and access to services such as power, water, and wastewater, there are no such accepted measures for social vulnerability. However, the need for evidence-based and empirically derived information to support structural mitigation and response planning efforts related to social vulnerability has been generally agreed upon within research and practitioner communities.[5]

> Socially vulnerable populations are often more profoundly impacted during disaster events and generally experience a slower post-disaster recovery process following significant disaster events than their less vulnerable neighbours.

Much of today's research into social vulnerability builds on the Hazards-of-Place model and

Figure 1: Many factors influence social vulnerability (Photo: Mike W./flickr).

methodologies established by Susan Cutter and colleagues as part of their Social Vulnerability Index.[6] These studies often include socioeconomic indicators to identify potentially vulnerable groups within a population. Such indicators are quantitative measures of a single characteristic of a population and are often derived from census statistics (e.g., percentage of renters, percentage aged 65+), but can also include travel times to key services (e.g., walking time to nearest primary school, travel time to nearest food market via public transit) or the number of facilities within a given distance or travel time (e.g., number of medical clinics within 2 km, number of community hubs within a 30-minute walk). Individual indicators are often combined into indices or "themes" that allow for targeted assessment of vulnerable groups sharing similar traits.

ALIGNMENT WITH THE SENDAI FRAMEWORK

At the Third United Nations World Conference on Disaster Risk Reduction in 2015, delegates adopted the Sendai Framework for Disaster Risk Reduction 2015–2030. This framework identifies four priorities and seven key targets for policy actions to reduce disaster losses and the costs associated with disasters. Our project directly addresses the first priority for action, *understanding disaster risk*, and provides information for two other priorities: *investing in disaster risk reduction for resilience* and *enhancing disaster preparedness for effective response*. This work also addresses several targets of the Sendai Framework, including: *reduce the number of affected people globally*; *reduce direct economic loss in relation to GDP*; and *increase the number of countries with national and local disaster risk reduction strategies*.

SOCIAL VULNERABILITY FROM EARTHQUAKE IN VANCOUVER NEIGHBOURHOODS

Our team at UBC partnered with colleagues from the Geological Survey of Canada at Natural Resources Canada (NRCan), the City of Vancouver (the City), and Sage on Earth Consulting (Sage) with the shared goal of better understanding the spatial distribution of socially vulnerable populations within the City of Vancouver, as part of the City's seismic retrofit program. The project aimed to assist policymakers in identifying Vancouver neighbourhoods with populations most vulnerable to the physical impacts of a significant disaster event. We used physical disaster impact assessments completed as part of NRCan's recent earthquake scenario modelling efforts to estimate social impacts for three socially vulnerable groups. Our end goal is to provide information and insights for designing measures to reduce vulnerability and increase earthquake resilience within Vancouver neighbourhoods.

Together, we identified a set of fourteen indicators of socioeconomic vulnerability, using census dissemination area (DA) polygons as our units of analysis and proxies for "neighbourhoods" for the City of Vancouver. We combined these indicators into three themes that addressed aspects of social vulnerability most relevant to the policy interests of the partnership (Table 1).

This work resulted in a set of indicator, cluster, and theme maps at the neighbourhood scale for the City of Vancouver. These maps highlight some of the many aspects of social vulnerability within the area of interest. We provided this information to the City of Vancouver to assist policy makers in updating the City's seismic retrofit policies. In addition to identifying areas of elevated social vulnerability related to financial, housing, and social service demand at the neighbourhood level, the information can also assist with creating targeted social programs to address the root causes of social vulnerability in highlighted neighbourhoods.

THE NEIGHBOURHOOD SOCIAL VULNERABILITY ASSESSMENT PROCESS

We established a six-step approach to measuring and summarizing information about social vulnerability and iterated upon this approach with our project partners. Our initial goal was to determine what the group's policy objectives were going to be, how best to address the questions related to those questions, and how best to identify the appropriate social vulnerability groups. This required identifying and reviewing potential indicator data, establishing vulnerability thresholds, and creating associated map products for review by our partners (Figure 2). We provide more detail on each step in the following sections.

In addition to identifying areas of elevated social vulnerability related to financial, housing, and social service demand at the neighbourhood level, the information can also assist with creating targeted social programs to address the root causes of social vulnerability in highlighted neighbourhoods.

Table 1: Three themes

Reduced Financial Capacity	Greater Social Service Dependency	Housing and Shelter Challenges
Neighbourhoods with above-average concentrations of residents that may have a lower financial capacity to respond following a disaster:	Neighbourhoods with above-average concentrations of residents that may have a greater dependence on social services:	Neighbourhoods with above-average concentrations of residents that may face difficulties acquiring emergency shelter or permanent housing:
Indicators: • Low-income workers • Government transfer recipients • Unemployed workers • Workers who work from home • Tenants in subsidized housing • Households that spend at least 30% of their income on shelter	Indicators: • Young children • Elderly adults • Low-income workers • Unemployed workers • Single-parent families • Not fluent in English	Indicators: • Renters • Recently moved into the community • Adults without a high school education • Tenants living in subsidized housing • Families living in non-suitable housing • Households that spend at least 30% of their income on shelter

