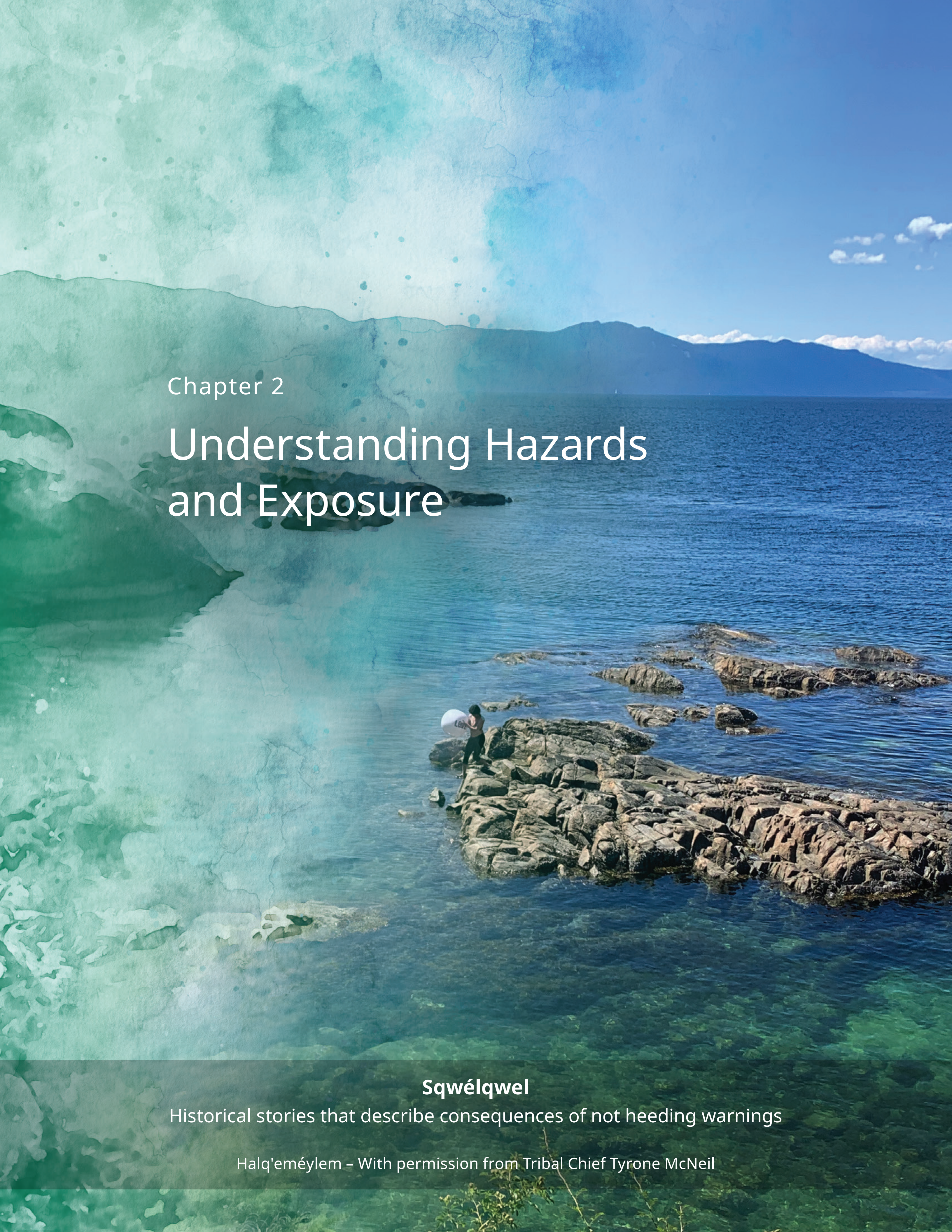


Chapter 2

Understanding Hazards and Exposure

Sqwélqwel

Historical stories that describe consequences of not heeding warnings

Halq'eméylem – With permission from Tribal Chief Tyrone McNeil

Chapter 2: Table of Contents

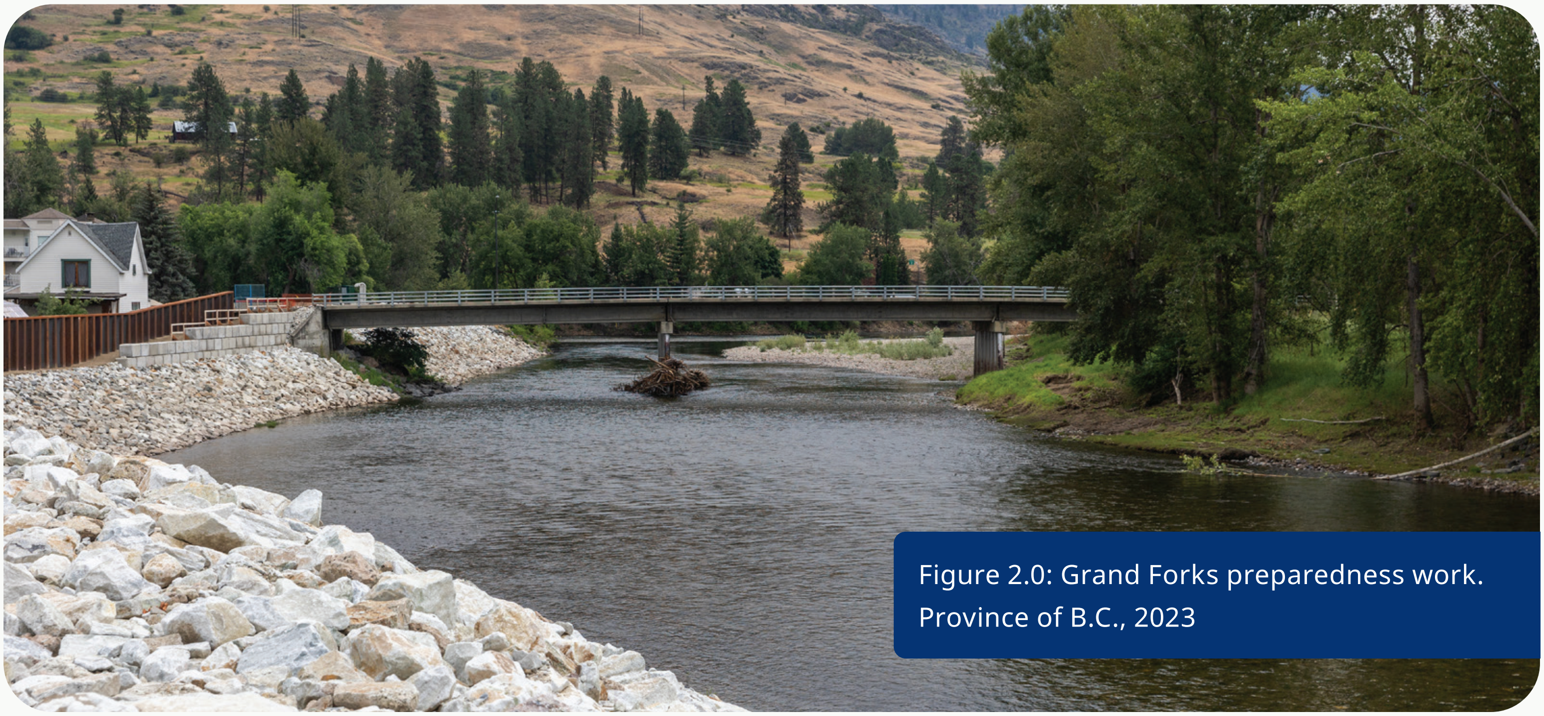


Figure 2.0: Grand Forks preparedness work. Province of B.C., 2023

2.0 Understanding hazards and exposure

British Columbia context

The lands known as British Columbia (B.C.) are characterized by diverse natural environments and landscapes with unique features such as rugged mountainous terrain, extensive forested areas and diverse weather patterns. This diversity makes the area particularly susceptible to several hazards. These settings are shaped by physical, chemical and biological processes that react in the atmosphere, hydrosphere, biosphere and geosphere.

Climate change is altering environmental conditions and intensifying the hazards in B.C. The changes will be in the frequency, intensity, spatial extent and timing of climate events. The annual global mean temperature reached 1.5°C above pre-industrial temperatures in 2024,[1] and Canada is warming at nearly twice the global rate.[2] Since 1948, B.C. has experienced a rise of 1.7°C in annual average surface temperatures.[3]

Although there is much to learn from past events and their drivers, the advent of climate change and its influence on hazards makes previous experiences insufficient for planning and decision-making. Understanding the influence of climate change on hazards, including clarity on the gaps in current science and data, is crucial to grasp the range of potential impacts and to decide on the pathways to managing climate risks.

Understanding hazards

Most hazards are natural in origin, but it is often the human-caused alterations over generations that contribute to the intensity and frequency of these hazards and their impacts on populations, assets, services and conditions. Examples of human-induced disturbances include greenhouse gas emissions, natural resource development, flow alteration of rivers and settlement in hazard-prone areas.

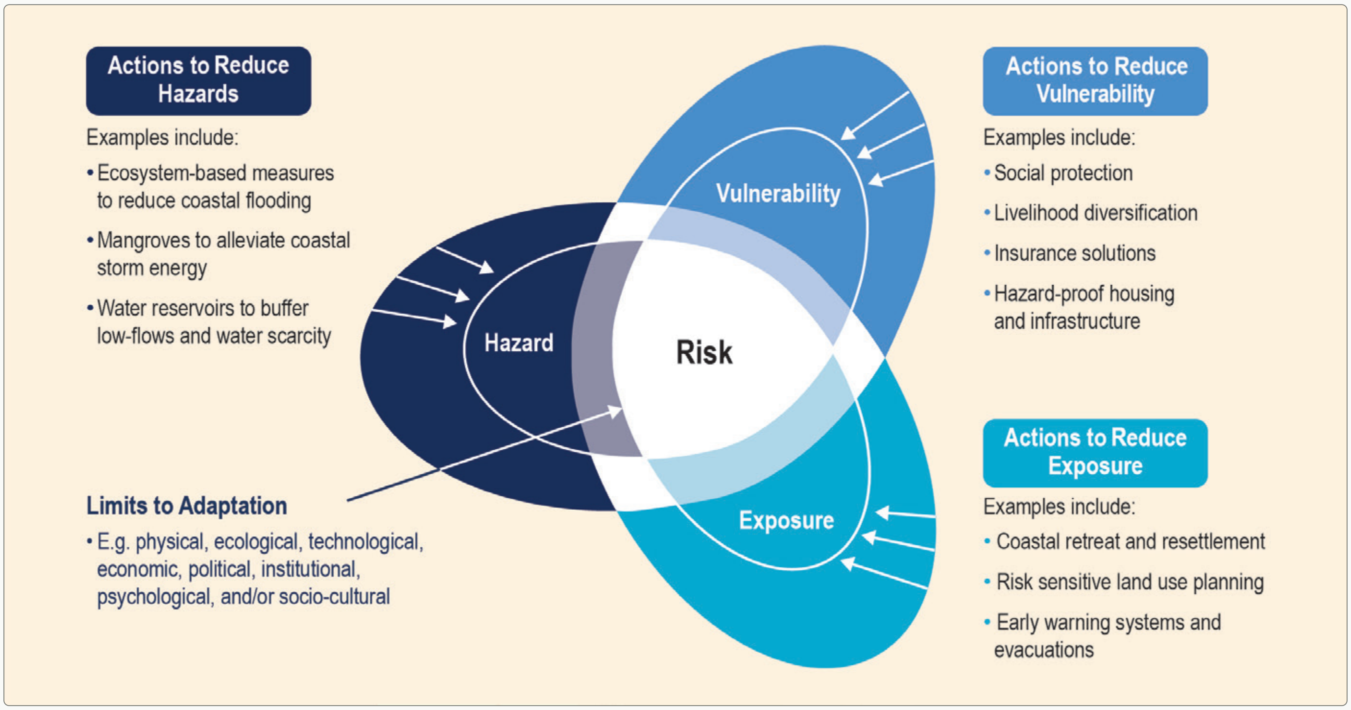
What is a hazard?

A hazard is a process, phenomenon or human activity that may cause loss of life, injury and other health impacts, property damage, social and economic disruption, or environmental degradation. It is characterized by the intensity, frequency and geographical area affected.[4]

Most hazards, such as extreme heat or wildfires, can directly impact the health of humans and all other beings exposed to them. Interactions between hazards and the built and natural environments, however, cause further health, social and economic impacts. For example, ground shaking from an earthquake in an open space is unlikely to cause injury, but ground shaking leading to damage or collapse of buildings can cause severe injury or loss of life, disruption of health services and essential supply chains, as well as direct and indirect economic losses.

Understanding hazards and their characteristics, including intensities, frequencies, drivers and distribution throughout the province, is important in designing risk management actions. Hazard information can be directly used in risk management measures, such as land-use planning or codes and standards for the design and operation of buildings and infrastructure. Understanding hazards can provide insights for developing actions to reduce the hazard itself. Figure 2.0.1 provides a conceptual framework of risk components and examples of targeted risk management measures.

Figure 2.0.1: Risk management actions can be targeted to reduce one or more risk components: hazard, exposure and/or vulnerability. The Intergovernmental Panel on Climate Change (IPCC). Source: IPCC 5th Assessment Report, 2014.[5]



First Nations relationship with hazards

Since time immemorial, First Nations have stewarded lands and waters, cultivating deep connections, understandings and ways of being in relation to changing natural conditions. Hazards have always threatened life and livelihoods, and First Nations have managed, responded to and learned from natural hazards, developing and evolving their Indigenous Knowledge to mitigate disaster and build resilience over millennia.

First Nations recognize that hazards have spirits, like all living things with which we live in relationship. The spirit of a hazard is understood to bring teachings or insights on the health and wellbeing of the land and water. First Nations communities and individuals have long sounded the alarm on the effects of human-caused alterations to the biosphere by observing, reflecting and learning from increasing and intensifying hazard events.

First Nations are also disproportionately exposed to hazard risk due to the colonial reserve system, which restricted First Nations communities to highly vulnerable lands and disrupted mobile ways of living. Disproportionate risk arising from forced relocation compounds with other negative impacts of colonialism—poor housing conditions, low water quality, under-funded programs and services, cultural erosion and economic marginalization—to make First Nations individuals and communities disproportionately vulnerable to climate change-exacerbated hazards.

First Nations intergenerational relationships and connections with the land positions First Nations Peoples as climate action leaders. Indigenous-driven climate solutions are informing new practices for hazard management and response.

Hazards of focus

The hazards selected for the Provincial DCRRA are:

- **Riverine flood**
- **Coastal flood**
- **Extreme heat**
- **Drought and water scarcity**
- **Wildfire**
- **Earthquake**
- **Multi-hazard**

In 2019's Preliminary Strategic Climate Risk Assessment for British Columbia, the risks from 15 climate-related hazards were evaluated. Wildfires, drought and water scarcity, and extreme heat were rated as high risk, whereas riverine floods and coastal storm surges (one component of coastal floods) were scored as medium. Since that assessment, catastrophic flooding in November 2021 caused significant damage to southern B.C. This became the costliest disaster in the province's history and made it clear that understanding the risks from floods, especially with the influence and impact of climate change, is crucial for the health and wellbeing of people and the prosperity of the province.

Earthquakes are included in the hazards of focus for the Provincial DCRRA because of the significant risk in the southwest part of the province—a very active tectonic region with a high concentration of physical assets. B.C. bears the largest burden of earthquake risk in Canada—with estimates of loss, due to the inevitable Cascadia M9 earthquake, on the scale of tens of billions of dollars in direct damage to buildings and a total cost of more than $100 billion.[6]

Hazards and risk assessments are often developed with a singular focus and an assumption that hazards are independent events. However, some hazards are innately tied (for example, a tsunami following an earthquake). Further, they may occur simultaneously by chance, especially when considering hazards of longer duration. For single events, there are relatively well-documented processes for analyzing hazards. However, multiple hazards may interact with unexpected effects in complex ways. Understanding the interaction of multiple hazards and their consequences is critical to addressing systemic risk and enabling comprehensive risk assessment, resilience planning with co-benefits across hazards, resource allocation and avoiding maladaptation.[7]

Geospatial data analysis and mapping are used for understanding the spatial distribution of hazards and risks. In the Provincial DCRRA, a geospatial hazard and exposure analysis was conducted for all six hazards and many key assets and populations. Exposure provides information on the portion exposed to the hazard, defined by a certain threshold. For example, the threshold for riverine floods is inundation with 0.5 percent chance of exceedance in any year (200-year return period flood).

In this chapter

This chapter provides a provincial overview of climate change and hazard characteristics, addressing several key aspects. This includes key climate variables, past and future characteristics and their interactions that influence other extreme hazards, a comprehensive hazard description that incorporates its relationship to secondary hazards, an analysis of hazard distribution with insights from geospatial data, an assessment of the exposure and a review of past events. It also explores the influence of climate change on climate-related hazards and identifies strengths, gaps and uncertainties in understanding the hazard and risk.

The first section of this chapter provides information on climate change in B.C. Each of the following sections focuses on one of the six hazards, and the last section provides insights on multi-hazard interactions. Below is the overview of how the information has been structured in all sections of this chapter.

Hazard description

A short description of each hazard, followed by an extended description of the hazard and the environments and processes that create it.

Secondary hazards

Most hazards can trigger secondary hazards, such as earthquakes triggering landslides, tsunamis or hazardous chemical spillage due to infrastructure damage, that compound the overall risk. This section provides a brief overview of key secondary hazards and their potential impacts.

Hazard distribution

This section provides an overview of hazard characteristics and distribution across the province.

Hazard exposure

This section describes how the hazard's interaction with people, nature and the built environment can lead to negative consequences, which asset types are susceptible to the hazard's impacts and what the key vulnerabilities are. Using geospatial data and analysis, this section provides insight into hazard exposure, identifying regions with high concentrations of assets and populations in high-hazard zones.

Past events

Details about the impacts of past events is provided based on openly available information (see text box later in this section and case study 1 in Appendix C). In the context of a changing climate, historical events cannot always guide us on the intensity and frequency of the climate-related hazard in near-term and long-term timelines. Nevertheless, understanding how past events have unfolded and their direct and indirect impacts is crucial for understanding risk and risk management.

Climate change influence

This section discusses how a hazard described in the preceding sections may be influenced by ongoing and projected climate change. These assessments are based on current research and, in some cases, custom analyses. The technical details for this discussion may be found in Appendix B: B.C. Provincial Climate Overview.

Strengths, gaps and uncertainties in understanding risk in B.C.

Each section provides high-level insight into existing strengths, gaps and uncertainties in understanding the hazards and risks in B.C. This information has been prepared based on discussions with the Hazard Working Group members.

Research highlight: State of disaster and resilience academic literature in B.C.

Extensive academic research is dedicated to disaster and resilience topics in British Columbia. However, within disaster studies, research and knowledge are commonly siloed between different fields. To better understand the state of research in the province, researchers from the University of British Columbia (UBC) reviewed available academic literature and identified trends in methodologies, disciplines, hazards and locations.

The literature review revealed that natural hazards were the primary subject matter for 87 percent of documents, while 13 percent discussed disaster and resilience more generally. Earthquakes were the most frequently discussed hazard, despite floods being the most frequent disaster-causing hazard. Storm/extreme weather and drought were the least discussed hazards, and only 14 percent of the documents discussed multiple hazards. Several hazards, scales and disciplines were underrepresented. For example, there was a trend towards global application of findings, often at the cost of making local recommendations or acknowledging local context.

The literature review points to the importance of non-academic literature and additional sources in addressing knowledge gaps, and it outlines desired expansion of academic research into underrepresented hazards and aspects of risk and resilience.

For further details on this research project, see case study 1, in Appendix C.

2.1 Climate overview

In recent years, human-caused climate change has become a pressing reality. Data gathered from across the globe have allowed climate scientists to document and quantify departures from historical norms and to build complex models of Earth's future climate. This information can be used to provide necessary input for decision-making and planning to safeguard our collective future.

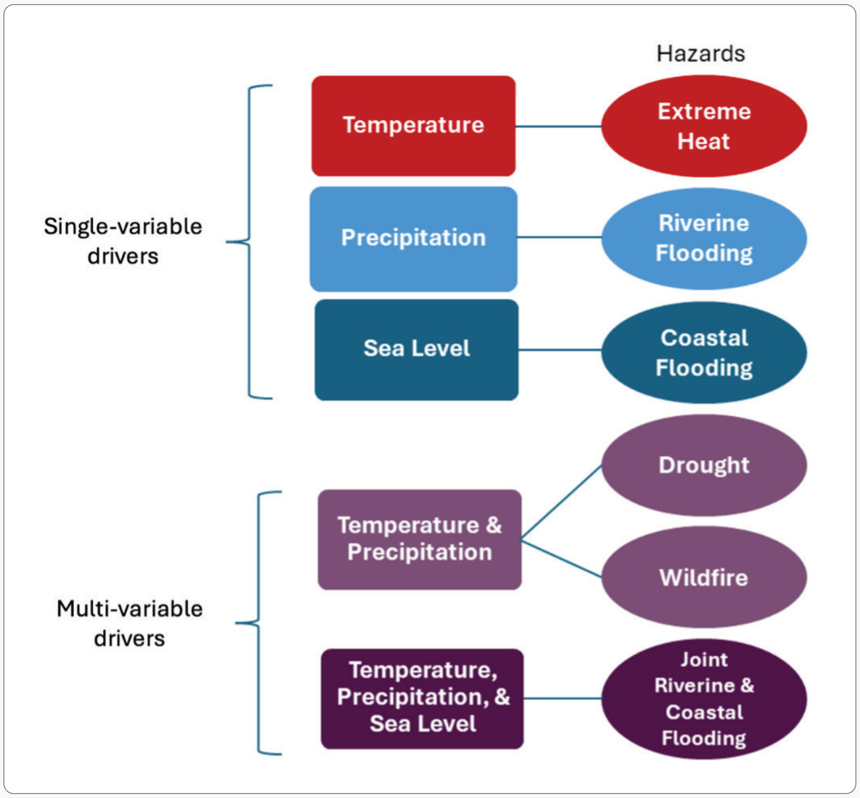
Linking climate to hazards in B.C.

Observations and models provide a wealth of information on climate variables. However, we are often most interested in the impacts that changes in those variables have on other systems over both the short and long term. When there are impacts on humans, the broader ecosystem or the built environment—as a result of extreme weather events that happen over days or persistent adverse climatic conditions—we refer to the corresponding climate variables as "hazard drivers." Examples of hazard drivers occurring at the scale of days are extreme high temperatures (sometimes in concert with high humidity), heavy rainfall and extreme wind. Numerous analyses conducted throughout B.C. have identified common features shared by nearly all climate model projections over all future emissions scenarios, spanning the 2050s and beyond. Figure 2.1.1 summarizes these robust changes.

Figure 2.1.1: Broad features of climate projections for B.C. that are robust across climate models and scenarios from mid-century (circa 2050s) onward.

Heatwaves, floods, and infrastructure or debris-related damage might result from these drivers. However, many hazards have multiple drivers, meaning that they cannot be adequately described by a single climate variable. Extended periods of below- or above-normal climate variables also count as hazard drivers. For example, low seasonal precipitation in concert with high temperatures can prompt both drought and wildfire hazards. Figure 2.1.2 presents a schematic describing which climatic drivers influence the hazards addressed in the next chapter of this report.

Figure 2.1.2: Flow chart describing which hazard drivers exert the most influence on the hazards included in this assessment.



This climate overview discusses the drivers associated with those hazards of focus in the Provincial DCRRA that are affected by climate: riverine floods, coastal floods, extreme heat, drought and wildfires. Since these have temperature and precipitation in common as hazard drivers, this overview begins with a look at these key climate variables, in addition to sea level changes. Further, since historical climate behaviour, patterns and trends are an essential starting point for anticipating future climate change, these drivers begin with a brief review of the recent historical change in each variable in B.C.

Temperature

Overview of historical temperature patterns and change across B.C.

In B.C., the familiar temperature gradient between southern and northern areas is strongly modified by physical geography. The bordering Pacific Ocean raises coastal annual mean temperatures compared to interior areas, while annual temperatures are lower in the mountainous terrain covering much of the province. Figure 2.1.3 clearly exhibits these features, along with details that largely reflect the complex network of river valleys throughout the province.

While much of the B.C. coast is characterized by a mild year-round climate, the rest of the province exhibits a continental-style climate with significant seasonal temperature variations, featuring hot summers and cold winters. Air is often trapped in steep valleys, and in summer, this increases the intensity of the heat experienced. The adjacent Pacific Ocean can bring cool breezes to coastal areas, but also occasional high-pressure ridges ("blocking highs") that stall over the province and manifest as extended and/or intense heatwaves.

Figure 2.1.3: Observation-based map of mean annual temperatures across B.C. for the 1970–2000 period, with a nominal horizontal resolution of 800 m. PCIC PRISM product, as represented on PCIC's Data Portal.