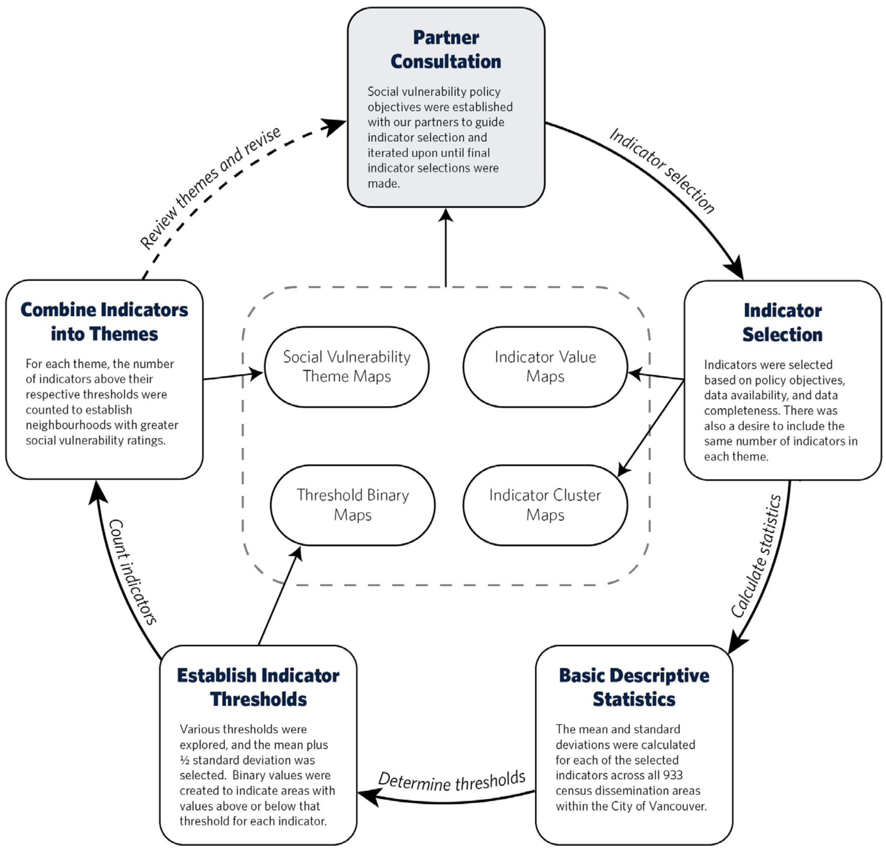

Figure 2: Social vulnerability assessment process (Graphic: UBC and Project Contributors).

STEP 1: ESTABLISH POLICY GOALS

We established an initial set of policy objectives to place this project into context, establish our scope, and guide model development. While the primary goal was to support policy-making processes related to the City's seismic retrofit program, it was also clear this information would be of interest to other groups within the City and to additional work being undertaken by our DRR Pathways partners.

STEP 2: SELECT INDICATORS

We conducted an initial review of academic and practitioner literatures to determine which indicators had been used in previous social vulnerability modelling in Canada, the US, and abroad. An initial set of 84 potential indicators were identified and reviewed to determine data availability and suitability at the neighbourhood scale within the City of Vancouver. From this list, a final set of 14 indicators were selected that met project objectives (Table 2).

A set of per-indicator maps were generated along with cluster maps highlighting hot and cold spots across the city. Figure 3 and Figure 4 show two such examples.

STEP 3: CALCULATE BASIC DESCRIPTIVE STATISTICS

With the final set of 14 socioeconomic indicators in place, we needed to establish which indicator thresholds we wanted to use. To this end, basic statistics were calculated for each indicator for all 933 DAs within the City of Vancouver, including mean, median, mode, standard deviation, minimum, and maximum values. Figure 5 shows an example of thresholds for one of the indicators.

STEP 4: ESTABLISH INDICATOR THRESHOLDS

Several different approaches to establishing indicator thresholds were explored and assessed for suitability. We determined that a cut-off equal to the indicator mean plus half a standard deviation ($\underline{x}+\sigma/2$) best fit our needs. A binary variable was created for each indicator to represent areas that fell above or below that threshold, as shown in Figure 5.

STEP 5: COMBINE INDICATORS INTO THEMES

We selected six indicators to contribute to each of the three social vulnerability themes identified in Step 1. Having the same number of indicators in each theme helps make comparisons between theme maps easier for map readers. Indicators were selected based on how they contributed to specific themes, and some indicators were used in more than one theme.

For each theme, we summed the number of indicators that were above the threshold values established in Step 4 for each of the 933 DAs within the City of Vancouver. In cases where data were not available for a specific DA, it was treated as being below threshold for the purpose of these counts. This resulted in above-threshold counts ranging between zero (very low vulnerability) and six (very high vulnerability).

A final set of maps was generated for indicator counts for each of the three social vulnerability themes, highlighting areas where four or more indicators were above the established threshold values. An example of a final theme map is shown in Figure 6.

STEP 6: REVIEW AND ITERATE

Once theme maps were generated for all themes, we reviewed them to ensure that the themes were addressing the previously established policy objectives and appropriately identifying groups that should be included within each theme. With updated guidance from our partners, the process was repeated to refine the indicators selected, establish more idealized thresholds, and adjust the theme maps to better address project goals (Figure 2). The final set of maps was completed on September 18, 2019.