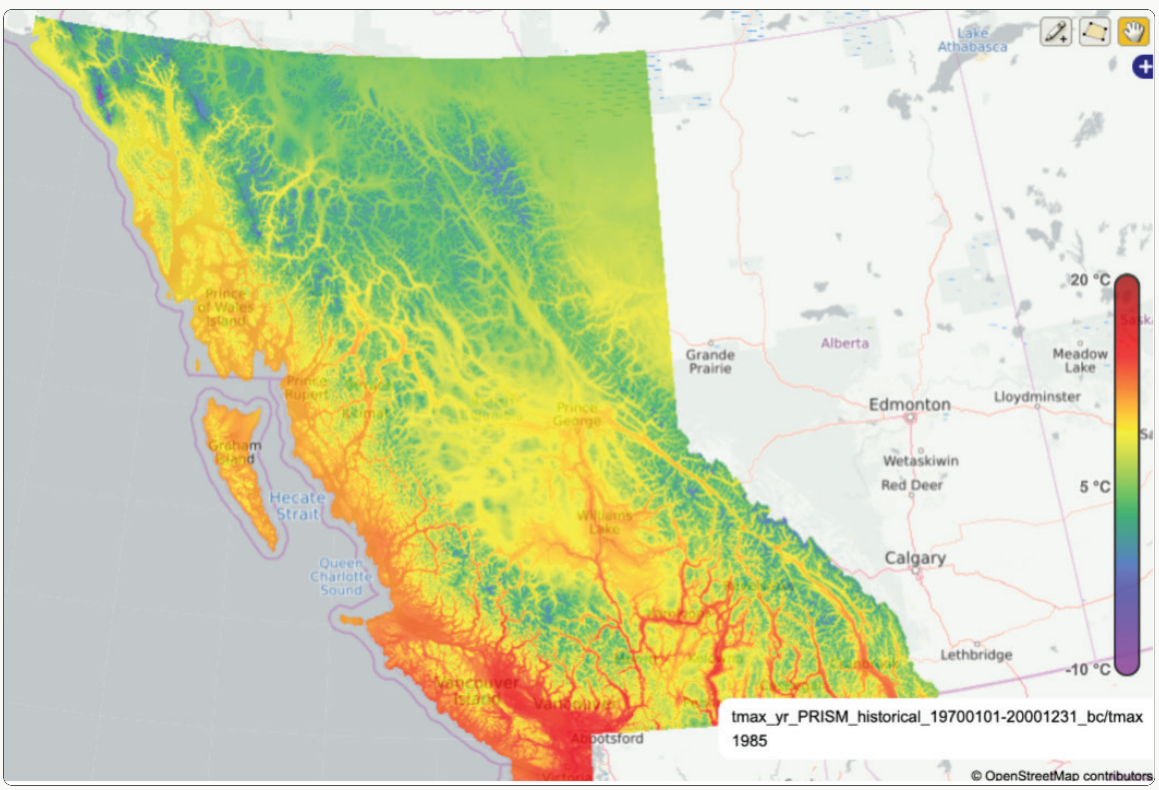
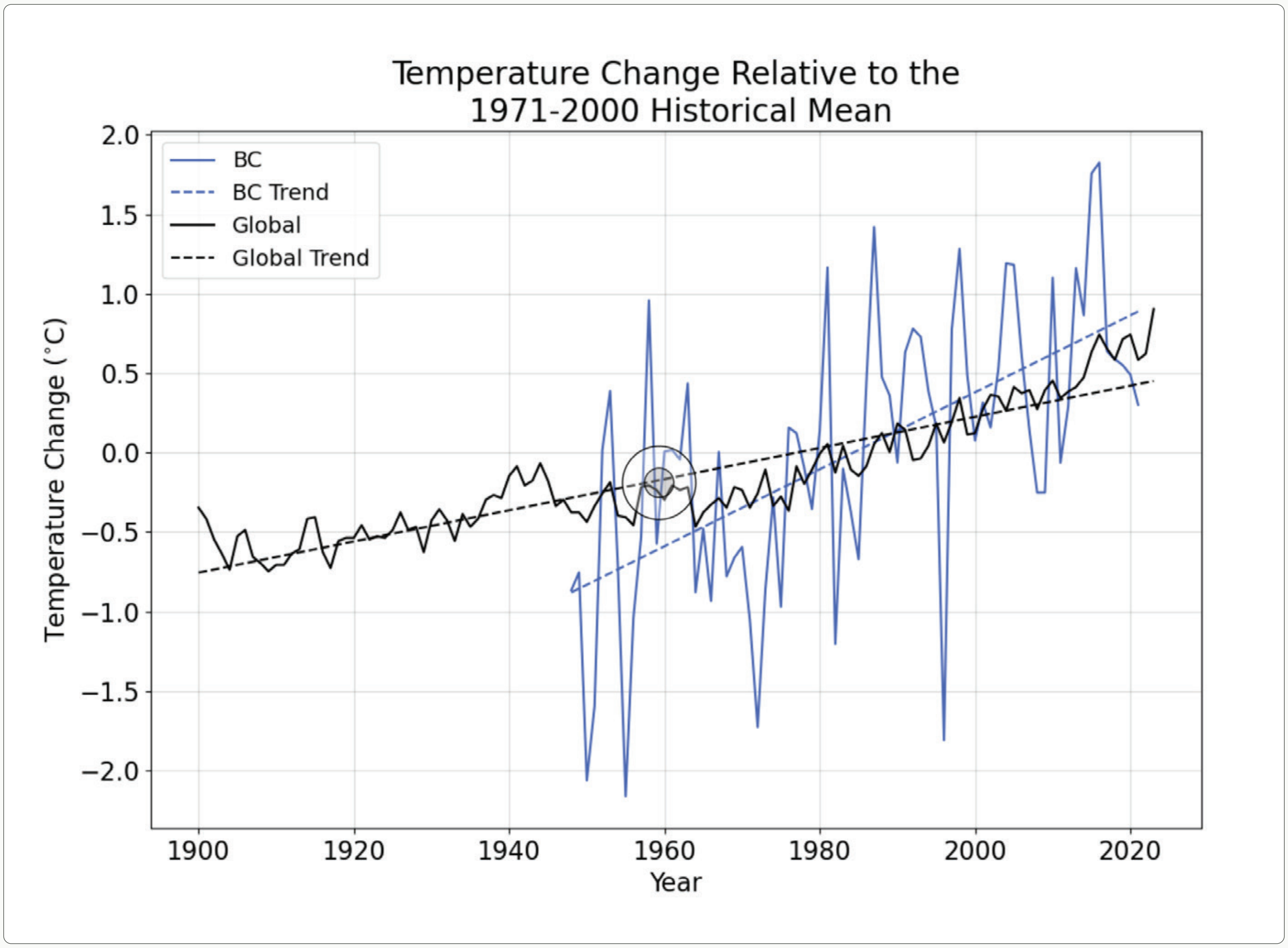


Figure 2.1.4 shows the change in annual surface temperature over B.C. (1948–2021) compared to that over the globe (1900–2023), relative to 1971–2000 historical mean values. In both cases, the linear trends indicate warming over the respective periods, with a much faster rate of warming in B.C. over the last 74 years. The year-to-year fluctuations in temperature, seen in both time series, are due to natural climate variability, which is much larger at the regional scale (B.C.) than it is at the global scale.

Figure 2.1.4: Annual surface temperature change globally (1900–2023; black curve) and in B.C. (1948–2021; blue curve) relative to the corresponding 1971–2000 mean temperature. The global time series is based on the Goddard Institute for Space Studies (GISTEMP) gridded station temperature product,[8] while the B.C. series is derived from the Provincial Climate Dataset (PCDS) maintained at PCIC. Linear trends, both of which are statistically significant at the 5% level, are indicated by the dashed lines. PCIC.



As shown, Table 2.1.1 summarizes the changes in average surface temperature annually and seasonally across Canada and B.C. since 1948. The table shows that the annual average surface temperature has risen 1.7°C in B.C. over this period. Both nationally and provincially, warming has been detected in all seasons except fall in B.C., and the change is nearly twice as large in winter as compared to the other seasons.

Table 2.1.1: Historical temperature change in Canada and B.C. Observed changes in annual and seasonal temperature between 1948 and near-present, as determined from a linear fit to the data over the entire period. Data for Canada are from an updated Environment and Climate Change Canada gridded station data product (1948–2023[9]), while those for B.C. are derived from PCIC's Provincial Climate Data Set (1948–2021). Trends consistent with zero at the 5% significance level are shown in parentheses.

Region	Season	Mean temperature change (°c)	Region	Season	Mean temperature change (°c)
Canada	Annual	+ 1.8	**B.C.**	Annual	+ 1.7
	Winter	+ 3.4		Winter	+ 3.2
	Spring	+ 1.7		Spring	+ 1.6
	Summer	+ 1.7		Summer	+ 1.7
	Fall	+ 1.7		Fall	(+ 0.83)

Future-projected temperature change in B.C.

The study of future climate change requires a shift in approach from data gathering to modelling of complex processes in the atmosphere, ocean and on land. Summary information is provided in this chapter; a comprehensive overview of climate modelling and projections can be found in Appendix B: B.C. Provincial Climate Overview.

The standard suite of global climate models used for international and national climate assessments comes from the Coupled Model Intercomparison Project (CMIP), which comprises a co-ordinated global effort to understand past and future climate change. These models use different estimates, called emissions scenarios, of how greenhouse gas emissions may change in the future.

In the most recent intercomparison (such as, CMIP6), models use scenarios called Shared Socioeconomic Pathways (SSPs) to describe how national-scale decision-making and socioeconomic factors, such as population growth and energy production, lead to different global amounts of greenhouse gases in the atmosphere. Ranked from low to high cumulative emissions over the century, the three most commonly used scenarios for running the models are: SSP1-2.6 (low), SSP2-4.5 (medium), and SSP5-8.5 (high). The previous intercomparison, CMIP5, used analogous scenarios (from low to high Representative Concentration Pathways (RCP), RCP2.6, RCP4.5 and RCP8.5.

In this climate overview, future projection information from both CMIP5[10] and CMIP6[11] are presented from various peer-reviewed studies and, in some cases, custom analyses. This is necessary because much of the research relevant to B.C. performed using CMIP5 models has not been repeated using the most recent model suite. Nevertheless, this research is still fully adequate for this assessment. It should also be understood that climate model projections are sometimes only available for a single scenario—often a high-emissions scenario—since this allows the envisioning of a “worst-case” outcome that can be helpful for policy decisions.

Figure 2.1.5 portrays the historical and future-projected annual mean temperature change over B.C. for a selection of CMIP6 models running the three emissions scenarios. In all three, temperatures warm into the future. The trajectory of the various projections reinforces the message that historical conditions do not provide reliable guides for the future. For example, even under the medium-emissions scenario, the projected lower limit of temperature change by the end of the century (just above 2°C) is warmer than the highest historical annual mean temperature (indicated by the black line).

Figure 2.1.5: Model-simulated historical (grey) and projected temperature (colours) change for B.C. under three future emissions scenarios: low (SSP1-2.6; blue), medium (SSP2-4.5; yellow), and high (SSP5-8.5; red). Coloured lines are median values, while shaded bands show the range across models, with different colours denoting overlapping range. Changes are relative to the 1971–2000 mean temperature. B.C.-averaged historical data from the PCDS are shown by the black line.[12]

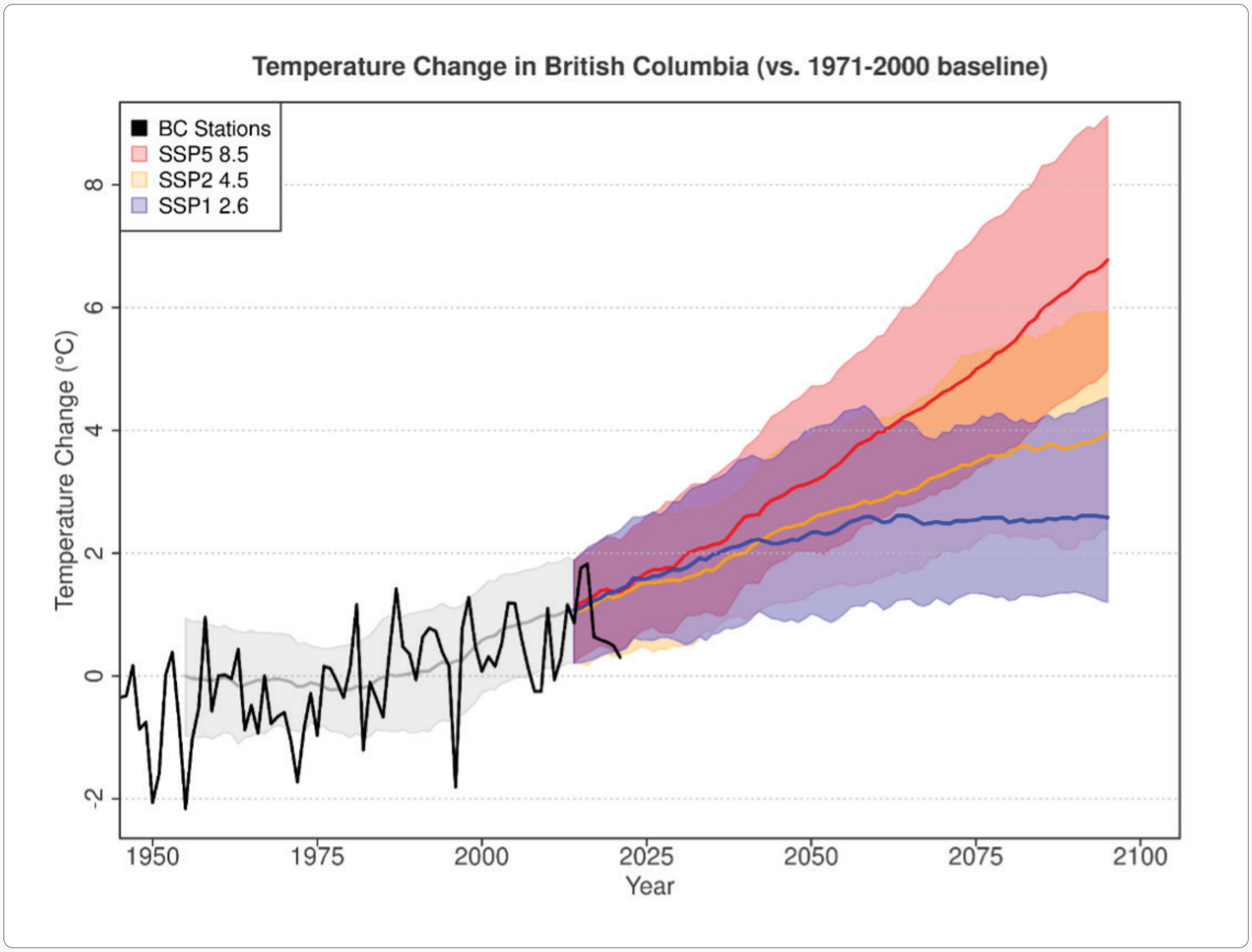


Table 2.1.2 shows median values of projected average annual and hottest annual surface temperatures in B.C. under the medium- and high-emissions scenarios. Also shown are changes relative to 1971–2000 values. Under the high-emissions scenario, B.C.'s average temperature is projected to rise by nearly 3°C by the 2050s (the 2041–2070 period), with an increase of 3.6°C in the

hottest annual temperature. By the 2080s (the 2071–2100 period), average surface temperature is projected to increase by 6°C, with the hottest annual temperature exceeding 7°C. Under a medium-emissions scenario, warming occurs more slowly, but the amount of warming by the 2080s (+3.5°C) exceeds the amount of warming projected to occur by the 2050s under the high-emissions scenario (+2.9°C).

Table 2.1.2: Future-projected temperature change in B.C. Values and projected changes in annual mean surface temperature and annual highest daily maximum temperature, averaged over B.C., based on outputs from CMIP6 climate models. Results are presented for two future periods under two emissions scenarios (medium and high) and also in terms of global warming level (GWL).

		Medium emissions		High emissions		GWL	
Variable		2050s	2080s	2050s	2080s	2.5°C	4.0°C
Annual average surface temperature (°C)	Value	3.7	4.9	4.4	7.4	4.2	6.3
	Change	+ 2.4	+ 3.5	+ 2.9	+ 6.0	+ 2.7	+ 4.8
Annual highest daily maximum temperature (°C)	Value	28.5	30.4	29.5	33.1	29.2	33.5
	Change	+ 2.5	+ 4.5	+ 3.6	+ 7.1	+ 3.4	+ 7.7

These results demonstrate a useful alternative way of presenting future climate projections by de-emphasizing the precise timing of warming under different scenarios and instead focusing on the magnitude of global temperature change (or global warming level, GWL) that might be exceeded. Since the severity of climate change-induced impacts tends to scale with GWL, presenting climate projections in this way, rather than for fixed future time periods, is a useful approach for impact and risk assessments. For this reason, Table 2.1.2 and many of the subsequent climate projections in this overview include results in terms of GWL.

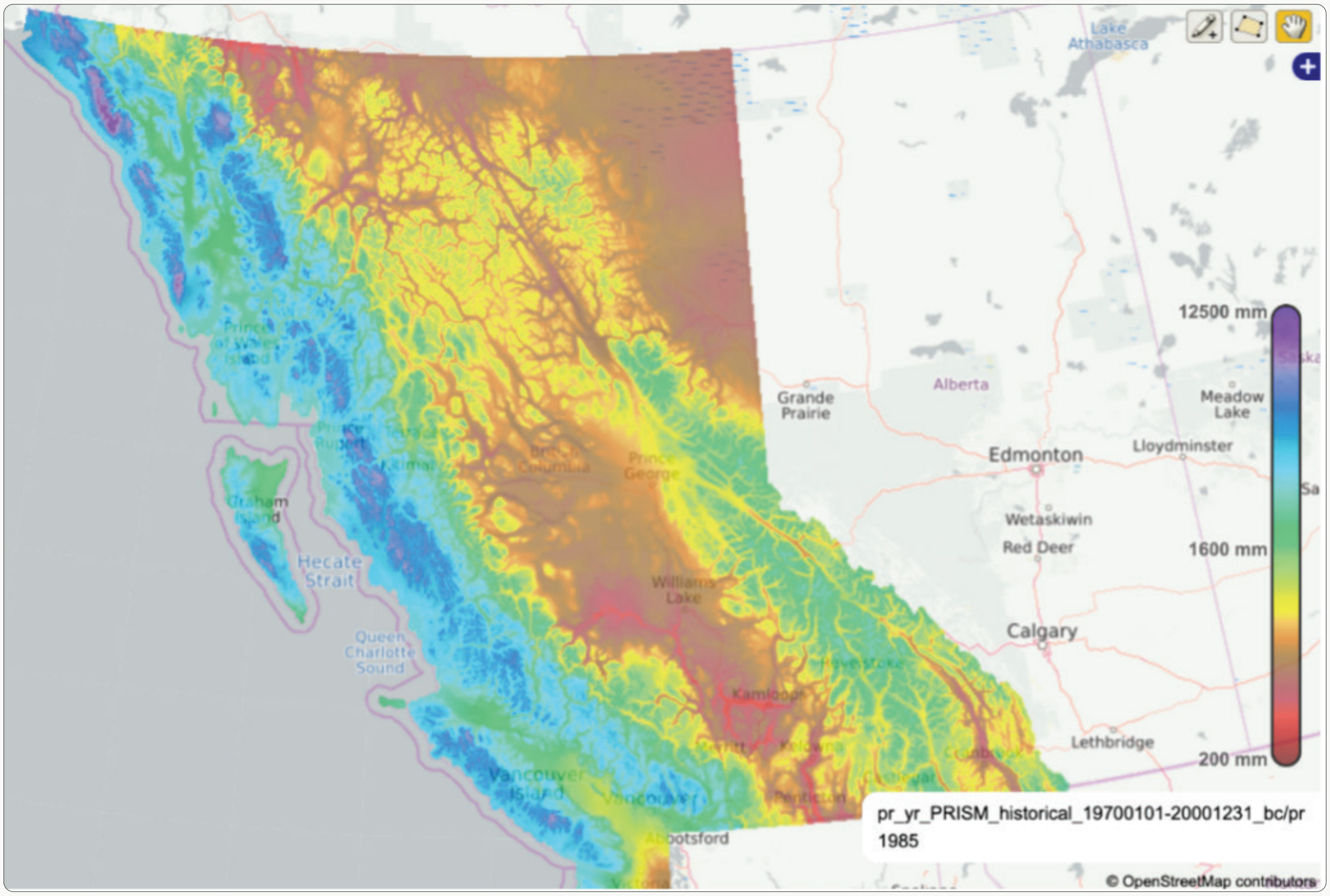
For example, if the GWL reaches 4.0°C, then B.C. average and extreme temperatures are projected to increase by +4.8°C and +7.7°C, respectively. These values are comparable to those given for the 2080s under a high-emissions scenario but are not identical since the timing of a GWL = 4.0°C is not exactly aligned with the midpoint of the 2080s. Similarly, if the GWL reaches 2.5°C, then B.C. average and extreme temperatures are comparable, though not identical, to those given for the 2050s under a high-emissions scenario. Also note that the B.C.-averaged temperature changes are always larger than the corresponding GWL, since the warming is stronger at northern latitudes.

Precipitation

Overview of historical precipitation patterns and change across B.C.

Like temperature, the variation of precipitation over B.C. is closely tied to the complex landscapes of the region and proximity to the Pacific Ocean. Relatively warm, moist air moving eastward from the Pacific Ocean is forced to rise as it encounters the mountainous west coast, resulting in precipitation falling on the windward slopes of the Coast Mountain range. The process repeats in the inland ranges all the way to the Rockies, with drier conditions on the leeward mountain slopes, interior valleys and plateaus. Figure 2.1.6, in combination with the temperature variations shown in Figure 2.1.3, shows the spatial pattern of total annual precipitation across B.C., which clearly reflects this strong topographic influence on the character and distribution of B.C.'s hydrological basins.

Figure 2.1.6: Observation-based map of total annual precipitation across B.C. for the 1970–2000 period, with a nominal horizontal resolution of 800 m. PCIC PRISM product, as represented on PCIC's Data Portal.



The seasonality of precipitation across the province varies considerably according to region.[13] Most of the precipitation in coastal regions (Haida Gwaii, Sunshine Coast, greater Vancouver area and the Fraser Valley, and Vancouver Island) falls as rain between October and March, but substantial snowpacks develop at higher elevations. In central B.C. (Fraser, Thompson and Okanagan) and southeastern B.C. (Kootenay and Upper Columbia), smaller amounts of precipitation are delivered more evenly throughout the year, mostly as snow in the winter months. These areas experience cold winters with substantial snowfall, especially in mountainous areas where perennial snowpacks and glaciers are found.

Northern B.C., encompassing areas east of the Alaska Panhandle to Alberta, experiences cold winters with moderate snowfall during the winter months. Throughout the B.C. interior, slightly more precipitation falls in spring and summer than in fall and winter, unlike near the coast. Summers in coastal B.C.

are much drier than in the cold season, but with comparable rainfall amounts to interior areas at the same latitude.

Both provincial and global precipitation records show no significant long-term trends of change. Figure 2.1.7 shows annual total precipitation change in B.C. and over the globe relative to the 1971–2000 historical mean.

Figure 2.1.7: Annual precipitation change globally (1921–2023; black curve) and in B.C. (1948–2021; blue curve) relative to the corresponding 1971–2000 mean value. The global time series is from the Global Precipitation Climatology Centre (GPCC) gridded station precipitation product, while the B.C. series is derived from PCDS. GPCC was accessed via the KNMI Climate Explorer (https://climexp.knmi.nl/). PCIC.

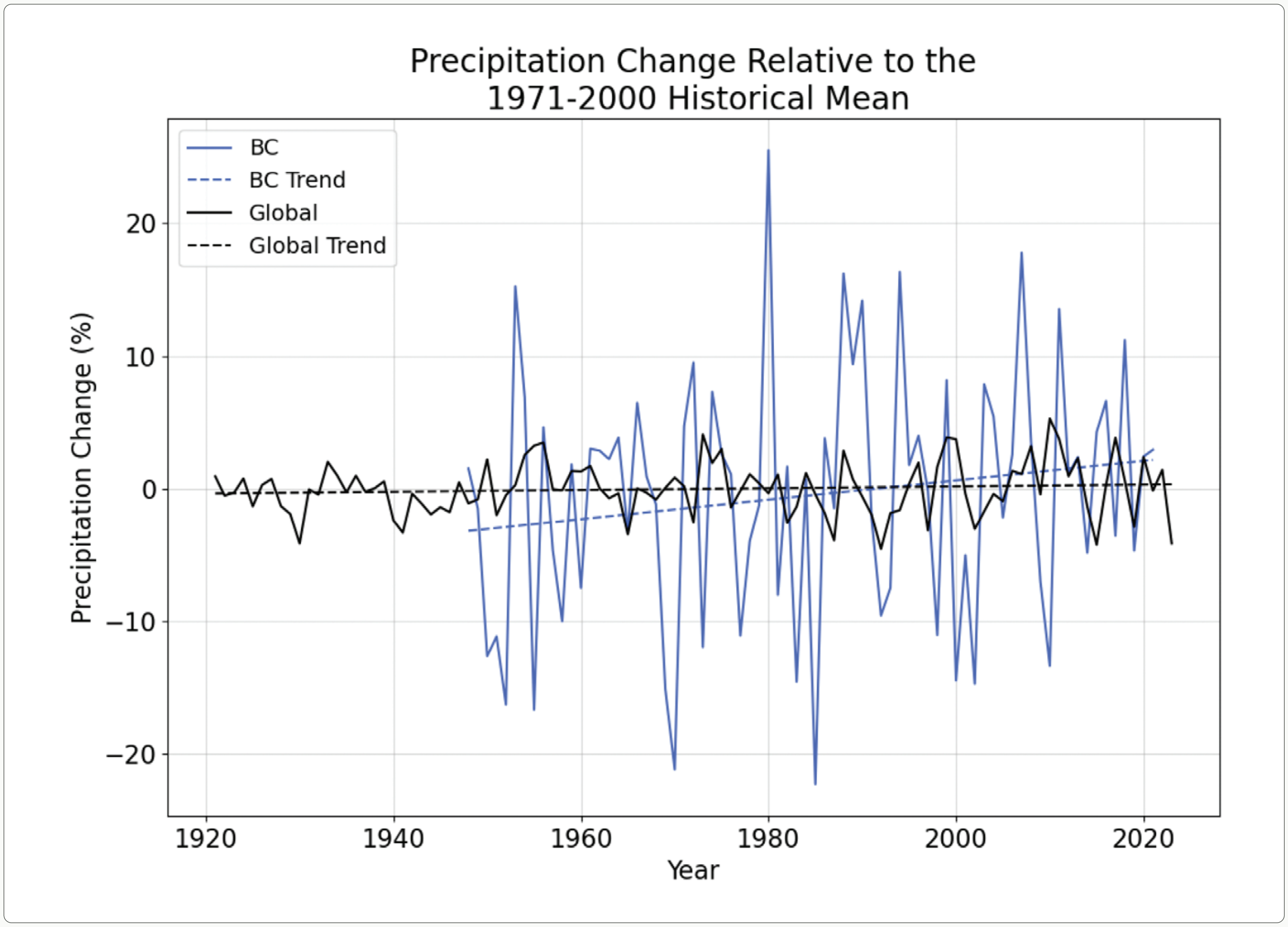


Table 2.1.3 summarizes observed changes in annual and seasonal precipitation in Canada and B.C. over the past seven decades. While there is no evident trend in annual mean precipitation in B.C. over that time, increases in spring (+14 percent) and fall (+18 percent) have been detected. There is a suggestion of a decrease in winter (when most precipitation falls in the province) and an increase in summer, but these changes are not statistically significant. In Canada as a whole, precipitation has increased significantly in all seasons except winter.

Table 2.1.3: Historical precipitation change in Canada and B.C. Observed changes in annual and seasonal precipitation in Canada and B.C. between 1948 and near-present, as determined from a linear fit to the data over the entire period. Data for Canada are from an updated Environment and Climate Change Canada gridded station data product (1948–2019)[14] while those for B.C. are derived from PCIC's Provincial Climate Data Set (1948–2021). Trends consistent with zero at the 5% significance level are shown in parentheses.

Region	Season	Change in precipitation (%)	Region	Season	Change in precipitation (%)
Canada	Annual	+ 12.9	**B.C.**	Annual	(+ 5.3)
	Winter	(+ 3.9)		Winter	(- 13.3)
	Spring	+ 18.8		Spring	+ 13.6
	Summer	+ 14.0		Summer	(+ 9.8)
	Fall	+ 16.8		Fall	+ 18.2

A significant fraction of B.C.'s precipitation is delivered by atmospheric rivers—long and narrow plumes (more than two thousand kilometres long by a few hundred kilometres wide) of water vapour originating over the Pacific Ocean that make landfall along the entire west coast of North America.[15] Based on data from 1948 to 2016, some 15 to 35 atmospheric rivers arrive on the B.C.–Alaska panhandle coast each year, most in autumn and fewest in spring.[16]

Over recent decades, atmospheric rivers are estimated to have contributed as much as 20 percent of total annual precipitation in coastal B.C., decreasing to 11 percent and 6 percent in the interior ranges, Columbia and Rockies, respectively.[17] This contribution varies by season and differs between rain and snow (for example, roughly 50 percent of rain from November to December is brought by atmospheric rivers). They should be considered an important component of natural precipitation variability in the region that has a mainly beneficial impact on B.C.'s ecohydrology and water supply, principally via snowpack maintenance. Occasionally, they do create conditions that lead to flooding, with the most notable recent example being the November 2021 combination of two successive atmospheric rivers that penetrated farther than usual into the Fraser Valley.[18]

Future-projected precipitation change in B.C.