Table 2: The 14 Social Vulnerability Indicators Selected for this Project

Indicator	Reason for Inclusion
1. Children, Aged 0–9	Children are generally dependent upon their parents or guardians, are often less mobile, require additional care when not in school, and may require greater assistance to evacuate during an emergency.
2. Older Adults, Aged 75+	Seniors often tend to have limited or fixed income, are often less mobile, are more likely to be government transfer recipients, may be more reluctant to evacuate, and may require additional assistance post-disaster.
3. Low-Income Adults, Aged 18–64	Low-income adults are more likely to be subject to “renovictions” if renting, while low-income homeowners may face greater limitations on their ability to rebuild or repair damages to their homes.
4. Government Transfer Recipients	Reliance upon government transfers for a large part of a household’s income can increase a household’s social vulnerability immediately following an emergency and throughout the recovery process. Transfers can include benefits and other forms of income or compensation from federal, provincial, or municipal governments.
5. Unemployed Workers	Unemployed workers and their families may be without income and health benefits resulting in decreased disaster response capacity and slower post-disaster recovery.
6. Workers Working from Home	Those who work from home can face issues not experienced by their peers who work in designated workplaces. Home-based workers can experience issues related to social isolation due to reduced social interactions through work. As their homes are their workplaces, any damage to their homes can directly impact their ability to earn income until necessary repairs are completed.
7. Home Tenure: Renters	Renters often lack control over their dwelling and are subject to contracts with landlords, impacting their overall housing stability. Insurance for renters can also be more restrictive than for homeowners.

Indicator	Reason for Inclusion
8. Households with High Shelter Costs	Households that spend 30% or more of household income on shelter costs often have little available capacity to cover additional costs associated with evacuation, repairs, replacement of goods, and other post-disaster recovery costs.
9. Households in Non-suitable Housing	Households where there are insufficient bedrooms for the size and composition of the household are already experiencing sub-standard living conditions, which are likely to be exacerbated by disaster impacts. Large families are especially likely to fall into this category.
10. Tenants in Subsidized Housing	Housing subsidies assist households by reducing their total shelter costs. Tenants in subsidized housing may face significant difficulties finding temporary or permanent shelter following a disaster as subsidized housing is often quite limited and may not be in a suitable location for their needs.
11. New to the Community in the Past Year	Those who have moved into a community in the past year are likely to be unfamiliar with local evacuation procedures, shelter locations, relief sources, and recovery information. Recent movers are also less likely to have developed deep or broad social networks they can turn to for assistance following a disaster.
12. Adults with No High School	Adults with fewer than 12 years of formal education are often less able to respond to disaster events, are more often dependent upon government support, and often have less overall adaptive capacity than those with higher levels of education.
13. Not Fluent in English	A lack of fluency in the official language(s) used by a community may indicate reduced integration into the broader community and shallower social networks, resulting in increased vulnerability. Language proficiency is also important in understanding emergency instructions and gaining access to assistance or relief.
14. Lone-Parent Families	Lone-parent households often face increased financial and support constraints, may have additional childcare responsibilities, and are more likely to live on post-disaster economic margins than two-parent families.

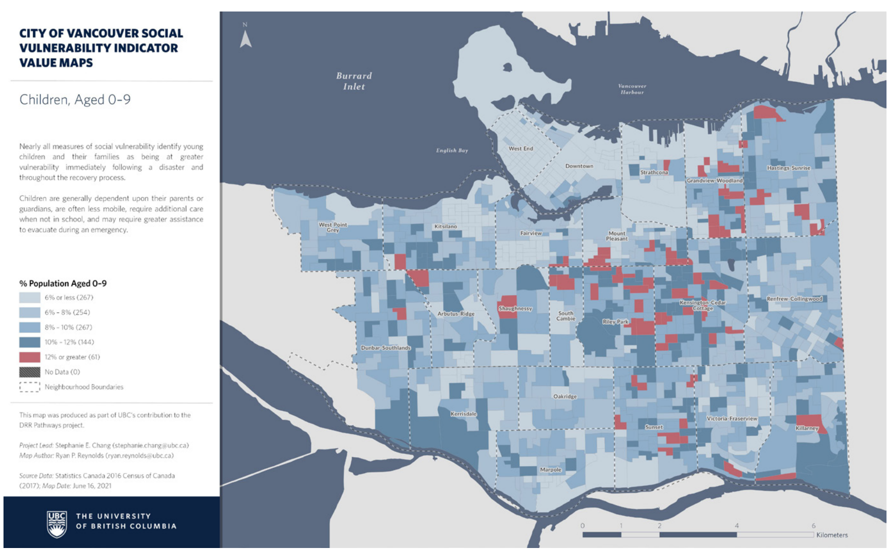

Figure 3: Indicator value map for children aged 0–9 (areas in dark blue and red show areas of elevated vulnerability).

ADAPTING THIS APPROACH BEYOND THE CITY OF VANCOUVER

While this project focused on specific vulnerabilities relevant to the seismic retrofit program at the City of Vancouver, our approach should be accessible to researchers and practitioners exploring social vulnerability anywhere in Canada where neighbourhood-scale data is available, or through adaptation at other scales where appropriate data exists. Statistics Canada makes DA data available for many larger communities across the country, and many municipalities collect their own data that could be adapted for use in social vulnerability assessments.

There are issues related to statistical correlation and suitability of purpose that should be fully considered before including specific indicator data into a social vulnerability index. Randomized rounding of census-style data can impact results when working at finer scales and must also be considered. Finally, some expertise in geographic information systems (GIS) and spatial analysis is required to properly generate—and possibly interpret—social vulnerability index maps. The sources included at the end of this report and in our endnotes may be of interest to anyone seeking to adapt this approach outside the City of Vancouver.