According to climate model projections, both total annual precipitation and annual maximum precipitation are expected to increase in B.C.

Table 2.1.4 shows future projections for total annual precipitation and five-day annual maximum precipitation over B.C. under the medium- and high-emissions scenarios. Under the high scenario, annual precipitation increases by 9 percent (2050s) and 13 percent (2080s), while the five-day maximum amount increases by 13 percent (2050s) and 26 percent (2080s). The faster rate of increase for extreme precipitation is consistent with other results found regionally throughout B.C. and with our knowledge of the water-cycle response to warming. While the increases are smaller under the medium-emissions scenario, projections for the 2080s exceed those projected under the high scenario for the 2050s. Alternatively, if the GWL reaches 4.0°C, then B.C. average and extreme precipitation are projected to increase by +12 percent and +19 percent, respectively.

Table 2.1.4: Future-projected temperature change in B.C. Values and projected changes (in percentages) for annual mean precipitation and five-day cumulative extreme precipitation over B.C., relative to 1971–2000, based on outputs from CMIP6 climate models. Results are presented for two future periods under two emissions scenarios (medium and high) and also in terms of global warming level (GWL).

		Medium		High		GWL	
Variable		2050s	2080s	2050s	2080s	2.5°C	4.0°C
Total annual precipitation	Amount (mm)	1,360	1,407	1,395	1,452	1,367	1,433
	Change (%)	+ 6.2	+ 9.8	+ 8.9	+ 13.3	+ 6.7	+ 11.8
Annual five-day maximum precipitation	Amount (mm)	94	98	96	107	94	101
	Change (%)	+ 10.6	+ 15.3	+ 12.9	+ 25.9	+ 10.9	+ 18.6

Natural climate variability

Natural climate variability refers to the natural changes and fluctuations in the Earth's climate that occur over various time periods without human influence. These changes can happen because of different factors like volcanic eruptions, changes in solar radiation or oceanic cycles such as El Niño and La Niña.[i] Unlike climate change, which is driven by human activities, natural climate variability involves short-term shifts, like warmer or cooler seasons, which are part of the planet's natural climate system.

Both historical trends and future-projected changes in temperature and precipitation occur on top of natural climate variability, though notably larger for precipitation than for temperature (compare Figures 2.1.4 and 2.1.7). B.C.'s climate is also affected by semi-periodic (approximately every five to 10 years), large-scale variability, the best-known examples of which are the El Niño–Southern Oscillation and Pacific Decadal Oscillation.[ii] Their influence is strongest in winter: for example, winters during La Niña tend to be cooler and wetter than average, while El Niño winters tend to be somewhat warmer and drier. This increased variability in winter may explain the weaker Canada-wide precipitation trends found in that season (Table 2.1.3).

The wetter and cooler conditions during La Niña often produce larger-than-usual snowpacks in mountainous areas, leading to higher-than-average annual river discharge. An opposite effect occurs in El Niño years. For example, at the main outlet of the Fraser River Basin at Hope over the last century, annual peak flows in La Niña years have been found to be significantly larger than in El Niño years.[19]

Global and regional sea level change

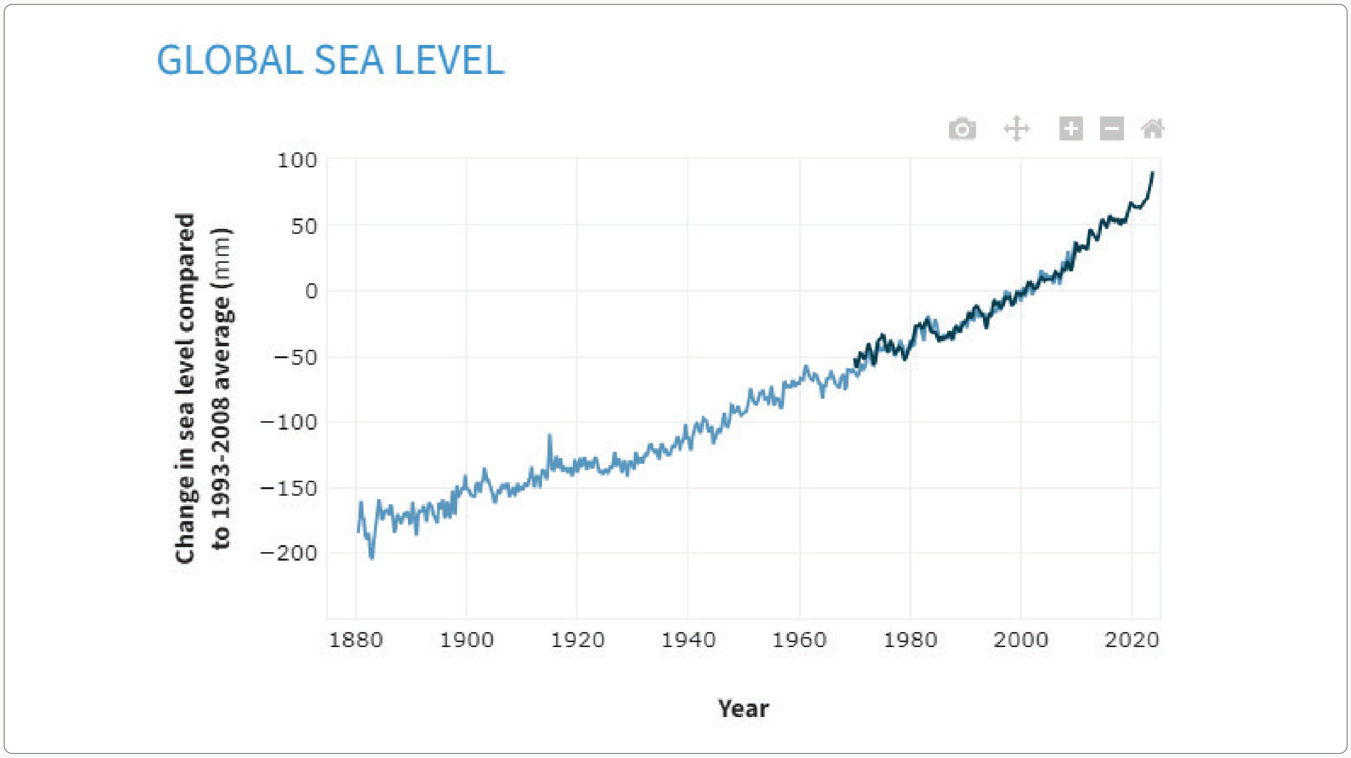
Sea level is a sensitive indicator of climate change. It responds to global warming both directly, via the heating and consequent expansion of seawater, and indirectly, via the loss of land-based ice (glaciers) due to increased melting (melting sea ice does not contribute to sea level rise, as the ice was already floating, displacing its weight in water).

i. El Niño (or El Niño–Southern Oscillation) is a phenomenon that occurs every two to seven years, when the surface waters in the eastern tropical Pacific Ocean become warmer than average. This changing pattern causes a shift in the atmospheric circulation, which impacts weather patterns across much of the earth. Conversely, La Niña is a phenomenon every three to five years of cooler than normal waters in the eastern and central Pacific Ocean. Government of Canada, https://www.canada.ca/en/services/environment/weather/data-research.html

ii. The Pacific Decadal Oscillation (PDO) is a longer-term ocean fluctuation, causing sea-surface temperatures to cool or warm over extended periods of time. National Centers for Environmental Education, Pacific Decadal Oscillation (PDO) | National Centers for Environmental Information (NCEI).

Glacier loss mainly includes melt from the Greenland and Antarctic ice sheets, with smaller contributions from mountain glaciers. Global ocean surface temperature increased by approximately 0.9°C between 1850–1900 and 2020 [20,21] with the most rapid rate of increase occurring since 2012.[22] Figure 2.1.8 shows recent data on global mean sea level (GMSL) rise from the U.S. National Oceanic and Atmospheric Administration (NOAA).

Figure 2.1.8: Global mean sea level rise from 1880 to 2023. Two records are overlaid: 1880 to 2009 from Church and White[23] (light blue line) and 1970 to near-present from the University of Hawaii Sea Level Center's fast delivery sea level dataset[24] (dark blue). Values are sea level change relative to the 1993–2008 average. R. Lindsey for NOAA.[25]



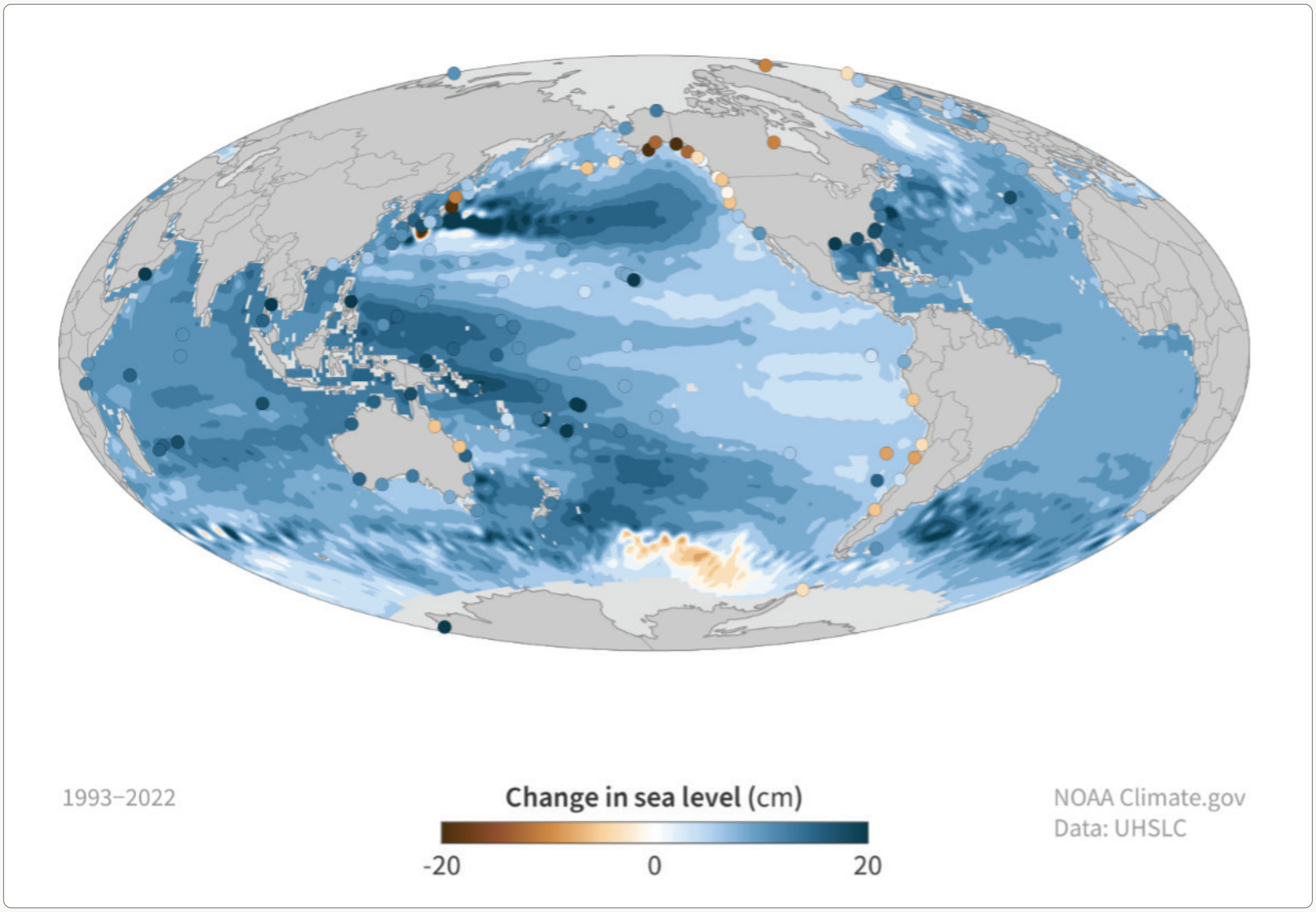
As summarized in the IPCC Sixth Assessment Report (IPCC-AR6): Global mean sea level increased by 0.2 m (0.15–0.25 m) between 1901 and 2018. The average rate of sea level rise was 1.3 mm/year (0.6–2.1 mm/year) between 1901 and 1971, increasing to 1.9 mm/year (0.8–2.9 mm/year) between 1971 and 2006, and further increasing to 3.7 mm/year (3.2–4.2 mm/year) between 2006 and 2018 (high confidence). Human influence was very likely the main driver of these increases since at least 1971.[26]

The ice sheet melt contribution from Greenland and Antarctica to GMSL rise was four times larger between 2010 and 2019 than from 1992 to 1999, making glacial mass loss the largest contributor to GMSL rise from 2006 to 2018.

Figure 2.1.9 shows a map of sea level change around the world between 1993 and 2022. In some ocean basins, sea level has risen by 15–20 cm (blue-shaded contours). Also shown on the map are differences between local sea level change at specific coastal locations and the global mean value (coloured dots).

Observed sea level change relative to a local, land-based frame of reference is called relative sea level (RSL). The map shows that local rates of RSL change can be larger (due to geological processes like ground settling) or smaller than the global average (due to processes like the centuries-long rebound of land masses from the loss of ice-age glaciers). B.C. lies within a larger area of northwestern North America where the land surface is still rebounding from the last glaciation, meaning that RSL is rising more slowly in some locations than in others, or even falling slightly, due to the complex interplay of processes.

Figure 2.1.9: Sea level rise measured at specific locations on land from 1993 to 2022. Data provided by Philip Thompson, University of Hawaii. R. Lindsey for NOAA.[27]



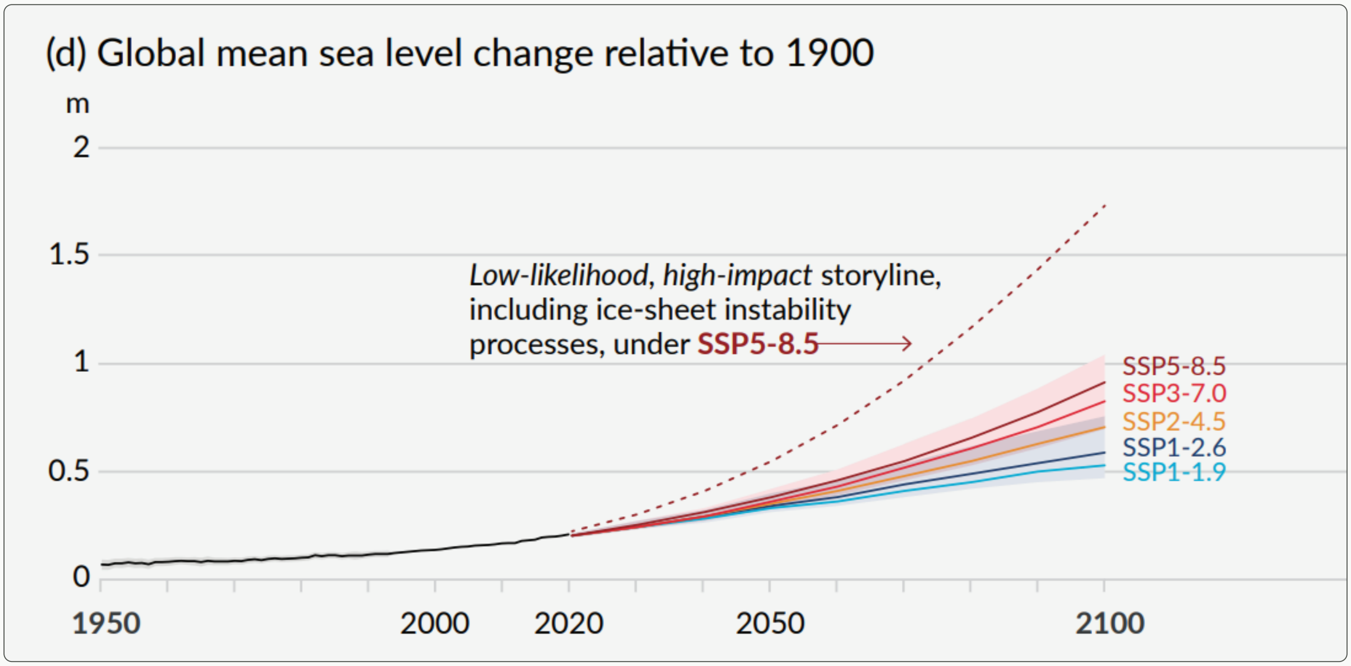
Future sea level projections

According to the IPCC-AR6 Summary for Policymakers[28]:

> The likely global mean sea level rise by 2100 (compared to a reference period of 1995–2014) is 0.32–0.62 m under the low GHG emissions scenario (SSP1-2.6); 0.44–0.76 m under the moderate GHG emissions scenario (SSP2-4.5); and 0.63–1.01 m under the high GHG emissions scenario (SSP5-8.5), where the ranges indicate the spread across model projections under a given scenario. With somewhat reduced confidence, the AR6-SPM included projections for an extended period to 2150, which gave upper limits of 0.99 m (low emissions); 1.33 m (moderate emissions); and 1.88 m (high emissions). Finally, the authors commented that, due to uncertainty in ice-sheet processes that are not explicitly included in most global climate models used in the AR6, upper limits of 2 m by 2100 and 5 m by 2150 cannot be ruled out.

Figure 2.1.10 shows historical and future-projected GMSL change relative to 1900 for a number of emissions scenarios, including an additional low-likelihood, high-impact scenario including ice sheet instability processes that are highly uncertain, a scenario that cannot be ruled out based on current knowledge. This scenario (sometimes referred to as SSP5-8.5+) is projected to result in more than +0.7 m of additional GMSL rise above the highest-emissions scenario, SSP5-8.5, by 2100.

Figure 2.1.10: Global mean sea level change relative to 1900.[29] Historical changes are observed using tide gauges pre-1992 and satellite altimeters afterward. Future projections are assessed using CMIP, ice sheet and glacier models. The mean change for five emissions scenarios is shown, including likely ranges for two of the scenarios (SSP1-2.6 and SSP3-7.0). The dashed curve shows the results of a low-likelihood outcome of the high-emissions scenario (SSP5-8.5), which includes high-impact ice sheet processes that are very uncertain and thus cannot be ruled out.



Regional sea level projections

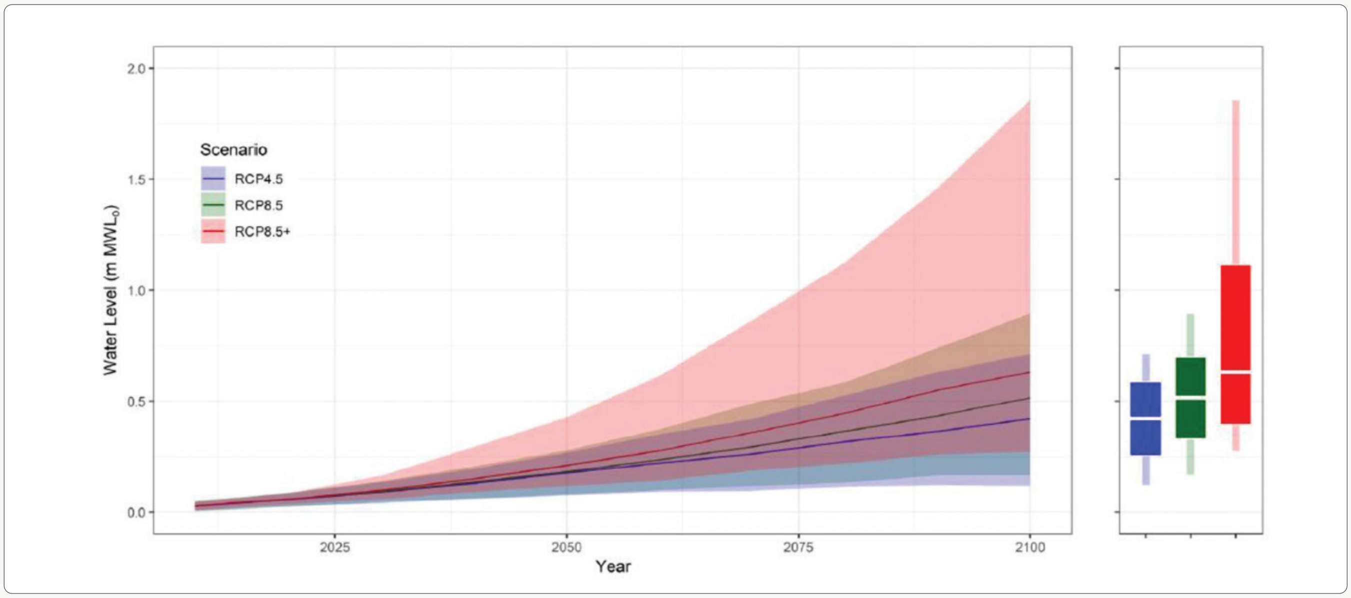
While projections of GMSL are helpful, especially in a global policy context, RSL change is more relevant from a coastal flood risk perspective. Here, we present RSL projections for a single B.C. location of interest, near the mouth of the Fraser River. Additional information for the rest of coastal B.C., using the same background climate data sources and based on the more comprehensive dataset, can be accessed at ClimateData.ca.

Figure 2.1.11 shows RSL projections for three scenarios for the mouth of the Fraser River (near Point Atkinson) from an unpublished study based on CMIP5 models.[30] In all three scenarios, the water level increases relative to the past. The most extreme increases in water level are seen under scenario

RCP8.5+ (the CMIP5 equivalent of SSP5-8.5+), with increases exceeding 1.75 m by 2100 at the high end of the very likely range. The greatest differences in water level between scenarios are seen at the end of the century where uncertainty in the projections is at its strongest.

RSL projections are available for coastal Canada from ClimateData.ca on a 10 km x 10 km grid, using the same background climate data sources and the more comprehensive dataset.[31] A recent provincial scale analysis[32] using this data revealed, for example, that by the year 2100, Caswell Point off the west coast of Haida Gwaii is projected to see increases in RSL by +66 cm and +140 cm under RCP8.5 and RCP8.5+, respectively. In Victoria, RSL is projected to increase +20 cm by 2050 and +57 cm by 2100 under RCP8.5.

Figure 2.1.11: Relative sea level projections of three scenarios for the mouth of the Fraser River.[33] The left panel shows a time series of projected sea level rise for the 21st century. Solid lines show the median and shaded areas show the very likely range. The right panel shows the median (white line), likely (thick bars), and very likely (thin bars) ranges for the year 2100.



More information

Complementary to this climate overview, which focuses on climate-related hazard drivers, the hazard overviews in this chapter provide the current understanding of climate change influences on each climate-related hazard. In addition, Chapter 5 looks at the potential of climate change in the likelihood of extreme events under different global warming levels.

Figure 2.2.1: Overland flooding of the Sumas Prairie in November 2021. Carie-Ann Lau, 2021

2.2 Riverine flood

Hazard description

Floods are among the most common natural hazards in B.C. and are often the costliest[34,35] (in the absence of a major earthquake). A riverine flood is the temporary inundation of normally dry land by water that leaves the river channel and flows onto the adjacent floodplain.[36] Riverine flooding is a natural process caused by the melting of a deep snowpack, intense or prolonged rainfall, stream blockages such as ice jams, steep creek processes (debris flood or debris flow), or rain-on-snow events. Floods can also occur from a failure of engineered structures, such as dikes or dams.

Temqoqo

The time of year when the water is high

Halq'eméylem – With permission from Tribal Chief Tyrone McNeil

Floodwaters carry nutrient-rich sediments that contribute to a fertile environment in diverse aquatic habitats and replenish surface water and groundwater sources.

Flooding on First Nations land and waters

Riverine floods are events that happen naturally and are part of a greater system linked to the forests, mountains, tides and other natural cycles. Today, riverine floods are exacerbated by broader land-use practices, unsustainable land-use planning and climate change.

First Nations have deep knowledge and relationships to areas impacted by floods and know that floodplain areas are important ecosystems that present many gifts from the Creator.

Today, First Nations are some of the most likely populations to be impacted by flooding, due to the colonial placement and restriction of First Nations to reserve lands that are often located in vulnerable locations such as floodplains.

First Nations adaptations to riverine flooding are diverse and include, but are not limited to, updating dikes, re-establishment of riparian areas, and water channelling and capture through nature-based solutions. First Nations people once placed themselves strategically on the land to exist in relation to natural cycles. This knowledge of the land and strategic placement ensured protection against the environment and safety from other people, as well as supported social gathering and food security.

– First Nations Committee on Disaster and Climate Risk

Riverine floods are a natural occurrence along streams, rivers and lakes across B.C. The factors affecting streamflow, and the potential for riverine floods, vary considerably across B.C.'s six major river basins (Fraser, Columbia, Peace, Skeena, Stikine and Liard) due to diverse topography and climatic zones.

Typically, floods occur in the spring (from April to early July, during snowmelt [freshet]) in the mountainous regions of B.C., and in the fall (from September to February, during the rainy season) on the coast; however, floods can occur at any time across B.C. due to localized storms (such as thunderstorms or other short-duration rainfall events). As warm, moist air collides with mountain ranges, it rises and cools, often causing heavy precipitation that, depending on local conditions, can contribute to flooding.

Land-use changes such as urbanization, forestry and agriculture can increase flood hazard by altering the storage and movement of water on the landscape or by reducing the infiltration capacity of the soil to absorb water during a rainfall or snowmelt event due to an increase in impervious surfaces (for example, pavement).

Human activities can alter the storage and movement of water by disconnecting a watercourse from the adjacent floodplain, such as through the construction of flood protection structures (for example, dikes or dams). Severe wildfires also disrupt the ability of the soil to absorb water, resulting in increased runoff following the fire.[37] The loss of subalpine forests due to wildfires or commercial timber harvesting can reduce snowpack retention in spring and early summer. The demise of diverse forest ecosystems can result in increased flooding with rapid snowmelt and compacted soil that does not support water infiltration.

Historically, most flooding in B.C. has occurred due to spring snowmelt, which can sometimes happen rapidly in response to sudden warming. But rapid rainfall-driven floods have also occurred, such as in November 2021. Past flood events have taken place on major B.C. rivers in 1894, 1948, 1972, 2017, 2018 and 2021 in response to snowmelt, rainfall and rain-on-snow events, reflecting the complexity of flood processes in the province.

Floods occur annually on smaller watercourses across the diverse B.C. landscape, with localized impacts. Snowmelt, rainfall and ice-jam floods are the most common flood types in B.C.

Snowmelt-driven floods occur during spring freshet from the rapid melting of the snowpack under warmer temperatures. The potential for flooding increases during conditions with an above-average snowpack, a sudden thaw of the accumulated snow, or if the snowmelt is compounded by runoff from heavy rainfall. Snowmelt-driven floods can also be exacerbated by a lack of natural shading due to logging impacts. The flood of record on the Fraser River occurred in May 1894,[38,39] when rapid snowmelt caused river levels to rise dramatically, triggering flooding from Agassiz to Richmond.

Rainfall-driven flood events generally occur in response to localized precipitation or large-scale storms. During a period of intense rainfall, localized flash floods can occur when the ground is saturated and not able to absorb the water quickly enough, resulting in high runoff that can cause rivers and streams to overtop their banks. As atmospheric rivers can produce copious rainfall over the mountainous coastal terrain, atmospheric river-related floods are typically larger than other floods in coastal watersheds in B.C.[40] The atmospheric river event in November 2021 brought two days of intense precipitation to the coast and inland that resulted in extreme flooding and extensive geomorphic change across the lower Fraser River watershed.[41] The atmospheric river was also a rain-on-snow event where the streamflow generated by rainfall was increased by melting snow, associated with a rapid rise in temperature. The flood event resulted in widespread landslides, washouts, bank erosion and channel avulsions. Impacts included: overflow of the Nooksack River in Washington State (which flooded the Sumas Prairie near Abbotsford); extensive damage to infrastructure, such as Highway 1, Highway 8, pipelines and bridges; loss of livestock and crops; extensive flooding in the towns of Merritt and Princeton; and impacts to First Nations communities in the Nicola Valley.

Ice-jam floods naturally occur in various regions in B.C., particularly where rivers and streams experience freezing temperatures and ice formation during the winter. Floating ice from spring thaw can accumulate along riverbanks and bridges and in the river channel due to low water levels, leading to blockages and subsequent flooding. Ice-jam flooding has occurred historically along major rivers in B.C. (for example the Fraser, Peace, Thompson and Skeena rivers).

Secondary hazards

Secondary hazards that can be triggered by a riverine flood event include landslides, steep creek processes (debris floods or flows), outburst dam flooding, bank erosion, washouts, channel avulsions and sediment deposition. Faster-moving water, especially when entrained with rocks or logs, can be more damaging and can contribute to bank erosion or channel avulsions, which can rapidly change the course of a river and alter the position of the river within the floodplain. Flood protection structures such as dikes or operational dams may be overtopped or undermined, resulting in a structural failure. Debris caught up in floods can cause damage through direct impact and environmental contamination.

Hazard distribution

Flood risk varies widely across B.C. depending on factors such as elevation and prevailing weather patterns that influence the timing and magnitude of snowmelt and rainfall-dominated flood events. Generally, B.C. can be divided into four regions in terms of flood hazards: Coastal and Southwest, Interior Central, Southeast and Northern. However, all areas of B.C. are susceptible to rainfall-dominated floods (short- and long-duration precipitation events). In addition, all mountainous regions are susceptible to snowmelt floods, while generally the northern portion of B.C. is more susceptible to ice-jam floods.

Coastal and Southwest region:

This region covers the southwestern corner of B.C. and includes greater Vancouver, Fraser Valley, Vancouver Island, Central Coast, North Coast and Haida Gwaii. The region experiences mild winters, with minimal snowfall at low elevations and deeper snowpacks at higher elevations. The majority of rain falls from October to March, with much smaller amounts during the warmer months. Snowfall accumulations near sea level are minimal and melt quickly due to warmer seasonal temperatures.

Flooding is often driven by heavy rainfall and atmospheric rivers originating in the Pacific Ocean. Rain-on-snow events at higher elevations can trigger rapid-onset, high-intensity flooding and debris flows on smaller, steeper catchments that are flanking valley slopes.

Larger rivers, such as the Fraser, Skeena and Bella Coola, can have higher elevation headwaters that also experience snowmelt-driven, high flows during spring freshet. This region is also subject to coastal flooding, including from storm surge during fall/winter storms.

Interior Central region:

This region covers a large portion of central B.C. and includes the Okanagan Valley. The region experiences cold winters with heavy snowfall, especially at higher elevations and near mountain ranges.

Flooding is typically driven by rapid snowmelt in the spring; however, some watersheds are subject to rainfall and flooding from atmospheric rivers (for example, Coldwater River watershed), resulting in mixed-process events and rain-on-snow events. Smaller watersheds may also be susceptible to peak flows triggered by short-duration rainfall from thunderstorm activity.

Rapid snowmelt and rainfall can also result in flooding to lakes in the Okanagan and Shuswap.

Southeast region:

This region covers the southeastern corner of B.C. and includes the Kootenay area. The region experiences heavy snowfall during the winter months. Snow accumulation can be significant at higher mountain elevations, contributing to glaciers and deep snowpacks.

Snowmelt-driven floods typically occur in the spring, and glacier melt contributes to summer streamflow. The region can also experience short- and long-duration rainfall events.

Northern region:

This region experiences cold winters, with heavy snowfall in the mountainous areas and moderate snow in the other areas during the winter months. Snowmelt-driven floods typically occur in the late spring.

Rivers in this region are often influenced by ice cover during the winter months and are subject to ice-jam flooding. In spring and early summer, northeastern B.C. can experience “wrap-around” rain events coming from Alberta, triggering high streamflows and flooding, such as at Dawson Creek in June 2016.

Figure 2.2.2: Areas (in red) with potential riverine flood inundation for a 200-year return period scenario in watersheds with a catchment area of at least 10 km^2.

Based on the geospatial hazard analysis conducted for the Provincial DCRRA, Figure 2.2.2 shows the areas with potential inundation related to riverine flood with 0.5 percent annual chance of occurrence (200-year return period) in watersheds with a catchment area of at least 10 km^2. Many of these valley bottom areas are also where the highest vulnerability exists, co-located with population centres, critical infrastructure and high ecological value on floodplains. Over 30 years, which is a span often used as a planning horizon, there is around 14 percent chance of experiencing a 200-year magnitude flood event in these locations (areas marked red in Figure 2.2.2). With variability in the terrain, snowpack and extreme weather conditions across such a large geographic area, the likelihood of experiencing significant flooding somewhere in the province each year is substantial.

The 200-year return period flood is significant in flood mapping and management in B.C. It is used as the regulatory flood standard for land-use planning and flood management purposes[42] and is often used to determine Flood Construction Levels (FCLs), which set minimum elevations for habitable floor space in flood-prone areas.[43] A 200-year return period represents a balance between protecting against relatively rare events while still being practical for implementation in land-use planning and building regulations.

Hazard exposure

River valleys and their associated floodplains have long been areas of human settlement. Many communities in B.C. are located in these areas, drawn by food sources, agriculturally rich soils, accessible transportation corridors, recreational opportunities and scenery. Many First Nations hold a deep understanding of floodplains from the pre-colonization period, including their natural changes according to season. Today, First Nations are some of the most likely communities to be impacted by flooding due to the colonial placement and restriction of First Nations to reserves, which were often established on vulnerable lands such as floodplains. Additionally, with many B.C. communities settled along rivers and within floodplains today, there is a need to understand a community's role in the flooding cycle and to develop respectful relationships with natural systems. Despite this need, a 2020 study showed that only 6 percent of Canadian homeowners who live in designated flood risk areas are aware of this fact.[44]

The majority of B.C.'s infrastructure and essential services are in floodplains. Floodplain development is perhaps most notable in the Lower Fraser and greater Vancouver areas, but it is also found in river valleys throughout B.C. and along the coastline. The development includes emergency services (such as hospitals), emergency evacuation routes and shelters, transportation and pipeline corridors, water treatment facilities, telecommunication infrastructure, housing and many other structures. Intensive development in flood-prone areas, modification of natural drainage, construction of flood protection structures and the building of infrastructure in valley bottoms all increase the potential consequence of flooding to the built environment. Impacts to the built environment in floodplains can also have consequences beyond the area that is directly flooded.

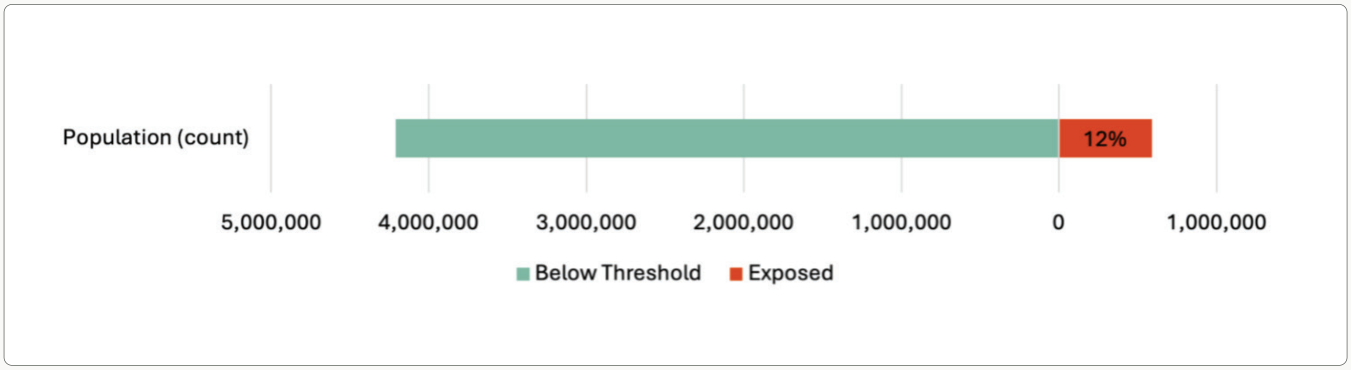
Most of B.C.'s food production and agricultural lands are situated in floodplains within the Fraser, Okanagan, Thompson and Nechako valleys. The development of the Agricultural Land Reserve has been an effective legislative tool for limiting more intensive land use and development on high-quality agricultural lands (including in floodplain areas). However, the agricultural sector has intensified in many areas of B.C., resulting in the increased potential for flood-related consequences (for example, impacts to greenhouses, livestock density, machinery and equipment, and migrant workers). Many food storage and processing or manufacturing facilities are also vulnerable to flooding because they are in flood-prone areas near agricultural production centres. This, along with transportation network disruption and other supply chain effects, can impact food security.

There are more than 200 regulated dikes in B.C.[45] and over 100 flood protection structures that are not maintained by a diking authority and are classified as "orphaned dikes."[46] Dikes are designed to withstand a "standard design flood" that is associated with the 200-year return period (0.5 percent annual exceedance probability) event or the 1894 flood profile for the Fraser River,[47] but can still fail under extreme conditions such as prolonged heavy rainfall, rapid snowmelt or peak river flows. An assessment of 74 regulated dikes in the Lower Mainland found that the dikes generally do not meet provincial standards to contain design flood levels.[48] Dikes require regular inspection and maintenance to remain effective; if maintenance is neglected or inadequate, dikes can deteriorate over time, compromising their ability to withstand flood events and increasing the risk of failure. Many dikes may also require upgrading to withstand potential liquefaction and subsidence from earthquake events.

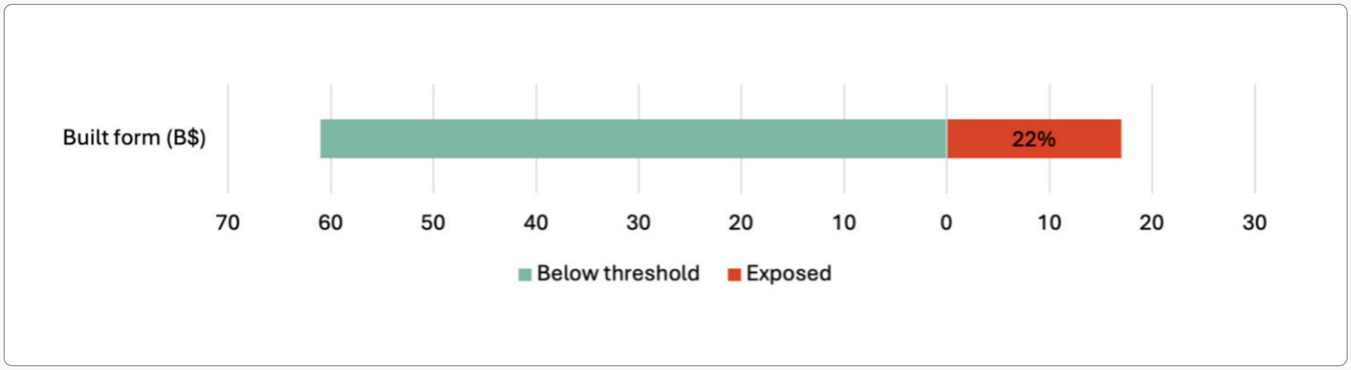
While flood protection structures such as dikes are designed to mitigate flood risk by containing and redirecting floodwaters, they can also increase flood risk under certain conditions. The presence of flood protection structures in a community can create a false sense of security and can lead to increased development and population growth in flood-prone areas. Such densification can exacerbate flood risk by increasing the exposure of people and property to floods, and dike breaches or overtopping can result in catastrophic flooding downstream. As well, dikes narrow and constrain the flow of an overflowing river, which may increase the flood intensity and exacerbate flooding in areas outside of the flood protection zone. This can also have an ecological impact by disconnecting the river from its floodplain and disrupting natural sediment transport processes.

For the purpose of the Provincial DCRRA geospatial analysis, the riverine flood hazard is defined as potential inundation with 0.5 percent chance of annual exceedance (200-year return period flood), along rivers with a catchment area larger than 10 km^2. The geospatial analysis confirms that despite impacting only 6 percent of the surface area of the province (Figure 2.2.2), the portion of assets and populations that are exposed to flooding is much higher (Figure 2.2.3). Specifically, riverine floods expose 12 percent of the population and 14–22 percent of critical facilities, major roads and railway tracks to risk of inundation. The presence of dikes or other flood protection is not considered in these hazard areas, since dikes are prone to failure and do not completely eliminate exposure to flood hazard. Finally, as the analysis defines exposure as any level of inundation, it does not differentiate between deep and shallow inundations, and it does not account for flow speed and debris-related hazards. For further information on the Provincial DCRRA Geospatial Analysis, see Appendix A: Hazard Exposure Geospatial Analysis – Methodology Report.

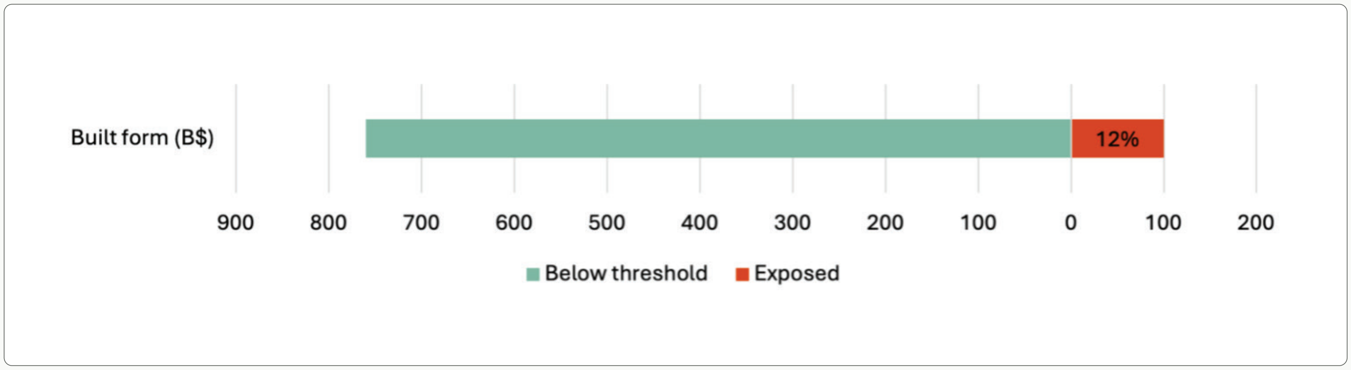
Figure 2.2.3: The assets, services, conditions and populations exposed to riverine floods.



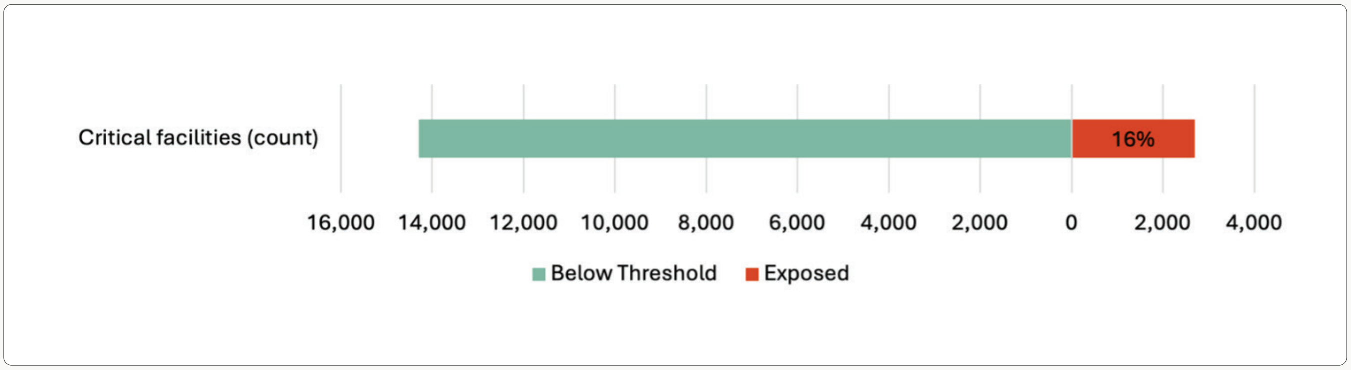
Population: 12% of the population (590,000 people) is within areas exposed to riverine flood inundation.



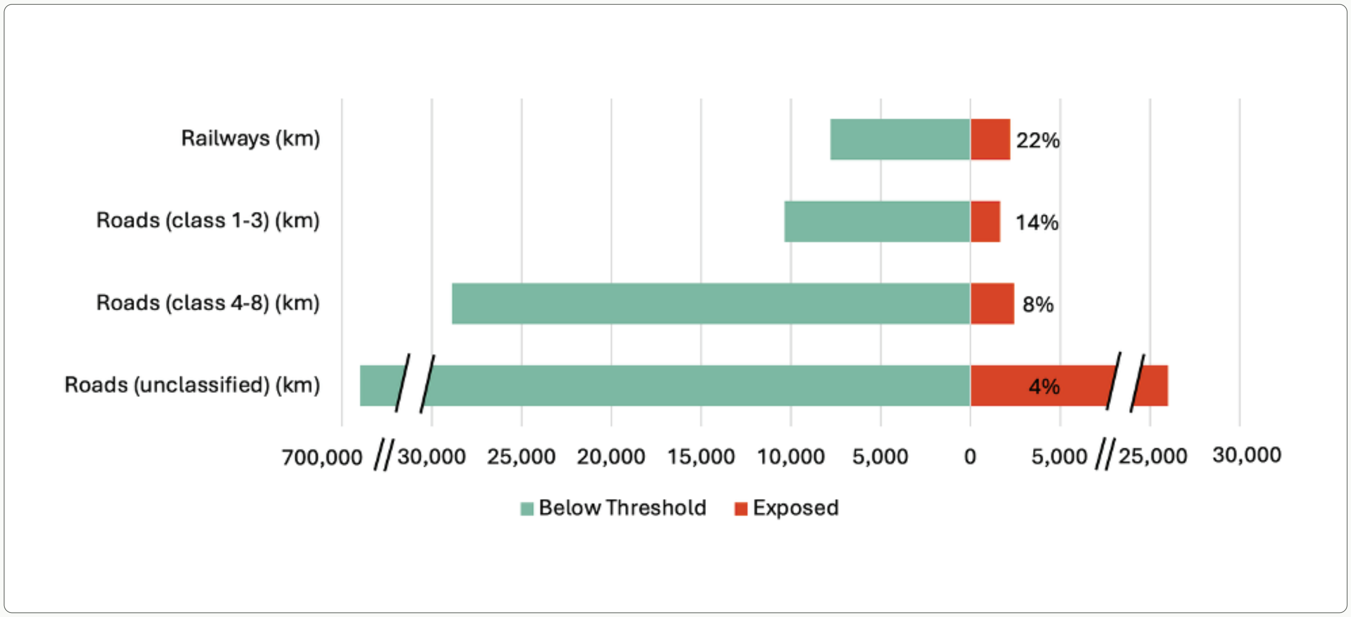
Built form, replacement value: 22% of the built form in First Nations reserves ($12B) is within areas exposed to riverine flood inundation.



Built form, parcel improvements assessed value: 12% of the built form ($100B) is within areas exposed to riverine flood inundation (excluding First Nations reserves).



Critical facilities: 16% of critical facilities (2,700) are within areas exposed to riverine flood inundation. Critical facilities are structures essential for public safety, disaster response, and maintaining essential services like health care, water and communications.



Railways and roads: 22% of railways (2,200 km); 14% of roads, class 1-3 (1,650 km); 8% of roads, class 4-8 (2,430 km); and 4% of unclassified roads (26,000 km) are within areas exposed to riverine flood inundation.

Past events

The Canadian Disaster Database identifies some of the impacts and costs for 40 damaging flood events in B.C.[49] However, a review of historical damaging flood events in B.C., carried out by a research team at the Geological Survey of Canada, identified 86 damaging flood events.[50] Please see Table 2.2.1.

Table 2.2.1: Past riverine flood events.

Flood event	Flood driver	Description	Estimated losses[i] *Where data is available
2021 Southern B.C.	Rainfall	Catastrophic flooding caused by a severe rainfall event (atmospheric river) in November 2021. The losses to southern B.C. make this the costliest natural disaster in the province's history.[51]	Between $9 billion and $14 billion[52] Insured losses were estimated at $696 million[53,54] Uninsured losses from flooding could have reached almost $5 billion—over seven times more than the insured losses[55] Public expenditures related to flooding and landslides were estimated at $7 billion[56]

i. Unless otherwise noted, losses are reported in the dollar value of the year in which the event occurred.

Flood event	Flood driver	Description	Estimated losses[i] *Where data is available
2018 Grand Forks	Snowmelt and rainfall	Major flooding caused by snowmelt during spring freshet and heavy rainfall in southeastern B.C. The City of Grand Forks was heavily impacted.	$48 million[57]
2017 Okanagan	Snowmelt and rainfall	Major spring flooding, caused by snowmelt during spring freshet and heavy rainfall, contributed to localized flooding across southeastern B.C. Impacts to communities across the Okanagan, Shuswap and Kootenay regions.	$73 million[58,59]
1972 Fraser River	Snowmelt	Major flooding, caused by snowmelt during spring freshet, primarily impacted the Upper Fraser River basin (Prince George and Kamloops) and a portion of the Lower Fraser River (Surrey). The diking system was considered effective in preventing large-scale damage.	$36.9 million in 1998 dollars[60]

Flood event	Flood driver	Description	Estimated losses[i] *Where data is available
1948 Fraser River	Snowmelt and rainfall	Catastrophic flood event caused by snowmelt during spring freshet and heavy rainfall in the Fraser and Columbia basins. Wide-spread flooding and damage to infrastructure including the diking system.	$225 million in 2020 dollars[61,62]
1894 Fraser River	Snowmelt	Flood of record for the Lower Fraser River caused by snowmelt during spring freshet. Wide-spread flooding, however damage was limited due to early European settlement. Fraser Valley diking system constructed after this flood event.	$1.8 billion if it occurred today [63,64,65,66]

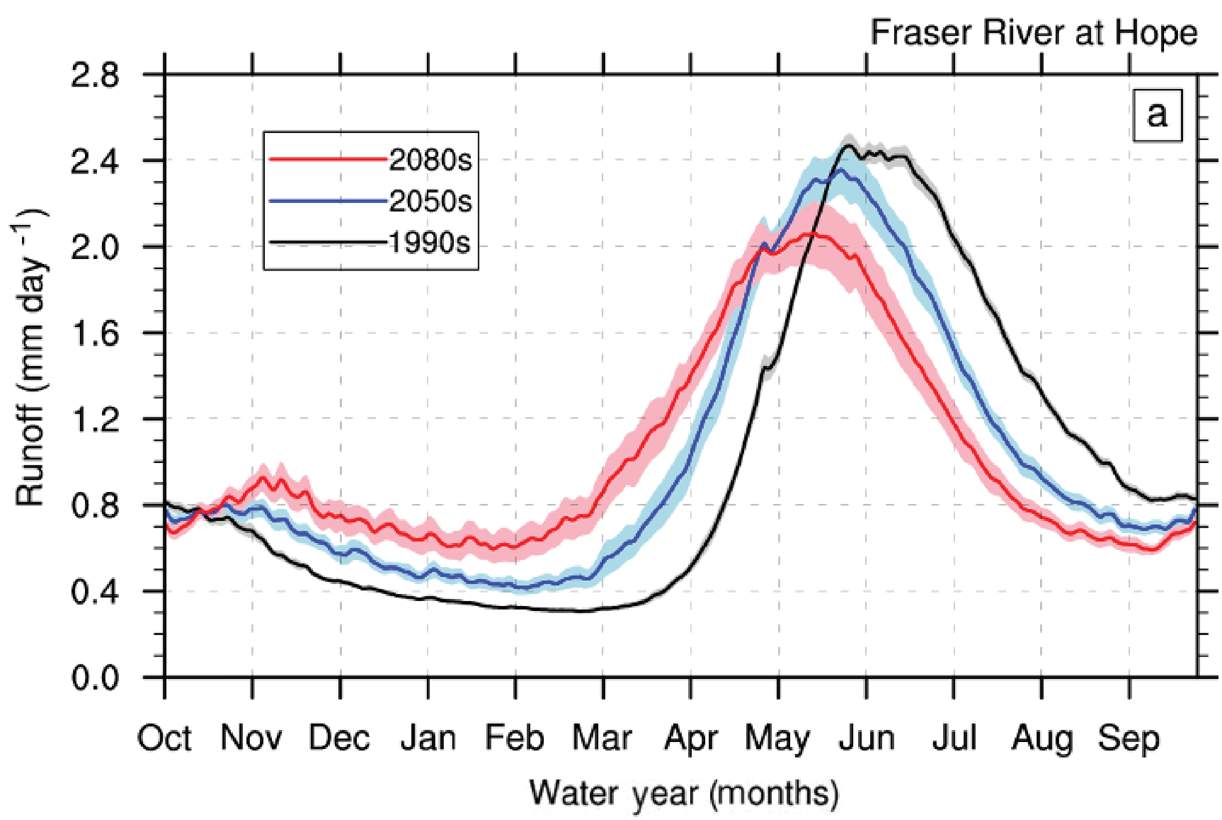
Climate change influence

According to climate model projections (Chapter 2.1), both total annual precipitation and annual maximum precipitation are expected to increase in B.C. in future decades. In addition, a larger fraction of precipitation is expected to fall as rain instead of snow. However, due to the complexity of the riverine flooding hazard, these increases do not necessarily imply more severe or frequent flooding—the timing and geographic patterns of climatic drivers, land-atmosphere interactions and geomorphology are all factors that need to be considered.[67] Regional warming is projected to induce a steep decline in maximum annual snowpack in the warmer coastal and southern basins (Skeena, Fraser and Columbia), a moderate decline in interior basins (such as Peace), and little to no change in northern basins (such as Liard).[68] Studies of snow-dominated basins have noted a clear tendency toward earlier maximum snowpack and earlier peak flows.[69]

In southern and central B.C. basins where substantial snowpack declines are projected by mid-century, the earlier and reduced snowmelt contribution to runoff results in earlier peak flows (by up to four weeks) and a reduction in peak freshet flows (of up to -20 percent), with the details varying by basin and emissions scenario (Figure 2.2.4).[70,71] Such reduced flows may lower flood risk during early summer, but also imply reduced summer water supply—all things being equal. However, these projections reflect median model behaviour over 30-year periods, meaning that peak flows similar to historical values can still occur in individual years even into mid-century, due to natural climate variability.