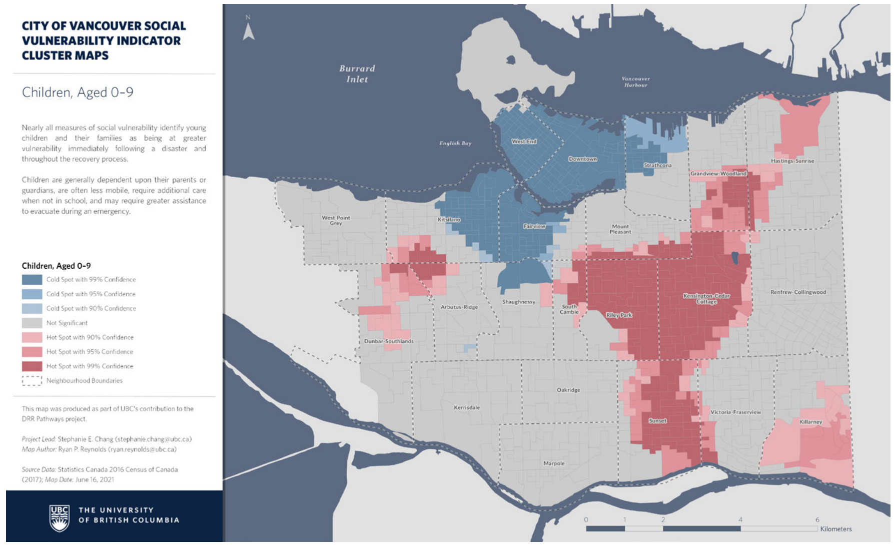

Figure 4: Cluster analysis map for children aged 0–9 (areas in red show high vulnerability hotspots, while areas in blue are cold spots).

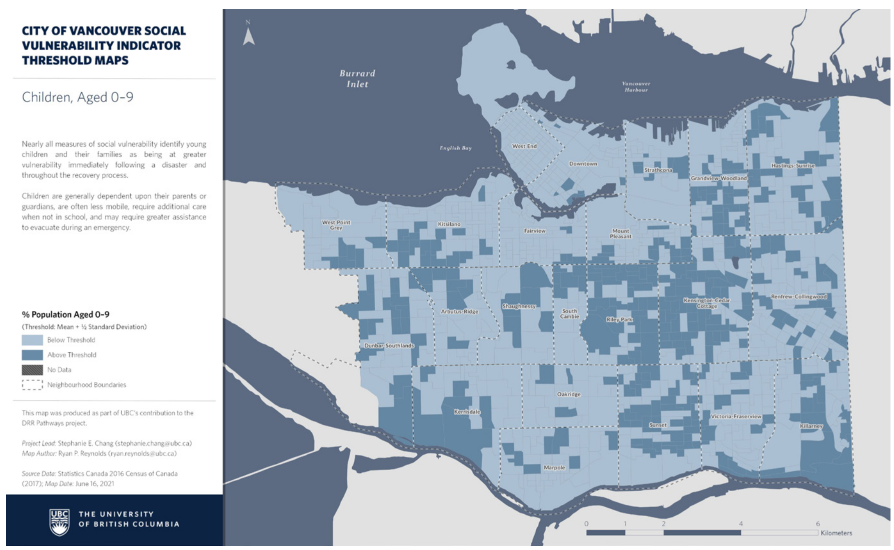

Figure 5: Threshold map for children aged 0–9 (areas in dark blue are above the indicator threshold, while light blue areas are below the threshold).

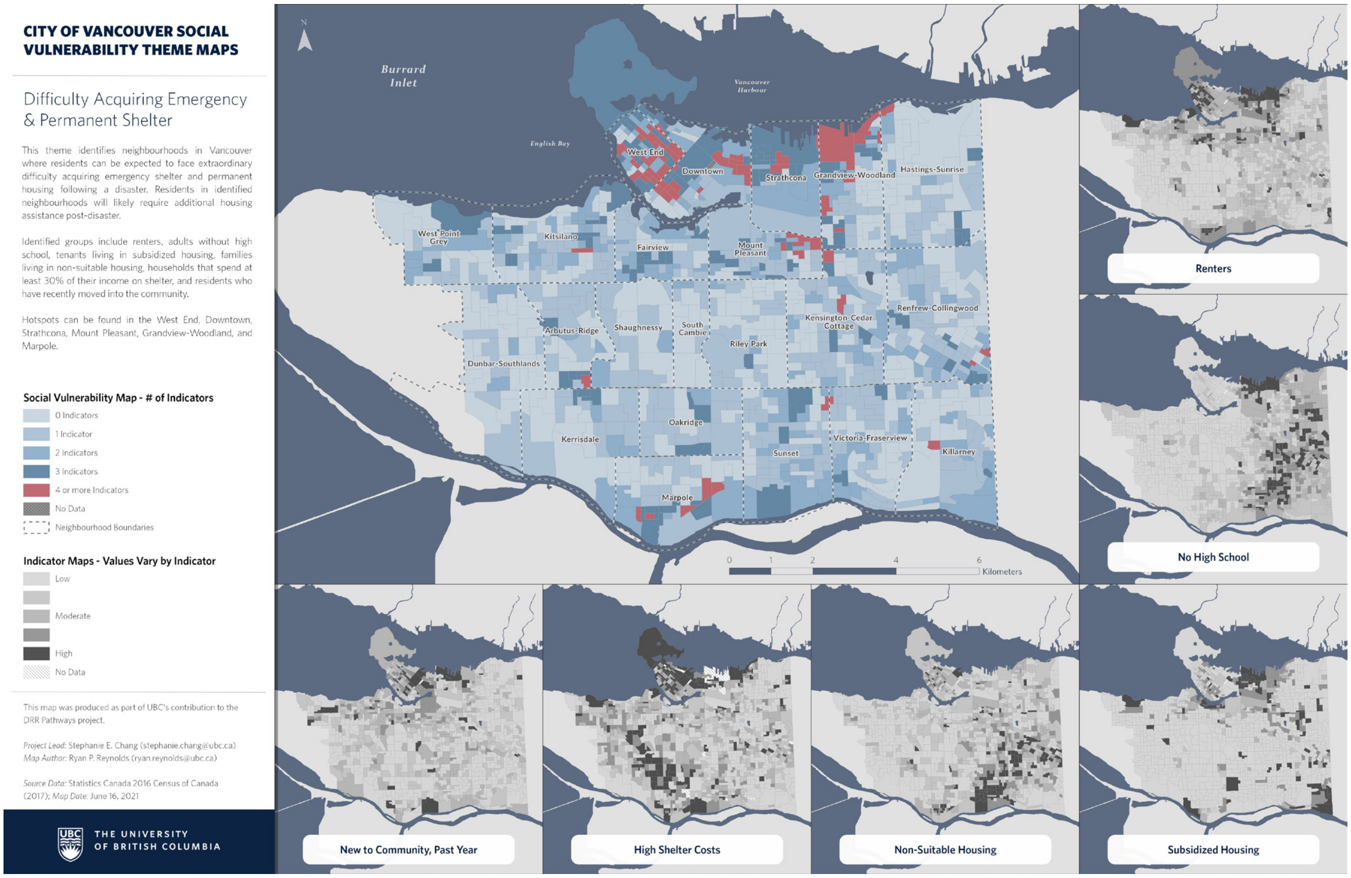

Figure 6: Social vulnerability theme map for residents facing difficulty acquiring emergency and permanent shelter.

OPPORTUNITY

RECOMMENDATIONS

Completing a neighbourhood-level social vulnerability assessment is important to understand how social impacts of disasters may be distributed throughout a community. Small changes made to community preparedness, emergency response, and disaster recovery plans and policies can significantly reduce potential impacts on vulnerable populations immediately following a disaster and help them recover from such events more quickly.

Knowing which communities are most vulnerable allows policy makers and emergency managers to prepare better to assist these populations should a disaster occur. Materials, equipment, and human resources can be pre-positioned to locations where the need is likely to be greatest. When combined with physical risk modelling, social vulnerability assessments allow decision makers to dispatch resources to the locations most likely to be in need following a disaster.

There is significant interest around measuring social vulnerability in BC, both as part of the DRR Pathways project and by the BC disaster risk reduction community at large. The approach we've described is just one of many[7,8] and we have also identified several potential future enhancements to our approach, which can be found in our technical report on the DRR Pathways website.[9]

CHALLENGES

There are three main challenges facing anyone working in neighbourhood social vulnerability assessments:

1. **Identifying policy objectives:** It is critical that there be clear policy objectives in place to

provide the necessary context and scope needed to guide social vulnerability model development for a community. It should be clear how the information provided by the social vulnerability assessments will be used to inform and adjust local policies, with the understanding that these needs may change or be clarified throughout the process.

2. **Identifying appropriate vulnerability indicators:** Indicators should be selected to meet policy objectives, based on data availability and completeness. The specific policy objectives should guide this process. Census data is often a good starting point, but other regional and local data sources should also be considered. Geospatial measures of proximity or density may also be appropriate.

3. **No silver bullet:** There is no single approach or set of indicators that is ready "out of the box." This process will take time and should benefit from the many voices that will be involved in and affected by policy and planning objectives. Social vulnerability assessments should be undertaken as part of a broader social policy movement within a community to be most effective.

RESOURCES OR SIMILAR PROJECTS

BC AND CANADA

1. Study describing unequal vulnerability to flood hazards:

Oulahen, G., L. Mortsch, K. Tang, and D. Harford. "Unequal vulnerability to flood hazards: 'Ground truthing' a social vulnerability index of five municipalities in Metro Vancouver, Canada." *Annals of the Association of American Geographers* 105, no. 3 (2015): 473–495.

2. Measuring social vulnerability to flood hazards in the context of environmental justice, across Canada:

Chakraborty, Liton, Horatiu Rus, Daniel Henstra, Jason Thistlethwaite, and Daniel Scott. "A place-based socioeconomic status index: Measuring social vulnerability to flood hazards in the context of environmental justice." *International Journal of Disaster Risk Reduction* 43 (2020): 101394.

3. Social vulnerability in national seismic risk model:

Natural Resources Canada is working on a national seismic risk model, which incorporates work on social vulnerability in addition to excellent modelling work around physical exposure and disaster impacts. This work is ongoing, but we hope to have more details about the social vulnerability impact in the near future.

INTERNATIONAL

4. Social vulnerability to environmental hazards; the Social Vulnerability Index (SoVI) tool:

Cutter, Susan L., Bryan J. Boruff, and W. Lynn Shirley. "Social vulnerability to environmental hazards." *Social Science Quarterly* 84, no. 2 (2003): 242–261. Accessed March 17, 2022. http://research-legacy.arch.tamu.edu/epsru/Course_Readings/Ldev671MARS689/LDEV671_Readings/Cutter_socialvuln_hazards_ssq.pdf

5. A review of social vulnerability methodologies:

Willis, I., and J. Fitton. "A review of multivariable social vulnerability methodologies: A case study of the River Parrett catchment, UK." *Natural Hazards and Earth System Sciences* 16, no. 6 (2016): 1387–1399.