When it comes to extreme flooding, the Fraser River Basin (FRB) is arguably the best studied in the province. Hydroclimate models have been applied to the basin as a whole, and hydraulic modelling studies of the lower floodplain portions were also conducted. An analysis of hydrological model simulations over the FRB, focusing on rare extremes, suggests changes in the magnitude of a 200-year freshet peak flow at Hope ranging from -10 percent to +20 percent (model range) by end-of-century, with a positive median projection irrespective of emissions scenario.[72] The changing frequency of extreme floods is scenario-dependent, however. Under a medium-emissions scenario, the frequency of a 200-year event increases to once in 50 years by mid-century, with a further increase to around once in 30 years by end-of-century. Under high emissions, higher rates of snowpack depletion result in more frequent high freshet flows at mid-century than at late-century. Under high emissions, the historical 200-year freshet flow becomes a 50- to 100-year event by mid-century, then becomes somewhat less frequent by end-of-century.

Figure 2.2.4: Annual cycle of simulated runoff for the Fraser River at Hope. Black, blue and red curves represent the multi-model means for the 1990s, 2050s and 2080s, respectively, under a high-emissions scenario. Shading represents inter-model spread, as indicated by a 5 percent – 95 percent model range.[73]



While climate model simulations are helpful for examining the broader effects of climate change on B.C.'s basins several decades from now, one should not overlook detailed hydroengineering simulations of historical floods and scenarios of extreme floods as a guide to the near term (for example, the next one to two decades). The hydraulic models used in these studies can be more closely tailored to actual floodplain characteristics, including engineered structures such as spillways and dikes in specific locations along watercourses. The Lower Mainland portion of the Lower FRB is arguably the best-studied floodplain in B.C. in this respect. A recent summary report gathered the results from several such studies comprising the Lower Mainland Flood Management Strategy initiative. The 2019 Hydraulic Modelling and Mapping Project examined 20 scenarios encompassing a range of extreme riverine floods (50- to 500-year), coastal storm surge (50- to 500-year), and various dike breach scenarios, as well as mitigation options. In a scenario where an event of the same magnitude as the 1894 Fraser River flood (estimated as a 500-year event in a stationary climate) occurred, the Project found that ~20 dikes would likely "be overtopped (and potentially more likely to fail in other ways) and flood nearly 300 km^2 of land." Finally, another possible consequence of climate change is hydrological regime change. Under strong warming, annual peak flows in snow-dominated basins, which currently occur exclusively during the freshet, may begin to occur during the cold season, particularly in coastal or coastal-adjacent basins like the FRB. Climate model ensembles project substantial increases (10–20 percent by end-of-century)[74] in fall and winter precipitation over historical norms. One consequence of this is enhanced runoff and river discharge in the cold season compared to present-day (Figure 2.2.4). Some modelling indicates that the FRB may begin to transition to a hybrid (snow-rain) behaviour where cold season peak discharge exceeds freshet flows in some years,[75] but not all studies agree on that point.[76] Nevertheless, there is agreement among available FRB model projections that large cold-season events that are rare in the historical climate (a 1-in-200-year event) will become more frequent by mid-century (perhaps a 1-in-20-year event) under a moderate-emissions scenario, and more frequent still (perhaps a 1-in-10-year event) under a high-emissions scenario.

An extended analysis of climate change influence on riverine flood is included in Appendix B: B.C. Provincial Climate Overview, and the conclusions of an associated extreme event likelihood analysis are summarized in Chapter 5. A previous scenario analysis of severe riverine flooding can be found in the Preliminary Strategic Climate Risk Assessment for British Columbia.[77]

When the river rises: A case study of Kwantlen First Nations management of flood risk

Kwantlen First Nation (KFN) primarily resides on McMillan Island on the Fraser River, north of Langley in the Fraser Valley. The Nation has been historically restricted to this space, and several other undeveloped locations, through colonial policies tied to the Reserve section of the Indian Act.

McMillan Island is exposed to seasonal spring flooding each year during the freshet, putting KFN residents and infrastructure at risk.

Despite this, KFN residents living on McMillan Island today would likely elect to stay on the island due to their deep connection to the land and water.

Colonialism impacts the KFN exposure and vulnerability to flooding and continues to influence emergency management practices today. Before the reserve system, the KFN would leave village sites on the banks of the Fraser River and move to higher grounds for the freshet season, returning to McMillan Island as a seasonal fishing camp. Colonial policies continue to exacerbate disproportionate vulnerabilities between KFN and non-Indigenous populations, where neighbouring off-reserve communities are far better protected through dikes and higher elevated lands.

In the recent past, there have been three major floods on McMillan Island—in 1948, 1972 and 2012. These floods impacted the island, where the east side is specifically prone to erosion. Over the last two decades, KFN has led projects to protect the island from erosion, including the installation of groynes and riprap. KFN has intimate knowledge of the island. Some of the most important aspects of flooding will always be site specific, which the Nation is physically, culturally and spiritually attuned to.

Alongside community-led initiatives and deep knowledge of the land, collaboration across communities and organizations is a strength of KFN's flood response and is core to their values. KFN holds collaborative, long-term relationships with some organizations, but work remains to improve other relationships.

The community has identified that effective relationships exist when: 1. Community interests are prioritized; 2. There is space for reciprocal dialogue to learn from one another; and 3. Relationships are built on previous relationships that centre on trust, transparency and respect.

The word "Kwantlen" translates to "tireless runner" and speaks to the Nation's resilience in the face of all things, including flooding. The Nation has and continues to advocate for their safety, act in care of each other, and follow their seven traditional laws in their flood response: Generations, Generosity, Humbleness, Health, Happiness, Forgiveness and Understanding.

Capacity, culturally appropriate supports and access to up-to-date information remain a challenge for Kwantlen First Nation. Despite this, the Nation is working towards self-determination, which presents a challenge and many opportunities. In reclaiming the right to make decisions for their communities, one member stated, "That's why First Nations have to take it over—because it is a different culture. That's why it can't be led by somebody other than the First Nation, which again cycles back to colonialism and trying to fit First Nation culture into the mindset of the [various levels of government]."

Relationship and collaboration efforts present the best opportunities for overcoming challenges related to risk mitigation and response. By asserting self-determination and doing good work in in the space of risk management related to flooding, KFN has the opportunity to be prepared with the tools and relationships they need when the river rises. With continued effort in these spaces and by following their traditional laws, Kwantlen First Nation will continue to care for the safety of their community.

– Adapted from When the River Rises: A Case Study of Kwantlen First Nation's Management of Flood Risk, with permission from the author, Carla Hanson and the Kwantlen First Nation

Strengths, gaps and uncertainties in understanding riverine flood risk in B.C.

Strengths

- The B.C. Flood Strategy[78] provides a roadmap toward 2035 to address a wide range of flood resilience challenges in B.C., including hazard assessment, capacity building, flood governance, emergency preparedness and mitigation planning
- A focus on collaboration has increased among First Nations, government agencies, research institutions and local governments to provide a holistic understanding of riverine flood risk
- Indigenous Knowledge is shared to understand floods and the natural cycles that guided First Nations settlement and relationships with floodplains; knowledge and expertise held by First Nations can inform future planning of floodplain use

and support healing of First Nations communities impacted by flooding

- Riverine monitoring infrastructure, such as hydrometric stations, has been developed to provide valuable data for understanding and predicting flood events; River Forecast Centre provides province-wide flood monitoring and advisories
- Land-use planning and provincially regulated zones, such as the Agricultural Land Reserve and conservation easements, are used to manage land use within floodplains
- Advanced technologies are available for hazard assessment to map floodplains and assess flood risk (see case study 6 in Appendix C)

Gaps

- The wide range of future climate scenarios poses a challenge in accurately modelling changes in flood frequency and intensity in most areas of B.C.
- Incomplete detailed flood hazard mapping and limited local hydroclimate data, especially in First Nations communities and remote or less populated areas of B.C., limit the accuracy of flood risk assessments in these regions
- Static historical floodplain maps used for emergency preparedness and policy are often outdated
- Community engagement and awareness regarding individual and community flood risks is incomplete

Research highlight: Machine learning for flood prediction in ungauged basins

Flood prediction and forecasting can reduce risks. While flood prediction is routinely done for many locations where measurements of water levels are available, there are many at-risk locations where no gauge exists.

Researchers from The University of British Columbia are developing a machine-learning model to transfer information from gauged catchments to ungauged catchments to expand flood prediction capabilities. Machine learning was applied to compare predictions in gauged and ungauged basins. Reasonable prediction quality was achieved in initial tests on gauged basins with nine years of data. Further validation of model forecasting is in progress.

For further details on this research project, see case study 6, in Appendix C.

Figure 2.3.1: Coastal erosion. Brett Eaton, n.d.

2.3 Coastal flood

Hazard description

Coastal floods occur when water levels in the ocean are higher than normal, resulting in an inundation of land that is normally dry along the coastline.[79] Coastal flooding is a natural process that may be caused by storm surges (temporary rise in sea level caused by a storm), high tides, tsunamis, sea level rise or wind-generated waves. Tsunamis are extreme waves that are triggered by seismic activity or landslides. Gradual sea level rise from melting glaciers and polar ice sheets due to climate change will exacerbate the impacts of coastal flooding. Floods can cause significant economic, environmental and social impacts, including damage to infrastructure and potential life loss.

Flooding on First Nations land and waters

Coastal flooding is an event that happens naturally and is part of a greater system that is linked to the forests, mountains, tides and other natural cycles. Today, coastal floods are exacerbated by land-use practices, planning and climate change. First Nations have deep knowledge and relationships to areas impacted by floods and tides, such as knowing that tidal zones are important ecosystems that present many gifts from the Creator. First Nations are some of the most likely populations to be impacted by flooding due to the colonial placement and restriction of First Nations to reserves that are often placed in vulnerable locations.

– First Nations Committee

B.C.'s coastline is characterized by low-lying areas such as river deltas, estuaries and coastal plains that are naturally more prone to flood inundation. Land-use changes such as urbanization, forestry, agriculture and alteration of natural drainage systems can exacerbate the exposure to coastal floods. Generally, coastal flooding can occur extremely rapidly, such as during a storm surge or tsunami, or gradually, such as from sea level rise over time.

Storm surges:

A storm surge is a temporary increase in ocean water levels due to an atmospheric event such as a low-pressure system and wind setup. As these offshore or near-shore storm systems move in from the Pacific Ocean, the change in pressure or wind conditions can cause ocean water levels to rise and generate storm surges that result in coastal inundation and flooding of areas that are at or close to sea level. During the fall and winter, these intense short-duration storms (lasting hours to days) are often accompanied by strong winds and heavy rainfall.

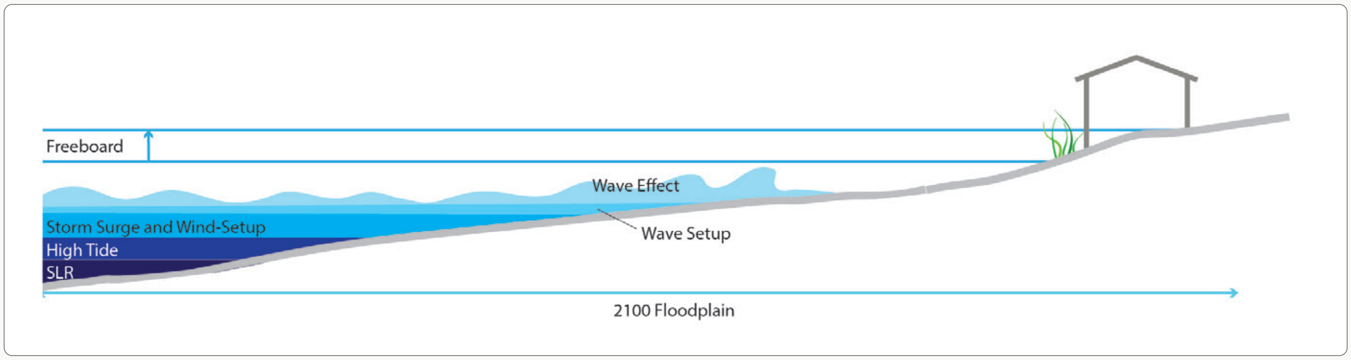
High tides:

Areas of B.C.'s coastline can experience significant tidal variations between high and low tides due to cycles in the rise and fall of the ocean's surface. Tidal fluctuations occur on diurnal (daily) and annual cycles due to changes in the relative position of the sun and moon. Extreme high tides occur annually from November to January, when the sun and moon are aligned and the moon is at its closest point of approach to the earth. When high tides coincide with storm surges or high winds, they can lead to localized coastal flooding and erosion.

Wave and wind action:

During a storm surge, strong winds can drive water towards the shore, resulting in a localized increase in water levels against the coastline. Large, powerful waves breaking on the coastlines of oceans have additional energy that can cause erosion and damage of natural barriers (such as beaches, dunes and wetlands) that protect coastal communities. Water level changes due to wind-generated waves are considered separate site-specific processes that are not included in the definition of storm surges. Figure 2.3.2 provides a simple sketch of coastal flood components.

Figure 2.3.2: Components of coastal flood level that determine extent estimates (SLR = sea level rise).[80] Ebbwater Consulting for City of Vancouver, 2016.



Tsunamis:

B.C. is located within an active seismic zone, and earthquakes can trigger tsunamis which can cause sudden coastal flooding. Tsunamis are extreme or long-period waves triggered by seismic events such as underwater earthquakes or landslides. The travel time before a tsunami reaches the shore depends on the distance from the earthquake source. A tsunami can last for hours, and the first wave of a tsunami is not always the largest. A tsunami can result in flooding, strong currents and damage to structures and infrastructure.

Rainfall and atmospheric rivers:

Extreme coastal flood events are often the product of combined high tides and storm surges. However, heavy rainfall or atmospheric rivers could exacerbate coastal floods, particularly in areas with a tidal influence such as the Fraser River valley. The Great Coastal Gale of 2007 is an example of a historical coastal storm resulting in widespread coastal flooding and damage across the Pacific Northwest, including B.C.[81]

Secondary hazards

Secondary hazards that can be triggered by a coastal flood event include landslides and slope instabilities, coastal erosion, salinization of soils, and saltwater intrusion to groundwater. Coastal erosion can cause the loss of natural barriers, such as beaches, dunes, wetlands and living dikes (for example, Mud Bay Living Dike[82]), that provide protection against storm surges and high tides. Flood protection structures within a coastal zone, such as engineered dikes and seawalls, may be overtopped or undermined, resulting in a failure. The intrusion of saline water into freshwater aquifers and estuaries can impact drinking water supplies, irrigation systems, coastal habitat and estuarine ecosystems. Land in estuarine areas can be at particular risk of flooding as tides and storm surge effects can act either alone or in combination to produce high water levels.

Hazard distribution

Coastal flood hazard varies across B.C. coastlines depending on factors such as geography, climate drivers and shoreline characteristics (for example, shoreline height, steepness and mitigations such as riprap placement). For the purposes of this report, in terms of coastal flood hazard, B.C. has been divided into two regions: Southern Coast and Central to Northern Coast.

Southern Coast region:

The Southern Coast region covers the southern half of B.C. and includes the greater Vancouver area, Fraser Valley and Vancouver Island. The region experiences mild winters with relatively little snowfall at sea level. When it does occur, snow often melts quickly due to warmer, seasonal temperatures. Precipitation mainly falls as rain, with higher amounts during the fall and winter months. Coastal environments most vulnerable to floods are characterized by low-lying coastal plains, river deltas (for example, Fraser River Delta) and estuaries. These areas are vulnerable to coastal flood events that are driven by storm surges, high tides and heavy rainfall events. In addition, the region is within an active seismic zone where tsunamis could be triggered, with the west coast of Vancouver Island being particularly exposed. Sea level changes have varied across this region, with an average rise in sea levels in Victoria and Vancouver over the last century, whereas average sea levels fell in Tofino, on the west coast of Vancouver Island, over this time period due to rising land from the geological process of post-glacial rebound.[83]

Central to Northern Coast region:

The Central to Northern Coast region covers the northern portion of B.C. and includes areas around Haida Gwaii, Prince Rupert, Bella Coola and Kitimat. The region experiences cold winters, with moderate snowfall during the winter months. Coastal environments are characterized by rugged terrain with fjords and steep coastal cliffs that are vulnerable to erosion, landslides and other coastal hazards during a flood event. Coastal areas directly exposed to ocean waves (such as Haida Gwaii) are more vulnerable to coastal flood hazards than sheltered ports (such as Port Clements). Sea level changes have varied across this region, with an average rise in sea levels over the last century.[84]

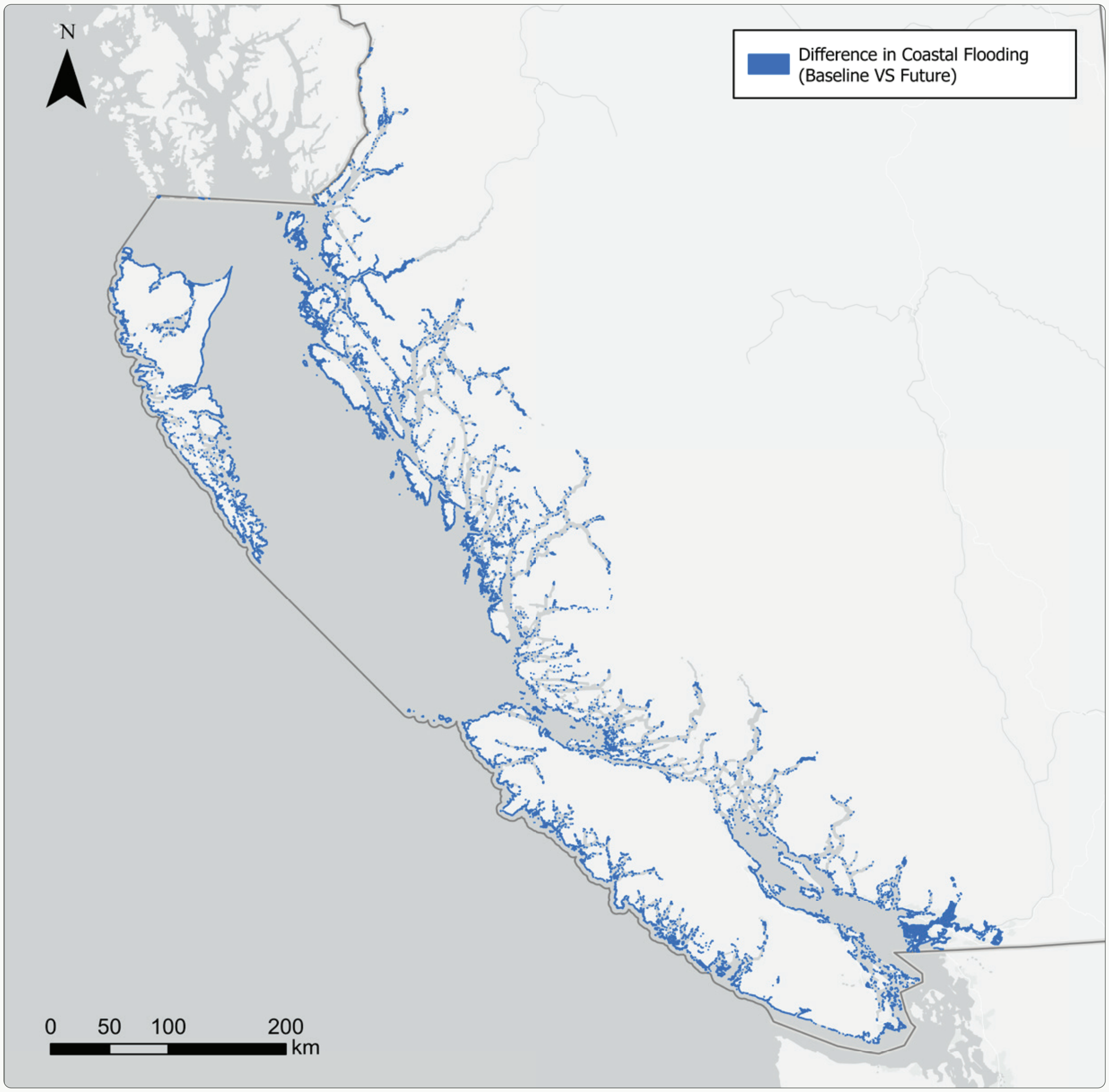
Hazard exposure

B.C.'s coastline contains densely populated flood-prone areas that are developed with infrastructure, such as major ports, airports and transportation corridors. Human activities can alter the storage and movement of water along coastlines by altering natural barriers (such as beaches, dunes and wetlands) that provide protection against storm surges and high tides. Coastal floods can include powerful waves that can cause structural damage to buildings and infrastructure and can erode and undermine flood protection structures over time. Coastal floodplains with a ground elevation below high tide and protected by sea dikes (for example, Richmond) or sea walls (for example, Delta) are vulnerable to flooding. In these areas, extreme coastal flooding would result in very deep flood depths (> 3 m) with potential for loss of life and severe impacts to infrastructure. Dike failures, especially in the Lower Mainland, are a potential and significant vulnerability. Also, the effects of tides, sea level rise and storm surge during high flow periods currently reach inland Lower Mainland communities along the Fraser River as far upstream as Mission (approximately 84 kilometres from the river mouth).

For the purpose of the Provincial DCRRA geospatial analysis, the coastal flood hazard is defined as potential inundation with 0.5 percent chance of exceedance in any year (200-year return period flood). The analysis identifies locations with any level of potential inundation as being exposed to coastal flood risk.

The coastal flood hazard associated with the 1-in-200-year return period event, is also modelled with climate change influence, including sea level rise (by year 2100) and storm surge (assuming high emissions and using multi-model maximum for the period of 2080 to 2099). The projected area at risk of inundation from coastal flooding increases significantly by the end of the century. The geospatial analysis indicates that the impacted area will increase by approximately 200 square kilometres (a 25 percent increase by end of century, see Figure 2.3.3).

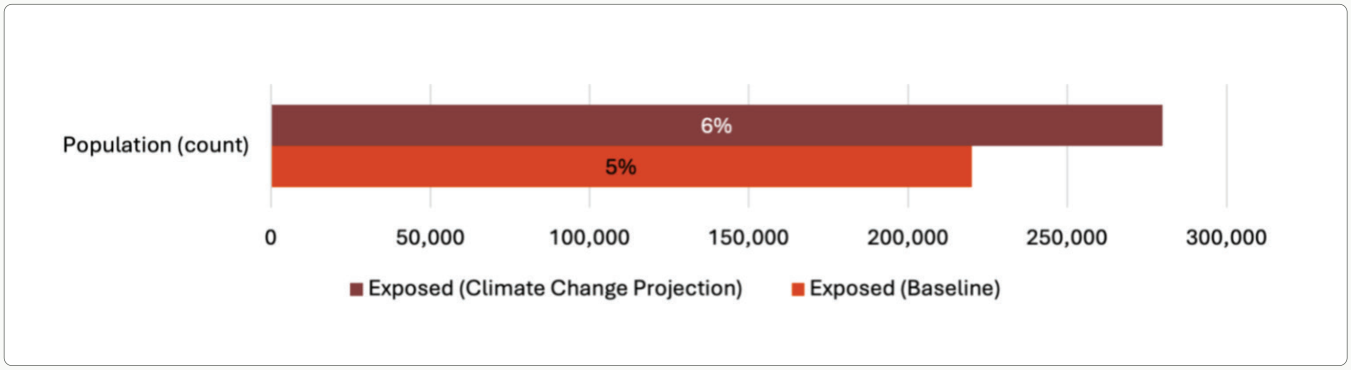
Figure 2.3.3: Coastal areas that are expected to become at risk by the end of the century as a result of climate change. The areas indicated in blue are currently not at risk, but are at risk in the geospatial analysis for projected 2100 conditions, assuming high emissions.



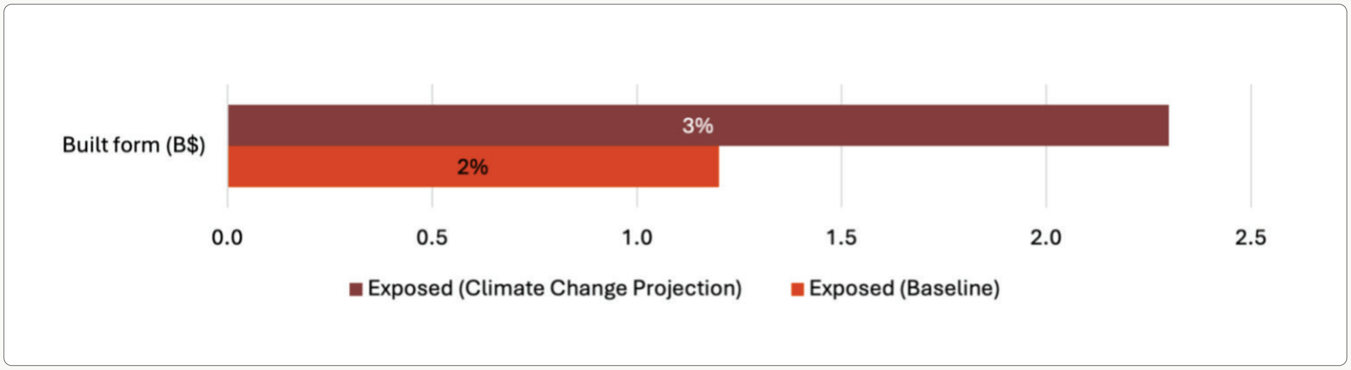
The comparison of current and future exposure also provides insights on impacts. The graphs in Figure 2.3.4 compare current (baseline) and future (projected) exposure of assets and populations[i] to coastal flooding.

i. Future projections of exposure do not account for population growth by 2100. The increase in population exposure in this analysis is only due to an increase in the area impacted by the hazard, and the people living within this area today (as of 2021 Census).

Figure 2.3.4: The population and built form within areas exposed to coastal floods in current conditions and with climate change based on current population and land use.

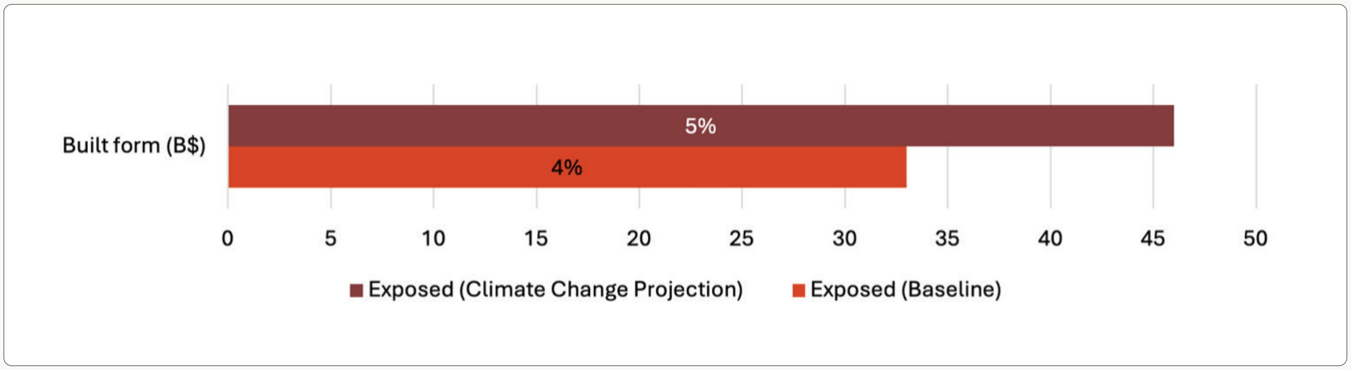


Population: Current exposure (bottom): 5% of the population (220,000 people) is within areas exposed to coastal flood inundation; **end of century projection** with climate change (top): 6% of the population (280,000 people[i]) is within areas exposed to coastal flood inundation.