6. A review of social vulnerability literature:

Cutter, S. L., Christopher T. Emrich, Jennifer J Webb, and Daniel Morath. "Social vulnerability to climate variability hazards: A review of the literature." *Final Report to Oxfam America*, 5 (June 17, 2009): 1–44.

ENDNOTES

[1] Susan L. Cutter, Bryan J. Boruff, and W. Lynn Shirley, "Social vulnerability to environmental hazards," *Social Science Quarterly* 84, no. 2 (2003): 242–261.

[2] UN/ISDR (United National International Strategy for Disaster Rediction), *UNISDR Terminology on Diaster Risk Reduction*, Geneva: United Nations, 2009.

[3] Liton Chakraborty, Horatiu Rus, Daniel Henstra, Jason Thistlethwaite, and Daniel Scott, "A place-based socioeconomic status index: Measuring social vulnerability to flood hazards in the context of environmental justice," *International Journal of Disaster Risk Reduction* 43 (2020): 101394.

[4] Chester W. Hartman and Gregory D. Squires, eds, *There is no such thing as a natural disaster: Race, class, and Hurricane Katrina*, Taylor & Francis, 2006.

[5] Susan L. Cutter, Christopher T. Emrich, Jennifer J Webb, and Daniel Morath, "Social vulnerability to climate variability hazards: A review of the literature," *Final Report to Oxfam America*, 5 (June 17, 2009): 1–44.

[6] Susan L. Cutter et al, "Social Vulnerability to Environmental Hazards."

[7] Jean Andrey and Brenda Jones, "The dynamic nature of social disadvantage: Implications for hazard exposure and vulnerability in Greater Vancouver," *The Canadian Geographer* 52, no. 2 (2008): 146–168.

[8] Greg Oulahen, Linda Mortsch, Kathy Tang, and Deborah Harford, "Unequal vulnerability to flood hazards: 'Ground truthing' a social vulnerability index of five municipalities in Metro Vancouver, Canada," *Annals of the Association of American Geographers* 105, no. 3 (2015): 473–495.

[9] Stephanie E. Chang, Ryan P. Reynolds, Juri Kim, and Jackie Z. K. Yip, "DRR Pathways technical report: Neighbourhood social vulnerability in the City of Vancouver," *Disaster Risk Reduction Pathways* (June 30, 2021), accessed March 17, 2022, https://241dccaf-92ec-466d-b658-ecf55b884b23.filesusr.com/ugd/c54559_f5ad16cdf58f46d29c5faafc255a8f29.pdf

Recommended citation
Reynolds, R.P., Chang, S.E., Kim, J., Yip, J.Z.K., Neighbourhood Social Vulnerability in Vancouver, in Resilient Pathways Report: Co-creating new Knowledge for Understanding Risk and Resilience in BC; Safaie, S., Johnstone, S., Hastings, N.L., eds., Geological Survey of Canada, Open File 8910, 2022 p. 310-320, https://doi.org/10.4095/330543

TERMINOLOGY

The following sources have been used in preparing this terminology document, which provide definitions only for the terms that were used frequently throughout the Resilience Pathways Report. In the case of terms whose definition can be found in various sources, the editorial team chose the most comprehensive and clear definition.

Sendai Framework Terminology (Sendai)

United Nations General Assembly. *Report of the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction.* 2016. https://reliefweb.int/report/world/report-open-ended-intergovernmental-expert-working-group-indicators-and-terminology.

(For a user-friendly website on Sendai terminology, see: https://www.undrr.org/terminology)

Intergovernmental Panel on Climate Change (IPCC)

Mathews, J. et al, eds. *Glossary*. Intergovernmental Panel on Climate Change, 2018. https://www.ipcc.ch/site/assets/uploads/2018/11/sr15_glossary.pdf.

Public Safety Canada (PSC)

Public Safety Canada. "National Emergency Response System – Glossary of Terms and Definitions." Government of Canada. Last modified 2018. https://www.publicsafety.gc.ca/cnt/rsrcs/pblctns/ntnl-rspns-sstm/index-en.aspx#gloss.

(The glossary uses Justice Institute of British Columbia Incident Command System and An Emergency Management Framework for Canada as source material.)

Emergency Management BC (EMBC)

Province of BC. *Modernizing BC's Emergency Management Legislation*. 2019. https://www2.gov.bc.ca/assets/gov/public-safety-and-emergency-services/emergency-preparedness-response-recovery/modernizing_bcs_emergencymanagement_legislation.pdf.

In the absence of official resources, the editorial team has also provided short definitions for terminologies related to data that are used in the report. These are presented in Box A.

Build back better: The use of the recovery, rehabilitation and reconstruction phases after a disaster to increase the resilience of nations and communities through integrating disaster risk reduction measures into the restoration of physical infrastructure and societal systems, and into the revitalization of livelihoods, economies and the environment. (Sendai)

Annotation: The term "societal" will not be interpreted as a political system of any country.

Capacity: The combination of all the strengths, attributes and resources available within an organization, community or society to manage and reduce disaster risks and strengthen resilience. (Sendai)

Annotation: Capacity may include infrastructure, institutions, human knowledge and skills, and collective attributes such as social relationships, leadership and management.

Capacity assessment: The process by which the capacity of a group, organization or society is reviewed against desired goals, where existing capacities are identified for maintenance or strengthening and capacity gaps are identified for further action. (Sendai)

Capacity development: The process by which people, organizations and society systematically stimulate and develop their capacities over time to achieve social and economic goals. It is a concept that extends the term of capacity-building to encompass all aspects of creating and sustaining capacity growth over time. It involves learning and various types of training, but also continuous efforts to develop institutions, political awareness, financial resources, technology systems and the wider enabling environment. (Sendai)

Climate adaptation: The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects. (IPCC)

Coping capacity: The ability of people, organizations and systems, using available skills and resources, to manage adverse conditions, risk or disasters. The capacity to cope requires continuing awareness, resources and good management, both in normal times as well as during disasters or adverse conditions. Coping capacities contribute to the reduction of disaster risks. (Sendai)

Critical infrastructure sectors: Federal, provincial and territorial governments in Canada define critical infrastructure as the processes, systems, facilities, technologies, networks, assets and services essential to the health, safety, security or economic well-being of people and the effective functioning of government. There are ten recognized critical infrastructure sectors as listed below. (PSC)

Critical Infrastructure Sectors	
Energy and Utilities	Electricity; petroleum and crude oil; natural gas; other
Health	Critical care; extended care; blood/organ facilities; pharmaceutical facilities
Transportation	Rail; road; marine; air

Critical Infrastructure Sectors	
Government	Federal; provincial; First Nations; local authority
Finance	Banking/financial institutions; securities/investments; point of sale/ATM machines
Communications	Telecommunications; radio; broadcasting; satellites
Safety	Police/law enforcement; fire; ambulance; emergency management
Water	Potable water; wastewater; dams
Food	Farming/production; processing/packaging; storage/distribution
Manufacturing	Defence industrial base manufacturing; critical manufacturing

Disaster: A social phenomenon that results when a hazard intersects with a vulnerable community in a way that exceeds or overwhelms the community's ability to cope and may cause serious harm to the safety, health, welfare, property or environment of people; may be triggered by a naturally occurring phenomenon which has its origins within the geophysical or biological environment or by human action or error, whether malicious or unintentional, including technological failures, accidents and terrorist acts. (PSC)

Disaster risk: The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity. (Sendai)

Annotation: The definition of disaster risk reflects the concept of hazardous events and disasters as the outcome of continuously present conditions of risk. Disaster risk comprises different types of potential losses which are often difficult to quantify. Nevertheless, with knowledge of the prevailing hazards and the patterns of population and socioeconomic development, disaster risks can be assessed and mapped, in broad terms at least.

It is important to consider the social and economic contexts in which disaster risks occur and that people do not necessarily share the same perceptions of risk and their underlying risk factors.

Acceptable risk, or tolerable risk, is therefore an important sub-term: The extent to which a disaster risk is deemed acceptable or tolerable depends on existing social, economic, political, cultural, technical and environmental conditions. In engineering terms, acceptable risk is also used to assess and define the structural and non-structural measures that are needed in order to reduce possible harm to people, property, services and systems to a chosen tolerated level, according to codes or "accepted practice" which are based on known probabilities of hazards and other factors. (Sendai)

Residual risk: The disaster risk that remains even when effective disaster risk reduction measures are in place, and for which emergency response and recovery capacities must be maintained. The presence of residual risk implies a continuing need to develop and support effective capacities for emergency services, preparedness, response and recovery, together with socioeconomic policies such as safety nets and risk transfer mechanisms, as part of a holistic approach. (Sendai)

Disaster risk assessment: A qualitative or quantitative approach to determine the nature and extent of disaster risk by analysing potential hazards and evaluating existing conditions of exposure and vulnerability that together could harm people, property, services, livelihoods and the environment on which they depend. (Sendai)

Annotation: Disaster risk assessments include: the identification of hazards; a review of the technical characteristics of hazards such as their location, intensity, frequency and probability; the analysis of exposure and vulnerability, including the physical, social, health, environmental and economic dimensions; and the evaluation of the effectiveness of prevailing and alternative coping capacities with respect to likely risk scenarios.

Disaster risk governance: The system of institutions, mechanisms, policy and legal frameworks and other arrangements to guide, coordinate and oversee disaster risk reduction and related areas of policy. (Sendai)

Annotation: Good governance needs to be transparent, inclusive, collective and efficient to reduce existing disaster risks and avoid creating new ones.

Disaster risk reduction: Disaster risk reduction is aimed at preventing new and reducing existing disaster risk and managing residual risk, all of which contribute to strengthening resilience and therefore to the achievement of sustainable development. (Sendai)

Emergency: A present or imminent event or circumstance that: a) is caused by accident, fire, explosion, technical failure or a force of nature; and b) requires prompt coordination of action or special regulation of persons or property to protect the health safety or well-being of a person or community or to limit the damage to property, significant Indigenous cultural sites or the environment; or c) any other situation prescribed by the Lieutenant Governor in Council. (EMBC)

Emergency management: Used, sometimes interchangeably, with the term "disaster management," particularly in the context of biological and technological hazards and for health emergencies. While there is a large degree of overlap, an emergency can also relate to hazardous events that do not result in the serious disruption of the functioning of a community or society. (Sendai)

Annotation: In Canada, including in BC, the term "emergency management" is used as an overarching term for the systems and processes used for preventing or reducing the impacts of emergencies on communities. Emergency management is conceptualized in four phases: mitigation, preparedness, response and recovery. EMBC's recommended definitions of each phase is provided in this terminology document.