Built form replacement value: Current baseline (bottom): 2% of the built form in First Nations reserves ($1.2B); and **future projection** (top): 3% of the built form in First Nations reserves ($2.3B) is within areas exposed to coastal flood inundation.

i. This number does not account for population growth by 2100.



Built form parcel improvements assessed value (baseline): 4% of the built form (parcel improvements assessed value) ($33B) is within areas prone to coastal flood inundation.

Built form parcel improvements assessed value (climate change projection): With the climate change projections, 5% of the built form (parcel improvements assessed value) ($46B) is within areas prone to coastal flood inundation.

The geospatial analysis of current and future hazard exposure highlights the potential impact, and climate change exacerbation of the impact, on the many remote communities and First Nations communities along the coast. Comparing the current and future projection shows a significant increase in coastal transportation infrastructure exposure, including length of railway (from 180 km to 300 km) and length of exposed unclassified roads (from 1500 km to 2000 km). By the end of the century, coastal flooding is expected to have more disproportionate impacts on coastal First Nations communities, with the increase of exposed population being much greater than that of non-Indigenous people.

For further information on the Provincial DCRRA Geospatial Analysis, see Appendix A: Hazard Exposure Geospatial Analysis – Methodology Report.

Past events

The Canadian Disaster Database identifies some of the impacts and costs for damaging coastal flood events in B.C.[85] However, a review of historical damaging flood events in B.C., carried out by a research team at the Geological Survey of Canada, identified over 35 damaging flood events in southern B.C.[86] and northern B.C. that include incidences of backwater flooding in the Fraser River Delta, resulting in dike breaches. Limited historical information on flooding in First Nations communities can be found in the database. A summary of the most devastating floods in B.C. is included in Table 2.3.1.

Table 2.3.1: Past coastal flood events.

Flood event	Flood driver	Description	Estimated losses[i] *Where data is available
2022 South Coast	Storm surge and high tide	High tides and strong winds in January 2022 resulted in closures and damage to infrastructure like seawalls and piers on Vancouver Island (for example, Qualicum Beach) and in Vancouver.	$80 million[87]
2007 Windstorm	Heavy winds and storm surge	Three storm systems brought hurricane-force winds and heavy rain, resulting in coastal flooding in areas along the Pacific Northwest in December 2007. Referred to as the "Great Coastal Gale of 2007," it is the most significant storm since the 1962 Columbus Day windstorm.	$1.5 billlion[88]
2006 Delta	Storm surge and high tide	A winter storm and high winds in February 2006 resulted in a one-metre storm surge that combined with high tide, resulting in dike breaches and flooding.	$6,406,00[89]

i. Unless otherwise noted, losses are reported in the dollar value of the year in which the event occurred.

Flood event	Flood driver	Description	Estimated losses[i] *Where data is available
2003 Haida Gwaii	Storm surge	A winter storm in December 2003 impacted parts of Haida Gwaii, causing flooding and erosion. Described locally as the "worst storm in half a century."	$250,000+ (for highway repairs)[90]
1990 Northern B.C.	Storm surge and high tide	A winter storm in late November 1990 caused flooding to several communities (such as Terrace, Kitimat, Hazelton, Stewart, Greenville, Daajing Giids). A high tide caused localized flooding in Prince Rupert. [91]	-
1962 Windstorm	Heavy winds and storm surge	Gale-force winds and storm surge in October 1962 resulted in one of the most destructive storms recorded in the Pacific Northwest (referred to as the "Columbus Day Windstorm"), with impacts to Vancouver Island and the Lower Mainland.	$600 million in 2016 dollars[92]

Flood event	Flood driver	Description	Estimated losses[i] *Where data is available
1941 Vancouver Island	Storm surge and high tide	High tide, storm surge and rain-on-snow event in late November 1941 resulted in widespread flooding of upper Vancouver Island. Similar events on Vancouver Island have been documented during subsequent winters, with varied impacts.[93]	-
1909 Victoria	Storm surge	Several winter storms caused significant erosion of Ross Bay. A concrete seawall was constructed by the City of Victoria.[85] Similar events in Victoria have been documented during subsequent winters, with varied impacts.[94]	-
1908 Squamish	Storm surge	A winter storm in December 1908 caused overtopping of the Squamish River dikes. Similar events have also been documented in the Squamish area (for example, in 1953).[95]	-

Flood event	Flood driver	Description	Estimated losses[i] *Where data is available
1871 Fraser River Delta	Storm surge and high tide	A severe winter storm in November 1871 caused backwater flooding of the Fraser River and dike breaches in Ladner.[96] Similar events at the Fraser River Delta have been documented during subsequent winters, with varied impacts (including dike breaches).[97]	-

Climate change influence

As described above, the historical susceptibility to coastal flooding in B.C. depends upon interactions between coastal morphology, tidal state and meteorological conditions, particularly storms. Until recently, these interactions have taken place against a backdrop of essentially unchanging absolute sea level. Under global warming, however, ocean height relative to land (relative sea level, or RSL) has steadily risen in most coastal areas due to the thermal expansion of seawater and the melting of land-based ice.

The situation in coastal B.C. is complicated by the complex pattern of vertical land movement due to post-glacial rebound, which changes at a similar rate to local sea level in this part of the continent. For example, while RSL has risen by several centimetres in Victoria and Vancouver over the past half-century, it has fallen in Tofino at twice that rate due to a higher rate of land uplift on Vancouver Island's west coast. This uplift on western Vancouver Island is caused by the subduction of the Juan de Fuca Plate beneath the North American Plate. However, an earthquake along this fault could result in sudden land subsidence, increasing exposure to coastal flooding. Climate model projections of RSL that account for this effect are available for coastal B.C. (ClimateData.ca). In southwestern coastal B.C., under a high-emissions scenario, median model RSL increases of approximately +20 cm (2050) and +55 cm (2100) are projected. By mid-century, sea level rise is projected to overtake the rate of land uplift along the entire coast of B.C., giving positive RSL values (ranging from +10 cm to +25 cm, depending on location). A one-metre change in sea levels by 2100 and two-metre change by 2200 are currently used for planning purposes in B.C.[98,99] A separate analysis using the same climate models was made to estimate the return period of extreme water levels during the cold season (October to March) at a location near the mouth of the Fraser River.[100] This suggests that a historical 100-year annual extreme water level might be expected once every four to ten years by 2050 (under a moderate emissions scenario) and perhaps every other year (high emissions) by 2100. It is important to understand that due to the inevitability of some additional warming of the oceans in the future, flood probabilities will increase, even without assuming any change in the frequency or intensity of major landfalling storms.

Additional information on the influence of climate change on coastal flooding is included in Appendix B: B.C. Provincial Climate Overview, and the conclusions of an associated extreme event likelihood analysis are summarized in Chapter 5.

Strengths, gaps and uncertainties in understanding coastal flood risk in B.C.

Strengths

- B.C. Coastal Marine Strategy[101] guides decision-making for B.C.'s coast for the next 20 years related to fostering healthy marine ecosystems, building resilience to climate impacts, and supporting vibrant coastal economies and communities
- B.C.'s Flood Strategy[102] provides a roadmap toward 2035 to address a wide range of flood resilience challenges in B.C., including hazard assessment, capacity building, flood governance, emergency preparedness and mitigation planning
- Collaboration has increased among First Nations, government agencies, research institutions and local governments to provide a holistic understanding of coastal flood risk and to co-create sustainable, nature-based solutions that reflect the needs and priorities of First Nations
- Advanced technologies and modelling are available for coastal hazard assessment, such as for storm surge, sea level rise and wave action

- Coastal monitoring infrastructure has been developed, such as tide gauges and meteorological stations, to provide valuable data for understanding coastal dynamics and predicting flood events
- Increasing research and implementation of nature-based solutions to address coastal erosion and impacts from storm surges, support improved water infiltration and decrease runoff
- Many B.C. coastal communities have already undertaken coastal flood adaptation actions related to mitigation and land-use policies to reduce their flood risk (see case study 7 in Appendix C)

Gaps

- Uncertainty exists regarding the rate and magnitude of future sea level rise, which complicates projections of coastal flood risk and corresponding policy guidance over the long term
- Modelling extreme coastal flood events, such as tsunamis and storm surges, remains challenging due to uncertainties in frequency and intensity
- Incomplete coastal hazard maps and limited local data, especially in First Nations communities and remote or less populated areas of B.C., limit the accuracy of flood risk assessments in these regions
- Static historical floodplain maps used for emergency preparedness and policy are often outdated
- Community engagement and awareness regarding individual and community flood risk is incomplete
- Uncertainty exists in the communication of potential risks to the public associated with tsunamis, given the low probability of occurrence and the lack of directly related experiences

Research highlight: BC local government actions to address coastal floods

Actions such as land-use planning or flood construction standards are important for reducing coastal flood risk. This case study provides a systematic overview of actions that local governments in B.C. are taking to address the risk of coastal floods. Researchers from the University of British Columbia are establishing a baseline of information on the degree to which local governments are already planning, adapting and taking action. Researchers analyzed data of 57 coastal B.C. communities available on the Resilient Coasts Canada (Resilient-C) online platform. The data have been collected from official community plans (OCPs) and supplemented by other sources, such as hazard risk and vulnerability assessments (HRVAs) and climate change action plans. Descriptions of specific actions were identified and systematically marked following an actions collection guide developed by the research team. The analysis revealed a wide range in how active communities have been—where four communities have not taken any coastal flood adaptation actions, while seven have taken over 30 actions each. Most communities have action portfolios relying on multiple mechanisms: Roughly 75% of communities have implemented actions related to land-use regulations, 56% have implemented actions of capacity building, and 49% have implemented projects aimed at mitigating coastal flood damage. Actions also reflect different long-term strategies: Most communities (68%) are implementing actions to accommodate flood events, while 54% of communities have "protect" actions that prevent hazards or their impacts through structural mechanisms. Only 4% of communities have implemented actions seeking to retreat from the coast.

Future recommended work is aimed to expand data sources and hazards and to engage with local community to better understand actions and approaches for reducing coastal flood risk.

For further details on this research study see case study 7, in Appendix C.

Figure 2.4.1: Heatwave in Victoria, B.C. Chad Pacholik, 2021

2.4 Extreme heat

Hazard description

Extreme heat occurs when weather conditions create significant risks to people, infrastructure or ecosystems. It is often categorized in terms of intensity (temperature and humidity) and duration (days).

Extreme heat is represented by increased daytime and nighttime temperatures for a prolonged period. The difference between daytime and overnight temperatures is important as well. When overnight temperatures remain high, the human body doesn't get the chance to cool off, rest and recover before the next day's heat. Some of the factors that can either amplify or abate heat intensity and duration include geographical features and interactions of the natural and built environments. However, identifying, locating and defining extreme heat as a hazard can be difficult, as extreme heat often covers a very large area, can be chronic, and its observed intensity is relative to the specifics of place, including climate and population susceptibility.[103]

In B.C., physical geography has a large role to play in determining the intensity of extreme heat. The high elevation of mountain ranges reduces the intensity of heat, while valley bottoms can trap

> ### Extreme heat on First Nations lands and waters
>
> Extreme heat is defined as prolonged, above-average temperatures that exceed common thresholds. It has specific, regional impacts to both ecosystems and people. Extreme heat impacts vulnerable populations most, such as Elders who live alone or away from family, people with disabilities, people who are living in poverty without access to cooling systems, and people with limited access to greenspace for cooling. Extreme heat is especially impactful at the beginning of the hot season, before acclimatization to the season. Extreme heat requires co-ordination between multiple government ministries to allow for early notification, public education and awareness. Decisions around extreme heat on First Nations lands and waters must have the Nations free, prior and informed consent at all levels (Province of B.C., federal government, municipalities) in alignment with the United Nations Declaration on the Rights of Indigenous Peoples.
>
> – First Nations Committee

air and increase the intensity of heat experienced. The Pacific Ocean can bring cool breezes to coastal areas, but it also contributes to high pressure ridges that stall over the province as well as increased humidity in coastal areas.

Several features of the natural environment can reduce the temperature of an extreme heat event. These include the presence of water features and forest canopy cover. Water features can, within limits, absorb solar radiation and can cool surrounding areas through evapotranspiration. For many animals and people, the ambient temperature of rivers and lakes is less than normal body temperature. Therefore, submerging oneself in a river or lake can have a temporary cooling effect. Similarly, a tree's shade and evapotranspiration can cool an area and those under the tree canopy.[104]

Secondary hazards

The hazard of extreme heat does not occur in isolation. It can compound with, or cascade into, various other hazards. Heat experienced near large bodies of water can contribute to the formation of thunderstorms.[105] Conversely, hotter weather, especially away from large bodies of water, is often accompanied by drier weather. Drier weather is correlated with increased risk of droughts and wildfires. Similarly, heat events can lead to decreased air quality, which has negative respiratory and cardiovascular health consequences, which are compounded again with wildfire smoke. Also, while drier soils generally lead to a decreased risk of landslides, if an area has experienced a wildfire (in part caused by hotter weather), there is a higher risk of landslide when precipitation returns and dry, hydrophobic soils contribute to flash flooding.

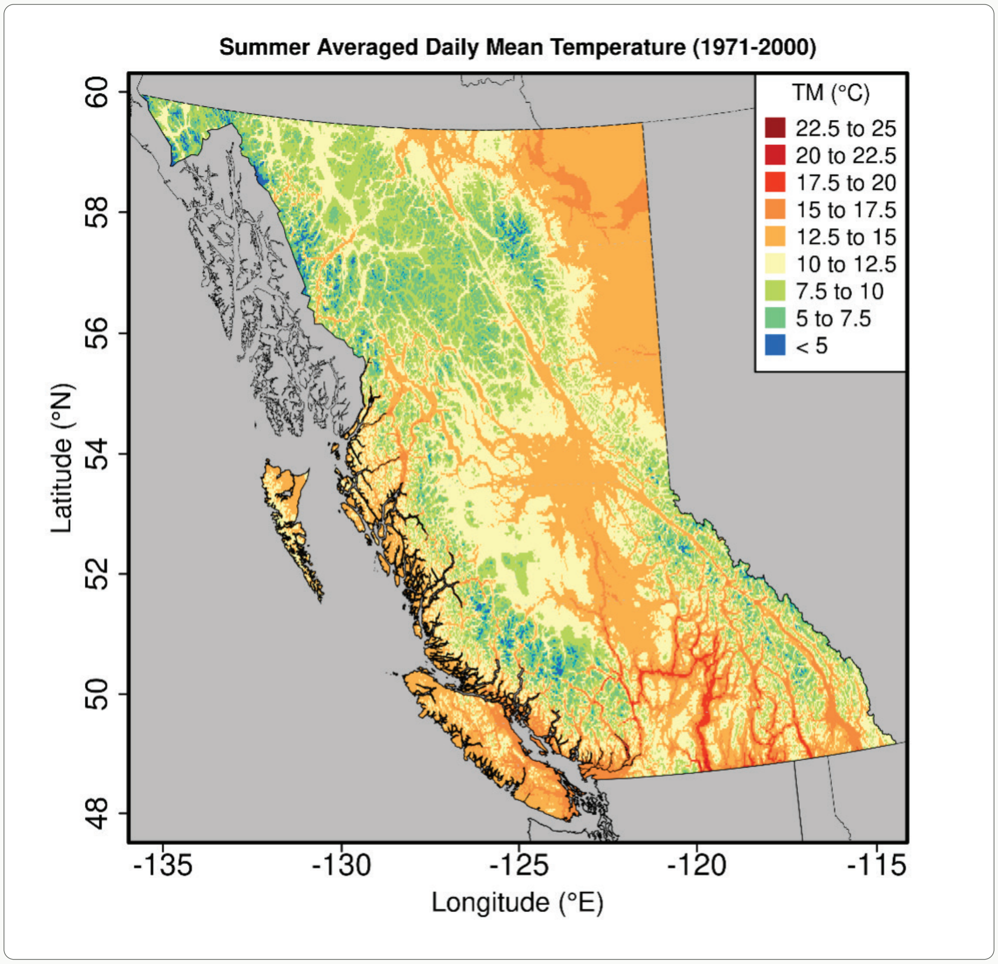
Episodic extreme heat affects short-term water supplies. Long-term climatic warming affects long-term water supplies, as deglaciation and low seasonal snowpacks are both driven by higher temperatures. These phenomena are common and will increasingly affect B.C.'s access to fresh water.

Although there is consensus among the scientific community that the frequency of extreme heat events is increasing due to climate change, the understanding of systemic risks and feedback loops that will continue to change our climate,[106] including extreme heat and its interrelated hazards, is incomplete.

Hazard distribution

The distribution of the extreme heat hazard over B.C. is related to the pattern of summer mean temperature (Figure 2.4.2), which shows clearly how summer temperatures are naturally limited in coastal and mountainous areas, compared to narrow valleys sheltered from cooling winds and less forested areas. Summer temperatures are often enhanced in urban areas, which can therefore be subjected to longer heatwaves. This is known as the urban heat island effect, which features increased daytime temperatures (1°C–3°C higher than in outlying areas),[107] reduced nighttime cooling, and sometimes higher air pollution levels caused by associated weather patterns.[108]

Figure 2.4.2: Summer averaged temperature over the 1971–2000 historical period. Pacific Climate Impacts Consortium, 2025.



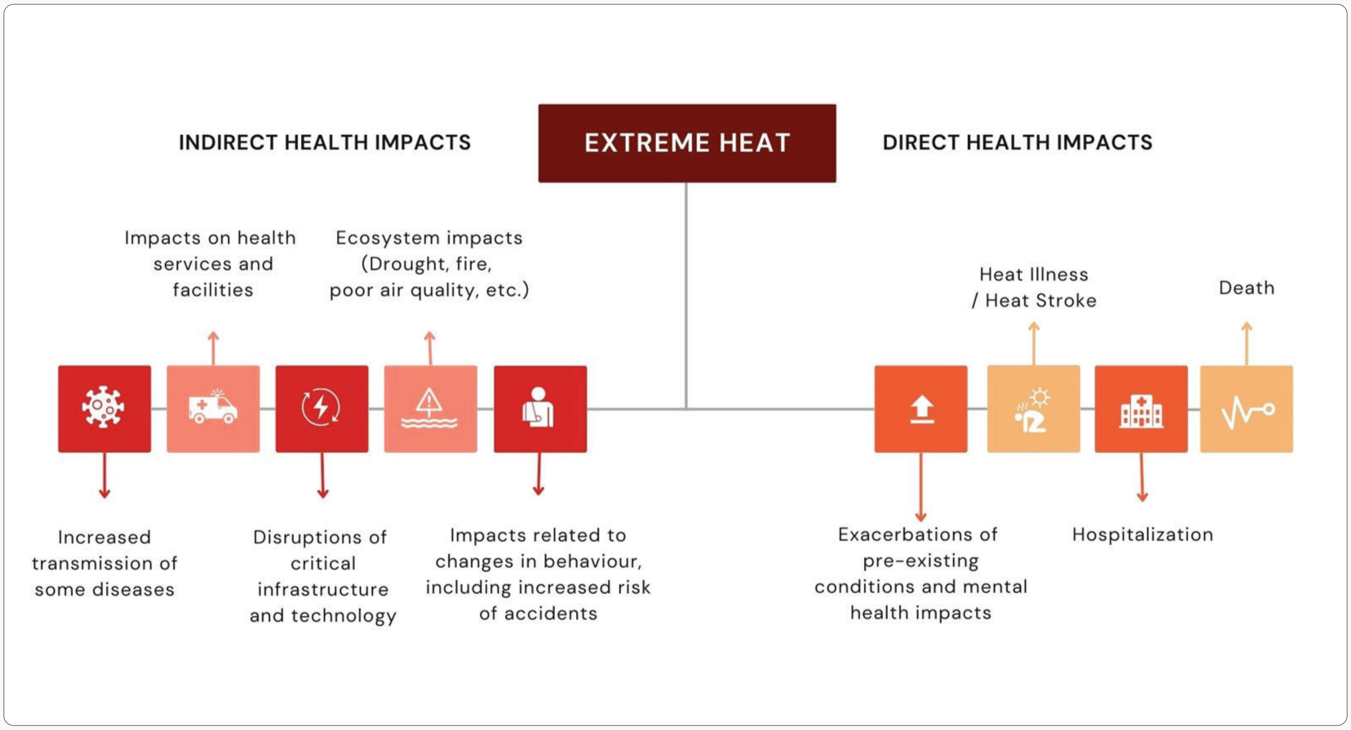
There are a few regions that historically experience the hottest temperatures in B.C. This includes Central and Southern Interior regions, the Okanagan Valley and the Fraser Valley (Fig. 2.4.2). However, while lower peak temperatures occur in the northern half of B.C., these regions can still be adversely impacted by extreme heat, due to limited acclimatization, outdated building and infrastructure design, and other factors. A 2017 study of the urban heat island (UHI) effect in cities across Canada found that B.C. cities feature increased temperatures relative to their surroundings, including Courtenay (+1.9°C), Kelowna (+6.1°C), Vancouver (+4.4°C), Vernon (+2.7°C) and Victoria (+2.9°C).[109]

Hazard exposure

The main risk from extreme heat is to human health. By compromising the body's ability to regulate its internal temperature, extreme heat leads to various illnesses such as heat cramps, heat exhaustion, heatstroke and hyperthermia. Exposure to extreme heat can also worsen chronic conditions such as cardiovascular, respiratory and diabetes-related conditions, compromise mental health and cause acute kidney injury.[110] Deaths and hospitalizations resulting from extreme heat can happen quickly, often on the same day or in the days that follow. This necessitates prompt interventions when a heat alert is announced.[111]

Extreme heat can disrupt and compromise essential health services and can cause power outages and transportation disruptions. Working productivity can be reduced and the risk of occupational accidents is increased. Extreme heat hampers both work and learning, sometimes forcing schools and other institutions to shut down.[112] The World Health Organization provides a simple overview of direct and indirect threats of extreme heat (Figure 2.4.3). The articles in Chapter 3 present in-depth information on how extreme heat affects different value areas.

Figure 2.4.3: Direct and indirect health impacts of extreme heat. World Health Organization.[113]



Extreme heat has disproportionate impacts on certain groups

The impacts of extreme heat are not experienced equally. While extreme heat events pose risks to all individuals, certain people face heightened dangers and are more susceptible to heat-related illnesses. Those with underlying health conditions or limited capacity to protect themselves from heat exposure are at the greatest risk. Extreme heat conditions tend to exacerbate existing societal inequities, as marginalized groups often experience compounding risk factors that further increase their vulnerability. As an example, the risk factor most strongly associated with mortality during the 2021 extreme heat event in B.C. was individual-level low income.[114] Individuals and communities may face a combination of challenges, such as limited access to cooling resources, inadequate housing conditions, pre-existing health issues and lack of awareness and preparedness measures, which separately and collectively amplify the impacts of extreme heat on morbidity and mortality.[115] See section 4.2 for more information on population groups that may experience disproportionate impacts from extreme heat.

From a human health perspective, the BC Heat Alert and Response System: 2024 (BC HARS) defines and updates metrics of concern for human health in five different regions of the province (see Fig. 11 in Appendix B).[i] Thresholds for a heat warning include an expected 5 percent increase in mortality of the general population, while an extreme heat emergency expects a 20 percent or more increase in mortality for the general population.[116] These thresholds are useful to identify broad geographic areas of concern.

BC HARS:2024 includes measures to account for early season heat events where the population is not yet acclimatized. While the human body can acclimatize to hotter temperatures, there is a narrow range to this adaptive capacity.[117] Heat-related illnesses, including hyperthermia, occur when the body surpasses safe core temperature thresholds. Normal internal body temperature is 37°C. At 38°C, a body experiences heat stress; at 39°C it reflects severe heat-related illnesses; at 40°C is when clinical hyperthermia sets in.

i. These regions, thresholds and descriptions are likely to be amended in 2025.

The effect of a heat hazard on human health is cascading and may be realized months after the hazard occurs. For example, the health of someone with underlying health conditions may be further compromised by an extreme heat hazard, leading to decreased immune system functionality and vitality. In time, the additive negative effect of extreme heat is one of many contributing factors to one's overall health and can be the difference between recovery and mortality.

Similarly, structures do not respond uniformly to extreme heat. This is due to variations in location, design, construction methods and the date built. The differences in temperature experienced at the building level are driven largely by orientation and solar heat gain.[118] Design features like material and colour choices can impact how much heat is absorbed or reflected.[119] Indoor air temperature can significantly affect occupant health, with extremes leading to respiratory issues, cardiovascular strain and decreased cognitive function. Even when outdoor temperatures are stable at safe levels, poorly insulated or inadequately ventilated buildings can experience unhealthy indoor conditions.

Building codes and design standards establish parameters and tolerances for aspects of the built environment, but updates to the BC Building Code and design standards are incremental and take time to have an impact on the entirety of the built environment. Older structures and infrastructure that were constructed using older codes and standards usually have poorer performance regarding heat. When design tolerances are exceeded, this can reduce efficiencies of the structure and decrease its expected operational lifespan. Therefore, much of our building stock is ill-equipped to address extreme heat hazards. While these deficiencies are well known and understood, building codes do not apply retroactively, meaning that a building does not have to be updated each time the code is updated, unless a building is being renovated or altered.

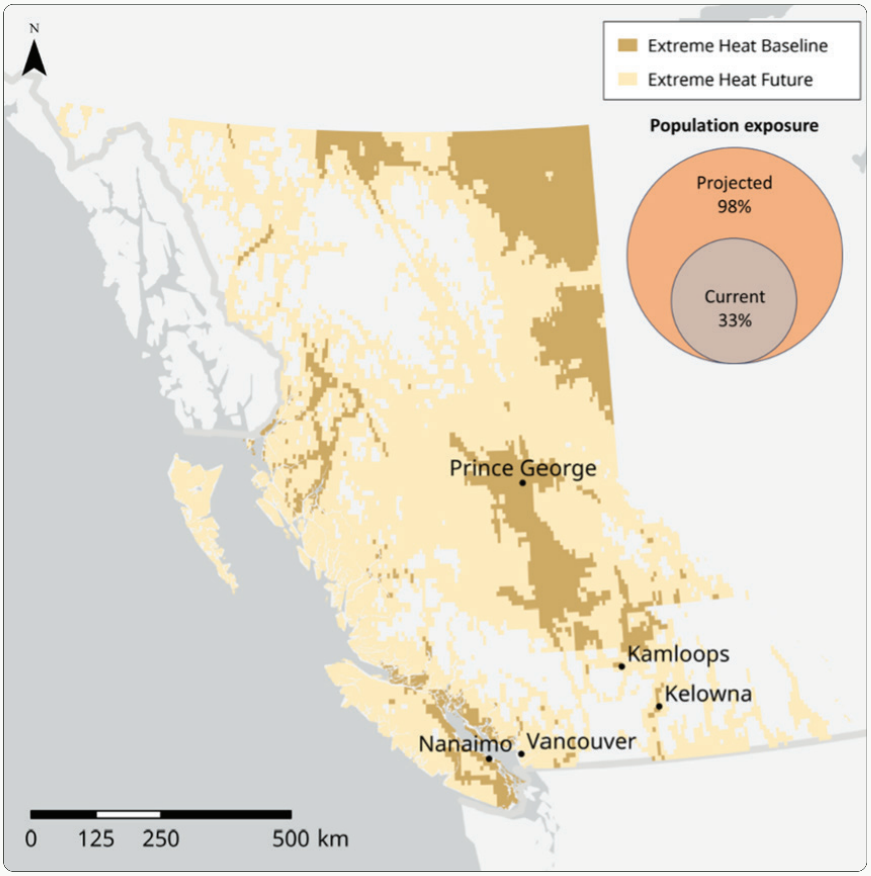
Decisions on how and where to build and develop can exacerbate the threat of extreme heat. This is largely attributable to the extensive replacement of natural green landscapes with human-made, heat-absorbing grey infrastructure, such as concrete and asphalt. The removal of greenspaces, whether urban or rural, most often results in heat-retaining qualities. The design and layout of urban areas—or urban geometry—also plays a critical role in the accumulation of heat within city environments, and this is compounded by the heat generated from human activities, including transportation, industrial processes and the operation of buildings.