Exposure: The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas. (Sendai)

Annotation: Measures of exposure can include the number of people or types of assets in an area. These can be combined with the specific vulnerability and capacity of the exposed elements to any particular hazard to estimate the quantitative risks associated with that hazard in the area of interest.

Hazard: A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. (Sendai)

Indigenous Knowledge: The understandings, skills and philosophies developed by societies with long histories of interaction with their natural surroundings. For many Indigenous Peoples, Indigenous Knowledge informs decision-making about fundamental aspects of life, from day-to-day activities to longer term actions. This knowledge is integral to cultural complexes, which also encompass language, systems of classification, resource use practices, social interactions, values, ritual and spirituality. These distinctive ways of knowing are important facets of the world's cultural diversity. (IPCC)

Local authority: Local authorities are defined in the EPA as: a) for a municipality, the municipal council; (b) for an electoral area in a regional district, the board of the regional district; or c) for a national park, the park superintendent. Including a Treaty First Nation whose Final Agreement defines it as a local authority, an appropriate body within the Stikine, or a group of willing First Nations, municipalities and/or electoral areas that wish to form a unified local authority for the purposes of undertaking some or all emergency management functions. (EMBC)

Mitigation (of climate change): A human intervention to reduce emissions or enhance the sinks of greenhouse gases. Note that this encompasses carbon dioxide removal options. (IPCC)

Mitigation (of disaster risk): The phase of emergency management in which proactive steps are taken to prevent a hazardous event from occurring by eliminating the hazard, or to reduce the severity or potential impact of such an event before it occurs. Mitigation protects lives, property, cultural sites, and the environment, and reduces vulnerabilities to emergencies and economic and social disruption. (EMBC)

Preparation: The phase of emergency management during which action is taken to ensure readiness to undertake emergency response and recovery. It includes, but is not limited to, hazard, risk, and vulnerability assessment, planning, resource planning, volunteer management, training, exercises, public/stakeholder education, and continuous improvement. (EMBC)

Preparedness: The knowledge and capacities developed by governments, response and recovery organizations, communities and individuals to effectively anticipate, respond to and recover from the impacts of likely, imminent or current disasters. (Sendai)

Annotation: Preparedness action is carried out within the context of disaster risk management and aims to build the capacities needed to efficiently manage all types of emergencies and achieve orderly transitions from response to sustained recovery.

Preparedness is based on a sound analysis of disaster risks and good linkages with early warning systems, and includes such activities as contingency planning, the stockpiling of equipment and supplies, the development of arrangements for coordination, evacuation and public information, and associated training and field exercises. These must be supported by formal institutional, legal and budgetary capacities. The related term "readiness" describes the ability to quickly and appropriately respond when required.

Recovery: The phase of emergency management during which action is taken to re-establish social, cultural, physical, economic, personal and community well-being through inclusive measures that reduce vulnerability to emergencies, while enhancing sustainability and resilience. It includes taking steps to repair a community impacted by an emergency and restore conditions to a level that could withstand a potential future event or, when feasible, improve them to increase resilience in individuals, families, organizations, and communities. (EMBC)

Three stages of recovery: short term (days to weeks), medium term (weeks to months), and long term (months to years).

Resilience: The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management. (Sendai)

Response: The phase of emergency management during which actions are taken in direct response to an imminent or occurring emergency in order to prevent, limit and manage impacts. Response includes the initiation of plans and actions to support recovery and may include deployment of registered volunteer resources. (EMBC)

Risk: The potential for adverse consequences where something of value is at stake and where the occurrence and degree of an outcome is uncertain. In the context of the assessment of climate impacts, the term risk is often used to refer to the potential for adverse consequences of a climate-related hazard, or of adaptation or mitigation responses to such a hazard, on lives, livelihoods, health and wellbeing, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure. Risk results from the interaction of vulnerability (of the affected system), its exposure over time (to the hazard), as well as the (climate-related) hazard and the likelihood of its occurrence. (IPCC)

Vulnerability: The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards. (Sendai)

BOX A: DATA AND DATA MANAGEMENT TERMINOLOGY

Prepared by Sahar Safaie, Sage On Earth Consulting

Closed data: Data that requires a specific licence for each use negotiated on a case-by-case basis.

Data (vs. information): Data are individual facts and figures presented in machine-readable formats such as .shp, .xls, .csv, or similar. Once data are organized and presented in a given context to make it useful, it becomes information.

Data management: Data management governs the process by which data are gathered from participating entities, the technical and quality standards to which new data will be produced, how data will be stored and maintained, and how the output data will be shared with users.

Data management platform: A data management platform is a software platform used for collecting and managing data. It allows unifying data and breaking down silos, giving access to a wider range of audiences, providing continuity in data production and use.

Hazard data: Data on geospatial distribution, probability, and intensity of hazard events.

Open data: Data that can be freely used, reused, and redistributed by anyone, subject only (at most) to the requirement to attribute and share-alike.

Post-disaster damage and loss data: Data on intensity and characteristics of various impacts from a certain event.

Post-disaster event data: Data on intensity, date, and location of a certain event.

Risk data: Data on geospatial distribution, possibility, and intensity of impact from events.

Risk data, provincial or regional: Regional or sub-regional risk data and information are produced using harmonized methodologies and provide information that allows for comparing risk levels between municipalities.

Risk data and information governance: Effective and efficient production, sharing, and use of risk information in policy and planning for disaster risk reduction. Good risk information governance includes regulatory and accountability frameworks, collaboration mechanisms, capacities, and incentives for production and use of risk information.