BC Building Code

Updates to the BC Building Code[120] have been incrementally increasing the thermal performance requirements for new buildings. The BC Energy Step Code, while targeted at energy efficiency, indirectly affects the thermal performance of buildings as well. To meet increasingly stringent tiers of the Step Code, a building will need to increase its thermal performance. Furthermore, the 2024 BC Building Code included, for the first time, a maximum design temperature of 26°C for at least one living space in every dwelling. Combined, these changes to the code will help to increase the thermal performance of new buildings. However, changes to the code will have limited or delayed impact on the existing building stock.

For the Provincial DCRRA, geospatial analysis of hazard exposure for extreme heat is modelled using regional HARS thresholds and both current baseline data and future projections with climate change influence (assuming high emissions – SSP5-8.5, 2041–2070; see Appendix A: Hazard Exposure Geospatial Analysis – Methodology Report). Figure 2.4.4 compares the area and population exposed to extreme heat under recent historical conditions (based on the historical period 1971–2000) and in the climate projected for the 2050s. Based on this analysis, the portion of population exposed to extreme heat greatly increases from 33 percent to 98 percent, and the surface area exposure increases from 17 percent to approximately 70 percent of the provincial surface area.

Figure 2.4.4: Surface area exposed to extreme heat in current conditions (brown) and with climate change influence (yellow/orange). Inset showing population exposure in current and projected future conditions.



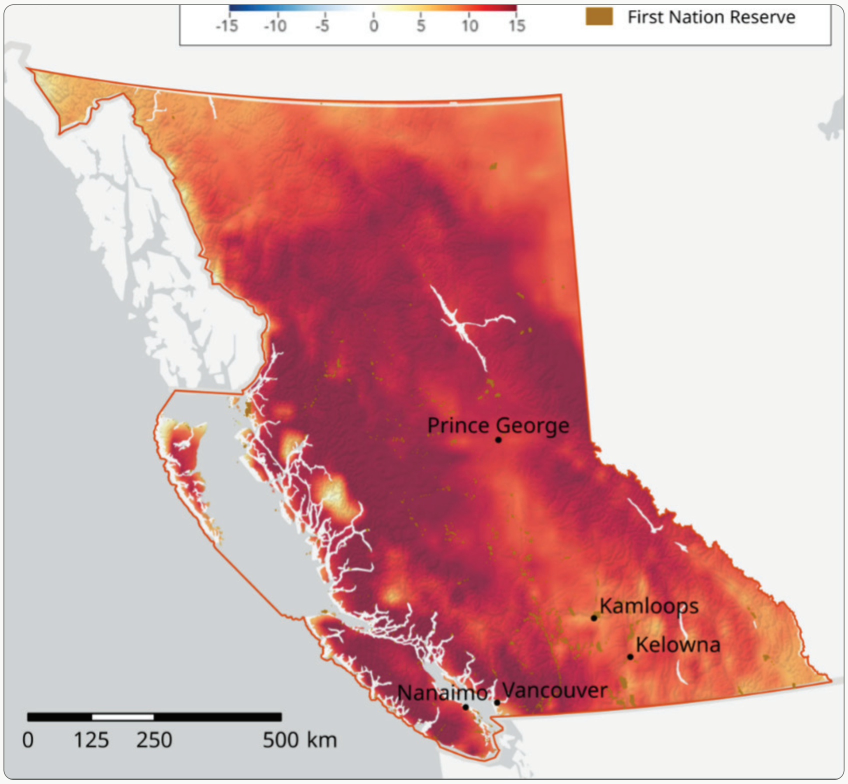
While provincial analysis has estimated that a significant portion (10–50 percent) of equity-deserving and other socially vulnerable populations are currently exposed to risk of extreme heat, and practically all are expected to be exposed in the 2050s, more insightful analysis of specific communities, vulnerabilities and local impacts of such extreme heatwaves must be studied separately.

Past events

High-intensity heatwaves differ from common "warm spells." The threshold temperature and duration of what is considered an extreme heat event varies considerably by location over the province. Over the period of instrumental temperature measurements, B.C. has experienced moderate heatwaves, mainly in the Southern Interior region, with some lasting up to a few weeks. Impactful heatwaves in B.C. occurred in 1941, 1981, 2007, 2009 and 2015. The 2009 Lower Mainland event led to many deaths, and in 2015, the entire province experienced heatwave temperatures. The 1941 heatwave, which encompassed much of Western Canada, was the most intense prior to 2021.[121]

The most significant extreme heat event on record was experienced from June 25 to July 2, 2021. During this period, the near-surface air temperatures deviated significantly from typical conditions, exhibiting anomalies ranging from 8°C–20°C above the normal levels across a vast geographical area (Figure 2.4.5). Numerous locations within this region shattered their all-time maximum temperature records by substantial margins, exceeding some previous records by more than 5°C.[122] There were 740 excess deaths and 619 heat-related deaths attributed to this event[123] as well as significant marine life die-offs, decreased agricultural production, river flooding due to rapid ice and snowmelt, and an increase in wildfires—the latter of which may have contributed to landslides in the following months.[124]

Figure 2.4.5: Areas of B.C. impacted by the extreme heatwave of late June 2021. The map, created by GeoBC from a larger version produced by the [Goddard Earth Observing System](https://earthobservatory.nasa.gov) **(GEOS) model, shows air temperature (2-m height) anomalies on June 27, 2021, when the heat intensified and records started to fall. Darker areas are where air temperatures climbed more than 15°C higher than the 2014–2020 average for the same day.** https://earthobservatory.nasa.gov/images/148506/exceptional-heat-hits-pacific-northwest



The extreme temperatures caused workplace safety issues, labour supply and productivity losses, damage to transformers and power lines, higher electrical demand, increased wear on roadways, flight disruptions, crop losses and livestock deaths, and impacts to traditional foods.[125]

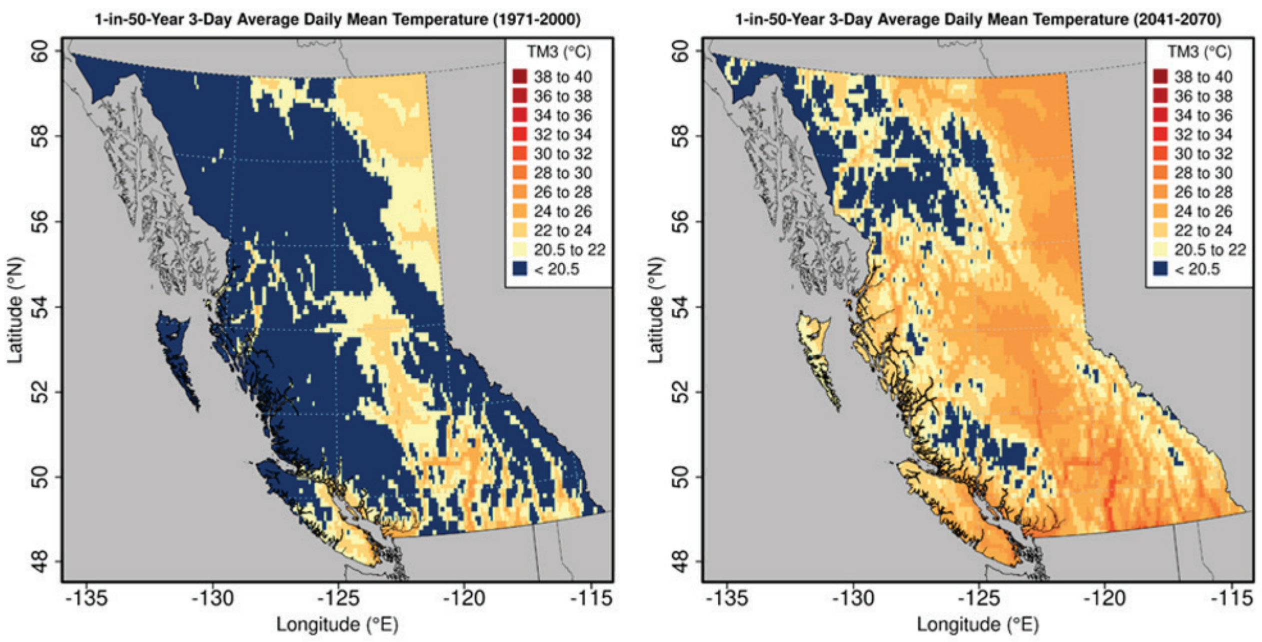
Several scientific analyses of the 2021 heatwave have been conducted. Long-term records of summer temperatures in the Pacific Northwest, derived from tree-ring data, show that the regional average summer temperature in 2021 was unprecedented in the last 1,075 years.[126] Other authors, analyzing the instrumental record only, derived a range of estimates for its expected frequency, varying from about once every 1000 years[127] to about once every 235 years.[128] This uncertainty in return period is a result of the lack of previously recorded events of comparable intensity: in other words, the statistical analysis of such small samples is highly uncertain.

Climate change influence

As a complement to historical analyses, extreme heat event climate models can help us to understand the intensity, persistence and likelihood of extreme heat events across B.C., both in the recent historical period and in a future context under increasing greenhouse gas emissions. For example, one recent modelling study concluded that climate change made an event like the 2021 B.C. heatwave at least 150 times more likely.[129] Looking ahead to mid-century (or to a global warming level of approximately 2°C), this study and another estimated that an event as intense as the 2021 heatwave could reoccur once every 2 to 10 years, depending on the emissions scenario.[130,131]

For the purpose of this assessment, we consider a heat event characterized by a three-day mean temperature that is sufficiently intense and rare that it occurs once every 50 years, on average. Figure 2.4.6 shows the simulated magnitude of this 1-in-50-year, three-day heatwave, both in the historical reference period (1971–2000; left) and in a projected 2050s climate (roughly corresponding to 2°C, along the current emissions trajectory; right).

Figure 2.4.6: Mean temperature of a 1-in-50-year, three-day heatwave event in the historical period (1971–2000; left), and in the climate projected for the 2050s by an ensemble of downscaled CMIP6 models. Results for the median model are shown. Pacific Climate Impacts Consortium, 2025.

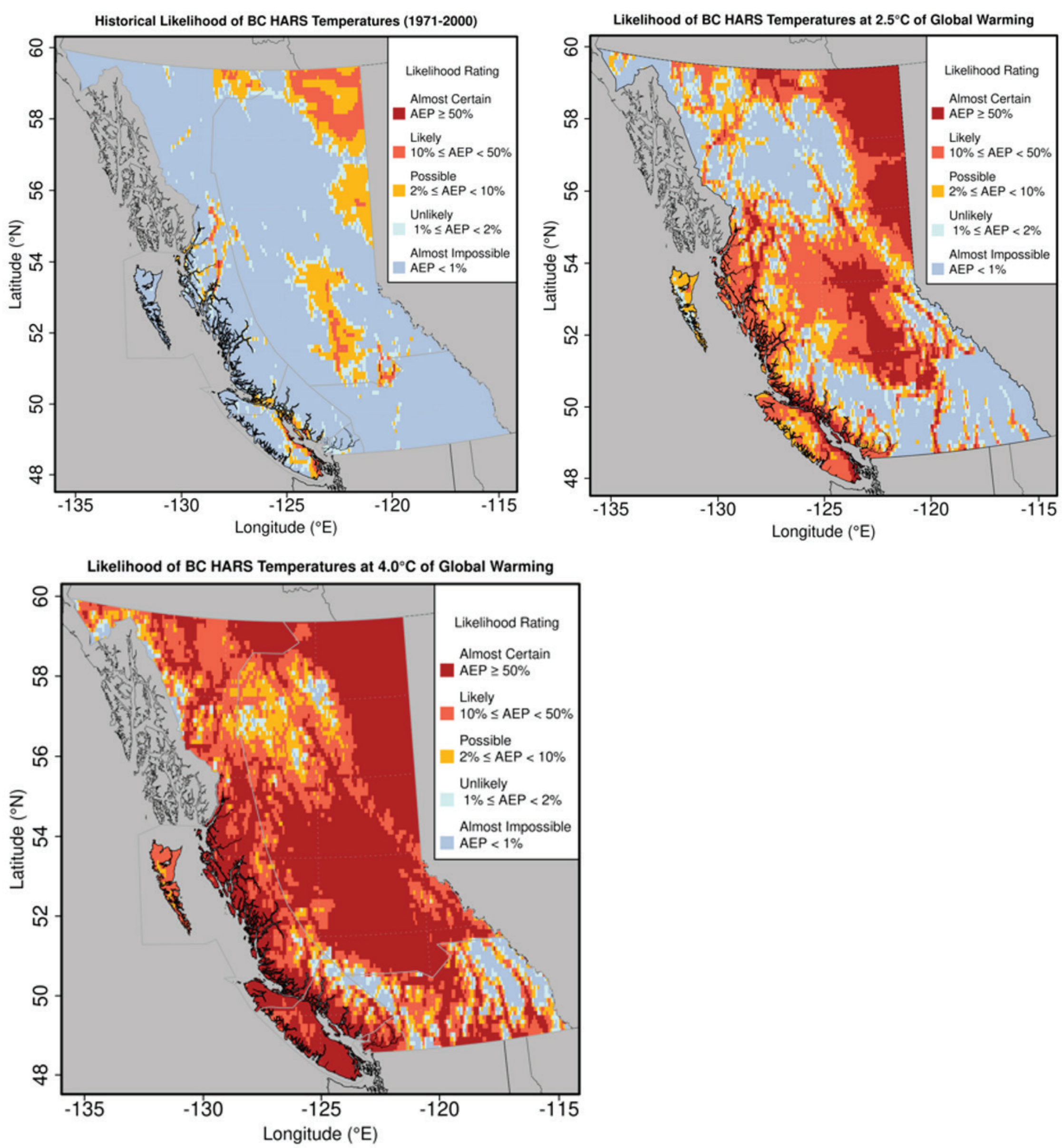


The left-hand panel of Figure 2.4.6 shows that in the simulated historical climate, the most intense three-day heatwaves have a mean temperature of around 28°C and occur in the far south of the province. However, over the majority of B.C.'s area, these 1-in-50-year, three-day events do not constitute a hazard. These areas, shown in dark blue, have intensities of less than 20.5°C, lower than the lowest threshold used for heat alerts anywhere in the province. The right-hand panel of Figure 2.4.6 shows that in the projected mid-century climate, these rare and intense three-day heatwaves have noticeably higher mean temperatures than in the historical period, exceeding 30°C in some areas.

The area of the province exposed to extreme heatwaves increases markedly in the 2050s, covering most of B.C.

BC HARS provides threshold temperatures of concern in different parts of the province, using a sequence of three consecutive daytime high and nighttime low temperatures (day-night-day).[132] This offers another way to use the model projections of three-day heatwaves: to calculate return periods and annual likelihoods for temperatures that exceed the HARS threshold values in each region of B.C. As shown in the left-hand panel of Figure 2.4.7, extreme heat events exceeding the average day-night-day HARS thresholds are very rare (annual exceedance probability: AEP < 1 percent) over most of the province, apart from the northeast and central B.C. At 2.5°C of global warming (middle panel of Figure 2.4.7), extreme heat events become possible or likely over about half the province, and almost certain in selected areas. By 4.0°C of global warming (approximately the 2080s), extreme heat events become likely to almost certain over most of the province.

Figure 2.4.7: Likelihood rating for 3-day extreme heat events using BC HARS thresholds for the historical period (left), GWL of 2.5°C (middle), and GWL of 4°C (right). Pacific Climate Impacts Consortium, 2025.



The details of an extended climate change influence analysis are included in Appendix B: B.C. Provincial Climate Overview, and the conclusions of an associated extreme event likelihood analysis are summarized in Chapter 5.

Strengths, gaps and uncertainties in understanding extreme heat risk in B.C.

Strengths

There has been significant attention and progress in understanding the risks since the 2021 heatwave:

- Public awareness and public experience of heat risk have increased, as has media attention to heat hazards.
- Access to data and information sharing exists among government and non-governmental organizations. Sharing of that information publicly is made possible via, for example, the Capital Regional District Heat Portal.[133]
- Health and epidemiology data collection has identified the importance of collecting data during high-risk times (for example, early season heat events).
- Designated funding streams are available to support heat risk assessments at the regional and local levels and by First Nations communities and are evolving to be more participative.
- BC HARS was developed in direct response to the 2021 heat dome, and its annual review and engagement seeks continuous improvement.
- The Province of B.C. applies an Environmental Social Governance (ESG) framework to guide the delivery of key government priorities through the development of public sector projects. The ESG Framework for Capital includes standards for capital projects to meet climate goals. Climate hazards must be considered and applicable climate risks mitigated in the recommended building design. Additionally, buildings are to be designed to meet a green building standard, reduce fossil fuel use, and electric vehicle charging infrastructure needs should be considered.
- First Nations communities and health centres focus on senior care, particularly seniors who live alone, by installing heat pumps and developing check-in systems.
- There are opportunities to learn from the traditional ways First Nations have lived with extreme heat in the past, such as building dugouts to preserve food and support food security.

Gaps

- Comprehensive data on the full scope of impacts from extreme heat events is lacking, particularly information on disproportionate impacts that may be experienced by people who are unsheltered or precariously sheltered, seniors and others who are socially isolated, people with disabilities, low-income groups, people with underlying health conditions and those requiring emergency medical care. Without this data, it is difficult to adequately understand the scale of need and to tailor responses effectively.
- Heat vulnerability and needs are inadequately understood in rural, remote and small-town communities that face unique challenges like isolation, lack of public transportation, occupational heat exposure risks (for example, farming), and limited resources for developing heat action plans.
- Gaps exist in risk communication, public awareness and acceptance, especially in reaching certain groups like those experiencing language or literacy barriers in rural areas.[134] Public information campaigns are under-resourced.
- Indigenous Knowledge systems and Western scientific approaches should be better integrated for understanding heat risks and developing adaptation strategies.
- Limited information evaluating long-term adaptation needs exists. While immediate health impacts are studied, there are gaps in comprehensively evaluating the long-term adaptation needs and sustainable housing and infrastructure requirements to reduce heat risks.
- Awareness and understanding of the value of risk management are lacking to incentivize the required changes and investments.
- Not all communities have undertaken heat risk assessments, and the impacts of heat on infrastructure and systems, and on people's daily life and routines, is poorly understood.
- A standardized methodology for conducting heat risk assessments is lacking, making it more difficult to compare one community's assessment to another's.
- Fewer weather stations in rural and remote areas of B.C., including in First Nations communities, makes it difficult to extrapolate local meaning and take appropriate action.
- There are several types of data that could be helpful but were not identified during the data screening process in this phase of the Provincial

DCRRA. These may exist but require more extensive research:

- Precise descriptions and thresholds to differentiate between severities of heatwaves and to clarify and differentiate relative risks from each
- Built environment design standards related to heat
- Absolute and relative impacts of heat on various types of assets in the built environment
- Inventory of heat thresholds for flora and fauna
- Speed at which heat health adaptations or acclimatization occurs
- Full understanding of relative heat impacts on different populations and what, if any, considerations of these differences exist in policy

Migrant labourers are especially vulnerable to heat

Migrant labourers in the agriculture sector are especially vulnerable to extreme heat events due to the strenuous nature of their work, the long hours and crowded accommodations. Within the Canadian agricultural sector, the majority of temporary migrant labourers are located in B.C., and in 2021, there were more than 10,000 migrant labourers in the province.

2021 was also the year of an unprecedented extreme heat event in B.C., where a late-June heatwave impacted communities across the province and beyond. A 2021 federal survey of temporary migrant labourers in the Canadian agricultural sector found that during the heatwave, 43 percent have no access to air conditioned or cooled accommodations. Some produce farms were forced to cancel shifts and tree fruit farms modified their harvesting time to after midnight to reduce heat stress on workers. Media reports from the Okanagan, an area greatly impacted by the heatwave, reported potentially unsafe living conditions among migrant farm workers due to a lack of cooling infrastructure.

– Adapted from The Case for Adapting to Extreme Heat: Costs of the 2021 BC Heat Wave, with permission from the Canadian Climate Institute

Figure 2.5.1: Temporary water use restrictions on Coldwater River in July, 2015. Province of B.C., 2015

2.5 Drought and water scarcity

Hazard description

Drought occurs when there is a lack of water in the system. In B.C., drought is often caused by a combination of insufficient snow accumulation, extended periods of hot weather and insufficient rainfall. Water scarcity occurs when there is insufficient water to sustainably meet the human and ecosystem needs or demands within a system. Hence, drought combined with demand can cause water scarcity. Land-use and water management policies and practices can exacerbate water scarcity by altering water storage and supply.

Meteorological drought is a natural phenomenon that occurs due to a combination of lower-than-normal precipitation (snow and rain), including reduced snowpack, and higher-than-normal temperatures for an extended time—usually several months or more. The severity of a drought is usually directly tied to its duration.

If sufficiently long-lived, meteorological drought may cause agricultural drought, hydrological drought, ecological drought and societal drought[135] (also known as "socioeconomic drought"). Agricultural drought occurs when there is insufficient soil water to properly support agricultural production. As a meteorological drought progresses, a hydrological drought results when small streams and creeks dry up, soil moisture and aquifer levels decline, and larger rivers experience decreased flow. Hydrological drought is often

Drought and water scarcity on First Nations lands and waters

Water scarcity can take on multiple forms but generally refers to when there is less water than average or not enough water to sustain systems. Cumulative effects of water scarcity, with increased frequency of drought events, causes systems to weaken over time. In the worldview of many First Nations, water is understood as a living entity and relative with which people share relationships and responsibilities. As per the United Nations Declaration on the Rights of Indigenous Peoples, First Nations have the right to steward, live in relationship with and maintain responsibilities to their water relatives for future generations. In many cases, water rights of First Nations have been infringed upon; however, there are also examples of collaborative water agreements in place to navigate water scarcity. Importantly, water scarcity impacts Pacific salmon, which are central to the way of life and food security of many First Nations.

– First Nations Committee

associated with low winter precipitation that manifests as low streamflow later in the year.[136] Ecological drought occurs when natural ecosystems are affected by meteorological and hydrological drought.[137] Meteorological, agricultural and hydrological drought can combine to impact society—creating societal drought—by adversely affecting the economy, community health and wellbeing, and infrastructure.

Short-term drought typically lasts for several weeks or months, while long-term drought can persist for several years or even decades. Flash drought is a rapid-onset drought that develops with a period of abnormally high temperatures, strong winds and little to no precipitation.[138] Flash drought can catch communities off guard, rapidly depleting soil moisture and stressing vegetation before mitigation measures can be implemented.[139] Short-term drought can have significant agricultural impacts, reducing crop yields and livestock productivity. Long-term drought can lead to severe water shortages, impacting municipal water supplies, hydroelectric power generation and ecosystems.

Drought can be exacerbated by the human management of water supply and demand. Water scarcity results in unsustainable water use because of a long-term imbalance between water supply and demand in an area.[140] Management choices that alter the movement of water can lead to a reduction in supply because of water exiting the landscape too quickly. Vegetation removal, stream modifications and wetland removal are examples of mismanagement that can accelerate the loss of water from the system.[141] In addition, water used in excess of supply can reduce streamflow and lower water levels in aquifers.[142] Hence, inefficient or excessive water use for a range of purposes can exacerbate drought, leading to enhanced water scarcity.

Secondary hazards

Drought and water scarcity may also increase the likelihood and intensity of wildfire and flooding. The loss of water from the system results in drier vegetation that can increase wildfire risk. Following wildfire or drought, vegetation may die. In both cases, vegetation loss leaves the soil exposed and hardened, with no root systems to support soil water retention. When rain falls, reduced water infiltration results in overland flow and soil erosion[143] and can increase the risk of flooding.

Hazard distribution

The distribution of the water scarcity hazard depends on the resiliency of systems to drought conditions, in addition to the distribution of drought conditions. The drivers of drought vary across the province. The climate in B.C. can be broadly divided into five regions:[144] Coast Mountains and the Islands, Interior Plateau, Columbia Mountains and Southern Rockies, Northern and Central Plateau and Mountains, and Great Plains.

The Coast Mountains and the Islands region, which runs the entire length of coastal B.C., has high precipitation, with most of the precipitation falling in the winter months. Higher elevations typically accumulate significant snowpacks. The high population centres in the southwest (greater Vancouver area, southern Vancouver Island) have high water needs and a rapidly growing population. Agriculture in the Fraser Valley relies on irrigation from aquifers and the Fraser River. Hence, drought in the southern portion of this region is particularly sensitive to reduced snowpacks that will affect streamflow and reservoir levels. Still, many watersheds—especially on the eastern side of Vancouver Island—are rain-dominated, with precipitation and high temperatures being the significant local drought drivers.

The Interior Plateau region is naturally drier because it resides in the rain shadow of the Coastal Mountains. Spring and summer are driest, with more precipitation falling in fall and winter. The Interior Plateau has some of the fastest growing cities in Canada.[145] In addition, agriculture is carried out throughout the region, with more intensively farmed areas, such as the Okanagan, also featuring a rapidly growing population that puts pressure on the water supply. The Interior Plateau relies on snowmelt to sustain river levels in the summer and fall.

The Columbia Mountains and Southern Rockies generally have arid valley bottoms, with most precipitation occurring as snow at higher elevations in the winter months. Hence, drought in this region is associated with low snow accumulation.

The Northern and Central Plateau and Mountains encompasses most of the northern area of B.C. Air temperatures are colder, and most precipitation occurs in the summer months. Drought is driven by a combination of low snowpacks, high air temperatures and reduced rainfall in the spring, summer and fall.

The Great Plains region is in the northeastern portion of B.C. This region has a continental climate and receives more of its precipitation during the summer months than wintertime. However, the region receives substantial snowmelt runoff from the North Rockies and the foothills. Hence, drought in this region is linked to low summer rainfall, combined with high air temperatures and low snowpacks.

For all of these regions, except for the Great Plains, insufficient snow accumulation is a main driver of drought.

Hazard exposure

Drought and water scarcity have a tremendous impact on the efficacy of dams, natural systems, the agricultural sector and access to drinking water. Changes in water levels affect ecosystems, hydroelectric power generation, industrial use and urban use.[146] B.C. relies on hydroelectricity to supply more than 89 percent of its electricity needs.[147] Hydrological drought will reduce streamflow and affect the management of reservoir levels, thereby limiting hydropower generation. The natural environment will experience reduced vegetative productivity because of reduced soil moisture. Fish populations will be under pressure, as hydrological drought reduces streamflow, impacts fish habitat and migration, and increases fish mortality. The agricultural sector will be impacted because farmers who do not irrigate will have difficulty producing their crops. Farmers with irrigation will need to use more water to compensate for reduced precipitation and higher evaporative demand. Livestock managers may not be able to supply sufficient forage because of reduced feed-crop productivity. Access by First Nations to traditional and medicinal foods will be constrained, impacting food security and sovereignty. Many communities rely on surface water and reservoirs to provide drinking water, and those users relying on shallow wells and small water bodies are particularly vulnerable. As water levels decrease, turbidity and sedimentation issues can degrade water quality, resulting in treatment challenges and contamination.

Human activity has promoted the rapid movement of water off the land. We have straightened rivers, drained wetlands and installed ditches to enhance water movement along highways and resource roads. This reduces the amount of time water stays on the land and has negative implications for groundwater recharge and surface water availability.

We do not adequately understand the level of threat that our use of water is causing. Water metering is not available in many communities, leading to an incomplete understanding of how water is removed from the system. Where water metering does occur, there is no central system to submit, record and compile the data. In many watersheds, the amount of available water and the water budget of most aquifers has not been quantified. There is evidence that in some regions, water extraction may exceed supply, resulting in limitations on new applications for water licences.[148] Hence, our lack of knowledge on both the supply and demand for water in B.C. limits the ability of the Province to know which regions are overusing water and are experiencing water scarcity.

A relationship with water

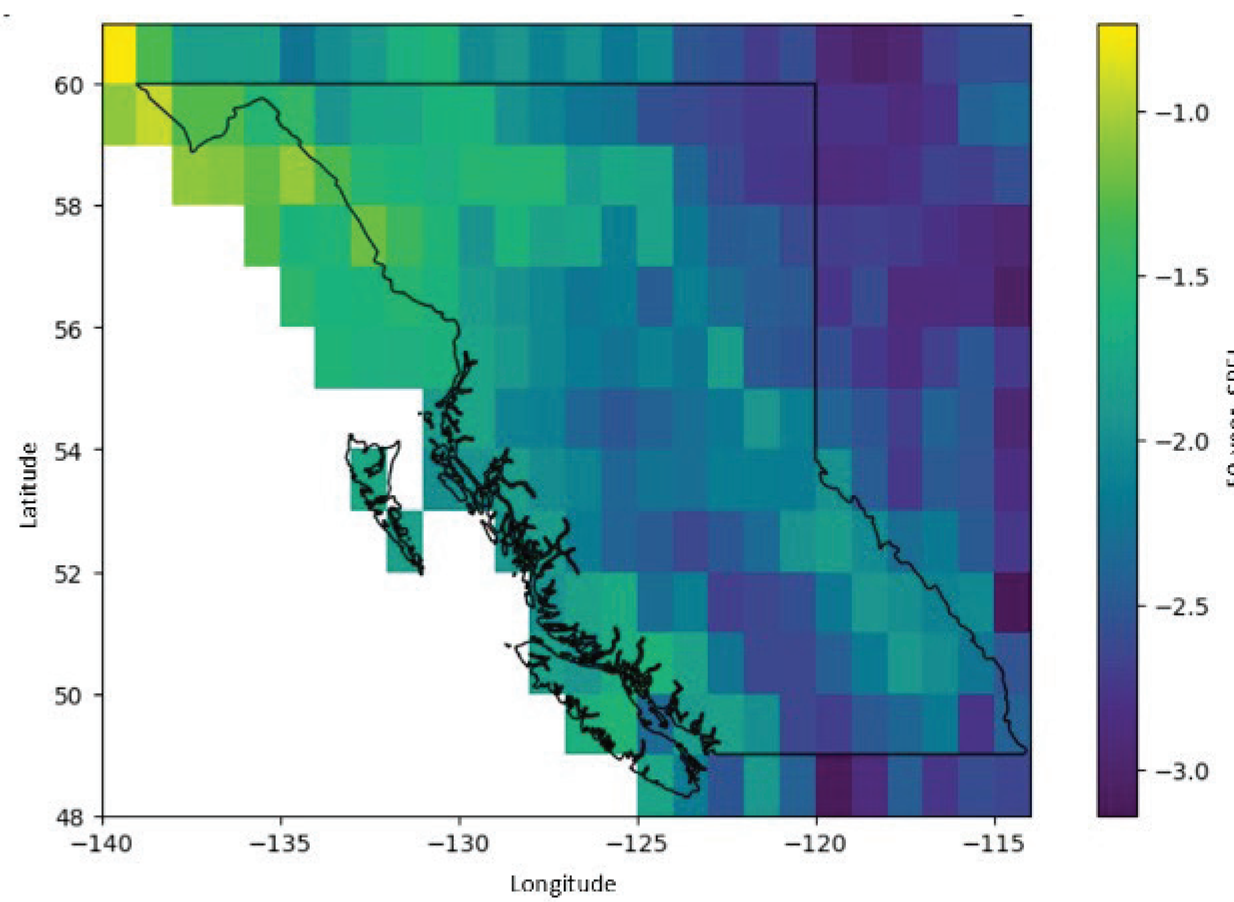
In the worldviews of First Nations, water is treated with great respect, as a relative and a living being. This perspective supports reciprocal use of water systems through multi-generational care. This is distinct from Western relationships to water which often centre water as a commodity—that can be bought, sold and owned. The rights of First Nations to water and to maintain their distinctive relationships with water is upheld in the United Nations Declaration on the Rights of Indigenous Peoples and through their traditional and inherent rights. Continued work and collaboration are needed to affirm and respect these rights.

For the purpose of the Provincial DCRRA geospatial analysis, meteorological drought hazard is assessed using the Standardized Precipitation Evapotranspiration Index (SPEI). SPEI is a relative measure of surface water surplus (positive SPEI values) or deficit (negative SPEI values) with respect to a reference period (1950–2014 in the Provincial DCRRA). In the analysis, annual SPEI values, and their return periods were calculated, an SPEI threshold value of –2 was determined to represent the 1-in-50-year drought in the reference period, and areas in the future period (2041–2070) where SPEI<–2 were determined to identify areas threatened by higher levels of drought compared to that experienced in the past.

In Figure 2.5.2, the grid cells exposed to extreme drought in the future (SPEI<–2) are drier than at least 98 percent of the years in the reference period (1950–2014). The SPEI values were estimated using the median of 25 global climate models, assuming SSP5-8.5.

Additional details on the analysis of drought can be found in Appendix A.

Figure 2.5.2: B.C. Meteorological drought hazard in the changing climate. Darker grid cells will be exposed to more droughts in the future. Pacific Climate Impacts Consortium, 2025.



Past events

As described above, seasonal drought typically results from a combination of insufficient snow accumulation in winter, prolonged hot temperatures and/or low rainfall. In recent decades, snow survey and hydrometric data indicate periods of low snowpack levels and low watercourse flows in snow-dominated regions of B.C. during 1981, 2001, 2003, 2005, 2015 and 2023. Even for normal snowpacks, indices of precipitation and snowpack might fail to capture intricate snow dynamics, such as rapid snowmelt, which can result in low river flows during the dry season. The development and persistence of past droughts in North America have also been linked to patterns of large-scale climate and ocean surface temperature variability, like the El Niño–Southern Oscillation and Pacific Decadal Oscillation, which exert some influence on the underlying climate variables during 1981, 2001, 2003, 2005, 2015 and 2023.

For a longer-term perspective, researchers have used dendrochronology—a study of annual growth rings in tree stems—to identify periods of drought prior to meteorological instrumentation in B.C. Researchers reported that there have been 12 multi-year fall-winter droughts in southwestern B.C. since 1719 that ranged from two to five years.[149] Most of these snow droughts occurred prior to 1914. In addition, other dendrochronology studies in the interior[150] and coast[151] reported that droughts were more frequent and severe prior to the 20th century. Since 1930, there have been three two-year droughts in southwestern B.C.: 1934–1935, 1941–1942 and 1980–1981.

The year 2023 was a year of extreme drought in B.C. By August, 75 percent of B.C.'s watersheds were in drought level 4 or 5. Many watercourses and aquifers were at the lowest levels ever recorded. The drought resulted in water restrictions in a range of locations across the province. To protect the fish population, some water users—including those using water for industrial purposes and irrigating forage crops—were ordered to cease diversions.[152] Some farmers reported reduced crop yields or had to sell their livestock early or initiate proactive culls. The low flows in the river reduced electricity production, forcing BC Hydro to purchase power from sources outside the province.[153] Low river flows affected salmon migration and caused salmon mortality.[154] In September 2023, the Village of McBride issued a Declaration of State of Local Emergency due to drought impacts on the McBride Community Drinking Water System and the threat to adequate water for drinking, sanitary service and fire protection.[155] Many other communities across the province escalated their water restriction levels as water became scarce.

Climate change influence

While natural climate variability can lead to large variations in year-to-year water availability, there are signs that climate change may already be contributing to drought and water scarcity in B.C.

Reduced snowpack and snow cover duration have been observed in many regions of the province,[156] presumably in response to warming winter temperatures. Permanent or seasonal snowpacks serve as critical reservoirs for the province's water supply during dry summer months. A reduced snowpack limits the natural recharge of rivers, lakes and groundwater sources, which can lead to drought. In recent decades, reduced summer streamflow has been observed at major outlets of snow-dominated basins, like the Fraser River and Peace River, as well as hybrid basins (for example, Campbell River).[157]

Looking to the future, climate models project an increase in precipitation in most of B.C. in all seasons but summer. However, this is not the whole story, as the timing and form of precipitation (dictated by local temperature) are critical. In the colder seasons, increased temperatures due to global warming cause more precipitation to fall in the form of rain, which often runs off and cannot be stored. Additionally, higher temperatures increase evaporation rates, further reducing water availability in the warm seasons. Climate model projections indicate that in summer and especially in fall, under both medium- and high-emissions scenarios, conditions are expected to become steadily drier in southern B.C. in the coming decades.[158] Recent studies suggest that summer increases in temperature and decreases in rain are drivers of low streamflow in summer and fall in rain-dominated and hybrid basins.[159]

B.C.'s hydrological basins are nearly all snow-dominated or hybrid, and so the evolution of future drought is strongly tied to the fate of snow and glaciers. Future warming will increase the melt rates of both. In one study that classified existing snowpacks by their susceptibility to melt, a +2°C regional warming resulted in large increases (10 percent – 30 percent) in the volume of snowpack in coastal and interior basins considered to be of high melt susceptibility.[160] The maximum annual snowpack in coastal and southern B.C. basins over the 21st century is projected to decline significantly.[161] The snowpack response to global warming differs between B.C.'s northeast (Liard), central (Peace) and southern basins (Skeena, Fraser, Columbia). In the northeast, the likelihood of annual snow drought (defined as being in the bottom third of the historical norm in a given year) is essentially unchanged from the historical period up to a Global

Warming Level (GWL) of 2.5°C (High), increasing only modestly thereafter by a factor of ~1.3 at a GWL of 4.0°C (High). By contrast, in southern basins, such as the Fraser and Columbia, rising surface temperatures and reduction of water storage in snowpack (and glaciers) is projected to increase the likelihood of snow drought by a factor of around 2.5 by a GWL of 2.5°C and by a factor of around 3 by a GWL of 4.0°C. Hence, in these two basins, snow drought is expected to occur nearly every year by mid-century. In years with snow drought, summer streamflow drought conditions are more likely to develop, particularly in southern basins like Whiteman and Capilano.[162] Since water demand is higher in these more populated southern basins, this suggests a higher likelihood of water scarcity in this part of the province in future decades.

The glaciers of Western Canada, most of which are in B.C., are also at risk. A 2015 study using a glacier model driven by global climate projections found that by the end of the 21st century, the volume of glacier ice in the region is poised to shrink by 50–80 percent relative to the 2005 amount, depending on the emissions scenario. Smaller glaciers like those on Vancouver Island could disappear completely (depending on the model but irrespective of scenario) by mid-century,[163] which would impact water sources like Comox Lake that supply drinking water to 45,000 residents in Comox Valley.[164]

Longer duration drought is much more difficult to simulate, but estimates based on climate projections for southern B.C. indicate a probability of < 20 percent for a decadal drought and < 10 percent for a multi-decadal drought in the remainder of the 21st century.[165] Coming from a single research study, these estimates should be taken very cautiously. Nevertheless, it is clear that the compounded effects of climate change necessitate robust water management strategies and adaptive measures to mitigate the risks associated with drought and ensure sustainable water resources for B.C.'s future.

More information on an associated extreme event likelihood analysis is summarized in Chapter 5.

Strengths, gaps and uncertainties in understanding drought and water scarcity risk in B.C.

Strengths

- Online portals are available for real-time data on streamflow and snowpacks[166] and data on wetlands and ecosystems at risk (iMapBC).[167]
- A drought information portal is provided by the Province and risks are communicated to the public.[168,169]
- Municipalities are updating water management plans (for example, Kamloops).[170]

- The Province has developed a province-wide drought response plan.[171]
- The First Nations Leadership Council (FNLC) is updating its 2013 BC First Nations Water Rights Strategy.
- The relationships First Nations have with water exemplify a respectful use of water.

Gaps

- The Province and others are working to address the gaps in data and analysis on drinking water systems that may be at risk of water scarcity from drought conditions.
- Groundwater levels and conditions throughout B.C. are needed to improve understanding of aquifers. More groundwater monitoring wells are needed.
- Effective water management requires a collaborative approach. Continuous improvements in co-ordination between the Province, regional districts and municipalities on water uses, data access and drought (water scarcity) risks across B.C. will enhance drought resilience in a changing climate. Small water suppliers across B.C. may be unaware of their vulnerabilities to drought conditions and climate change impacts in general. This also applies to individual water users who draw water from shallow wells or small streams.
- Ongoing drinking water advisories are in effect for First Nations across B.C. due to inadequate infrastructure and water scarcity.
- Many municipalities do not require a watershed assessment prior to community development planning. This can result in adding stress to watersheds that support community drinking water sources, and which may already be at risk for water scarcity resulting from drought conditions.
- Insufficient information exists on how areas with high water demands overlap with regions with low water availability. Some of this work has been done at the federal level;[172] however, this federal data needs updating.
- Similar to monitoring electricity consumption or carbon emissions, water metering can be an effective component of enabling water managers and water users to accurately monitor and ultimately reduce water consumption and effectiveness of drought response actions (for example, in 2023, the City of Kamloops introduced strict water use measures—but inconsistency in water metering and lack of a centralized system for tracking water consumption across various sectors

limiting the ability to manage water use effectively). Water metering in areas that may have moderate or high risk of water scarcity from drought conditions may be an effective tool to better understand risk and resilience in our water systems from drought conditions.

- There are experts working within the province but, relative to other risks, there is insufficient access to scientific and technological expertise on drought impacts on groundwater hydrology and surface water hydrology and society in B.C. Private expertise is generally focused on the financial benefits of water conservation, not the social or environmental benefits.
- An understanding is needed of how much precipitation or base flow is necessary to relieve the pressure on critical water values during drought conditions. If water use restrictions are being contemplated, we need to estimate and communicate how much precipitation is likely needed to achieve minimum base flows in the system before restrictions can be lifted.

Figure 2.6.1: Duhamel Creek fire near Nelson in 2015. Adrian Wagner Studio, 2015

2.6 Wildfire

Wildfires on First Nations lands

Fires are natural- and human-caused events that can cause both social-ecological hazards and benefits to humans and all living beings. Cultural burning is a First Nations practice of maintaining and stewarding land and has been enacted by First Nations for generations. First Nations fire stewardship supports ecosystem diversity, can reduce fire risk by decreasing fuel loads and improves food security. While awareness for cultural burning and other diverse risk mitigation strategies is becoming more recognized, colonial barriers continue to exist, impeding on First Nations rights and jurisdiction to steward their lands. Today, there is a need for increased public education on prescribed burns and other risk mitigation activities. In the face of fires, First Nations communities need the capacity and equipment to provide comprehensive services, including preparedness, prevention, mitigation, response and recovery supplemented by research, planners and technical experts, particularly as almost one-third of wildfire evacuations in Canada involve Indigenous communities.

– First Nations Committee

Hazard description

Wildland fire is a frequent and necessary natural ecological disturbance in B.C., as well as in many other regions across Canada and in other countries. "Wildland fire" is either a planned and intentional cultural or prescribed fire with specific ecological, cultural or hazard reduction objectives, or an unplanned wildfire that may result in undesirable negative impacts. A wildfire that involves the combination of vegetation and human development is a wildland urban interface (WUI) fire. For the purposes of this chapter, the primary focus is on wildfires and WUI fires.

Wildfires can result from natural causes and human activities. In B.C., approximately 58 percent of wildfires are started by lightning strikes, while the remainder of wildfire ignitions result from human activities.[173] Human-caused wildfires can result from escaped burn piles, fireworks, vehicles or engines, escaped outdoor campfires, industrial activity, arson or other activities.

Changing climate conditions and historical forestry and fire management practices have significantly impacted forest health, increasing the spread of forest insects, disease and invasive species to damaging levels, resulting in increasing wildfires in size, severity and frequency across B.C. In addition, growing human population and expanded development is contributing to more frequent wildfire impacts on communities and human values (including the wildland urban interface). The combination of these factors is leading to more extreme fire events and has prompted B.C. to identify wildfire as one of the highest-ranked risks facing the province, both now and in the future.[174]

Secondary hazards

Wildfires can alter ecosystems in various ways. Depending on the location, size and intensity of the wildfire and how severe an area was burned, ecosystem alterations include changes to forest cover, ground surface conditions and hydrological processes. These changes can result in ongoing risks downslope and downstream of the area burned and can increase the chance of soil erosion, floods, rockfall, landslides, debris flows and snow avalanches—referred to as secondary hazards.[175,176]

Secondary hazards may be triggered by a subsequent weather event such as heavy rain or snowfall. These secondary events can be intensified by climate influences on the weather events. For example, soils in areas that burned at high temperatures can become "hydrophobic," meaning they repel water. During a rain event, hydrophobic soils increase runoff, which can overwhelm drainages and lead to devastating floods or mudslides.[177] This can be further intensified by "atmospheric river" rain events also influenced by climate. Forested areas burned by a wildfire can experience more snowpack during the winter due to reduced tree cover and vegetation, leading to the potential for future snow avalanches or increased spring runoff and flooding.[178]

Widespread wildfire smoke is an emerging secondary hazard. As the occurrence rate of wildfires over 10,000 ha—often caused by extreme weather events such as cold fronts—increases in B.C., wildfire smoke is being distributed to populated areas at significant distances away. In 2023, wildfire smoke was pushed by wind events across Canada and into the United States and covered much of the province, degrading air quality. Vulnerable populations in B.C. often evacuate due to smoke rather than the imminent threat of a wildfire. Exposure to wildfire smoke can cause acute adverse health impacts as well as long-term impacts and an increase in all-cause mortality.

Secondary hazards like wildfire smoke can occur concurrently with or immediately after a wildfire (days or weeks); in some cases, the threat of post-fire flooding, landslides or debris flows can last for years.[179] Further, damage resulting from the secondary hazard may be greater or more widespread than the wildfire.[180,181]

The British Columbia Post-Wildfire Natural Hazards Risk Hub serves as a central repository for educating and informing users on post-wildfire hazards across the province. The hub includes a dashboard with reports conducted within B.C., guidance on post-wildfire hazard analysis and other materials.[182]

Hazard distribution

Since before humans arrived, wildfires have been an influence, in varying intensity, on the evolution of most of the forested lands and natural ecosystems of B.C. For at least 14,000 years (since the last ice age), Indigenous Peoples who inhabited the land within the border of what is now the Province of B.C. also used fire as an essential tool for hunting, cooking, warmth, managing habitat, growing medicinal plants, cultural uses and more.[183]

Over the last few centuries, expanding development patterns, changes to land use and resource management, and increased human activities have contributed to where wildfires occur, how they are managed and their potential impacts. Beginning in the late 1800s, wildfire ignition patterns and the use of fire in B.C. shifted following the first European settlements. The displacement of Indigenous Peoples from their traditional territories also removed their ability to manage the land based on traditional ecological knowledge and cultural burning practices.

Today, wildfire is a hazard that can impact all reaches of B.C., from the southwest coast to all borders. The province experiences an average of 1,530 wildfires each year,[184] although this can fluctuate significantly depending on the year. For example, more than 2,000 wildfires were reported in 2018, while there were fewer than 900 wildfires the following year. During the 2012–2022 period, 58 percent of wildfires occurred from lightning strikes and 42 percent were human caused.[185]

Wildfires can vary in size. The average amount of area burned in the province between 2015 and 2024 was just below 800,000 ha per year.[186] However, specific years can look very different. For example, 135,000 ha burned in 2022, while nearly 2.9 million ha burned in 2023. The majority of wildfires remain under four hectares in size, but some wildfires can grow to hundreds of thousands of hectares.

Wildfires are not experienced uniformly across the province. Due to differences in fuel type, terrain, microclimates, human development patterns and other factors, wildfires vary in number, size, severity and impacts. In addition, wildfires can occur in a variety of natural and built environments, and ignition patterns may depend on seasonality. For example, the northern portion of the province typically sees more fire activity in the spring whereas the Southern region experiences an increase in fire activity during the mid and late summer months.

Six regional fire centres across the province (Cariboo, Coastal, Kamloops, Northwest region, Prince George and Southeast region) manage wildfires based on their delineated area.

Hazard exposure

When multiple wildfires ignite at the same time, or large wildfires require significant resources, the Province utilizes both the British Columbia Emergency Management System's "response goals" and "assessing values at risk" to determine response priorities and resource assignment to wildfires. In the context of wildfire, "values" are natural resources, areas of cultural significance and human-built improvements/developments, with measurable or intrinsic worth, that could be destroyed or otherwise altered by fire.[187] Over time, and particularly in most recent years, the impacts of wildfire have threatened many different values in nearly every area of British Columbia.

Not all wildfires result in adverse outcomes. Some wildfires have ecological benefits that maintain or restore habitats, prompt reproduction cycles in trees or bring nutrients to soil. In some cases, wildfires may be allowed to burn under certain conditions to allow for these benefits to the ecosystem. Other wildfires—including WUI fires—can have a range of negative impacts to the built and natural environments, including smoke and poor air quality;

contamination of soils and water sources; damage to properties; timber resources; natural and cultural resources; injuries or fatalities; business disruptions; mental and emotional trauma; and other social, environmental and economic impacts. Wildfire outcomes (beneficial or negative) will be influenced by the size and location of the wildfire—including if the wildfire burned through a developed area, the degree to which a wildfire altered the environment (how "hot" a wildfire burned, the type of vegetation it burned, etc.), the presence and effectiveness of response and suppression activities, and whether mitigation activities were in place before the wildfire occurred (such as fuel treatments, home and infrastructure preparedness and protection, or evacuation preparedness). Under certain conditions like drought, high temperatures, low humidity and strong winds, wildfires can exhibit extreme fire behaviour, which includes rapid spread rates, intense heat output and rapid shifts in direction, making them incredibly dangerous and hard to fight.

Wildfire risk is specifically defined by the probability of hazard, which includes the likelihood of a fire occurring and the intensity that it is expected to burn, combined with the consequence or the susceptibility of the values (impact or loss) that is expected.[188,189] The vulnerability of values is determined by the individual characteristics of each value. For example, the vulnerability of an individual house is determined by the ability of the structure's exterior materials to resist heat and ember exposure and the condition of the home's immediate surroundings (vegetation, stored materials, etc.). Critical infrastructure such as power and gas utilities, communications networks and emergency response facilities are also at risk during an interface wildfire event.

WUI fires can also be described by the level of economic impact, including property and infrastructure damage; interruptions to resource extraction, tourism sectors and agriculture and livestock industries; local business interruption losses; and post-recovery challenges (for example, loss of social infrastructure, damaged ecosystems and lost habitat).

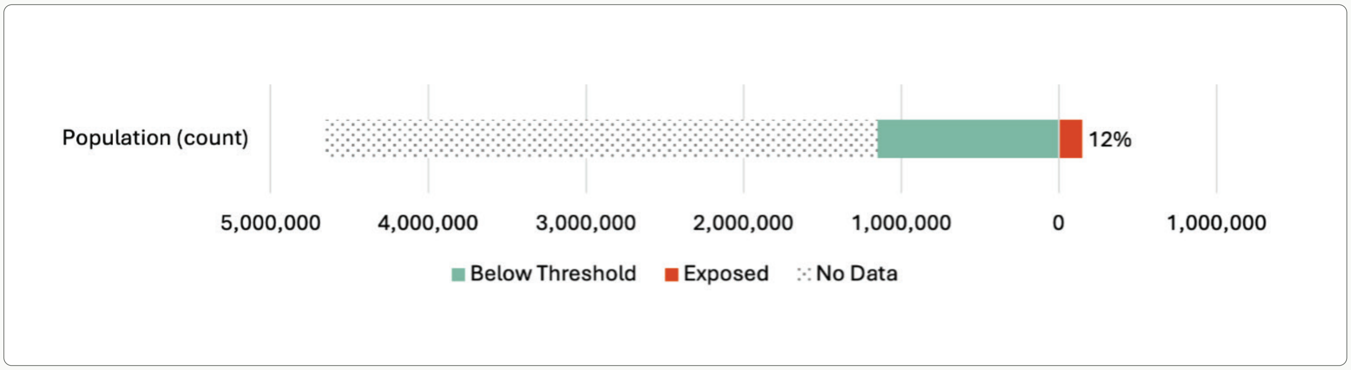
Currently, there is no consistent risk assessment product available for reference in British Columbia that quantifies the susceptibility of individual values. However, the B.C. Wildfire Service (BCWS) publishes the Provincial Strategic Threat Analysis (PSTA) that is made publicly available (online) for anyone to access, and particularly for local governments, industry and other stakeholders to use. The PSTA was developed to provide a consistently applied, province-wide process for assessment and mapping of the potential wildfire threats to values on public lands across British Columbia.[190] PSTA primary data inputs include the BC Forest Vegetation Inventory, historical wildfires greater than four hectares, the Provincial Digital Elevation Model, the BC Fuels Layer and 90th percentile fire weather. The weighted inputs of fire density (number of wildfires in a 10 km radius) (30 percent), 90th percentile head fire intensity (energy output at the head of the fire under extreme weather) (60 percent), and spotting impact (adverse outcomes of ember cast) (10 percent) were combined to determine fire threat.[191]

The 2021 updated PSTA identifies 39 million hectares (45 percent) of public land in B.C. rated as "high" or "extreme" wildfire threat, and 28 percent is rated as "moderate" wildfire threat.[192] When the coverage of these areas is combined with the locations of values, it provides a picture of what is threatened and can help with determining vulnerability of values and with decision-making for reducing the threat. PSTA maps and information are available publicly at : https://www2.gov.bc.ca/gov/content/safety/wildfire-status/prevention/fire-fuel-management/psta.

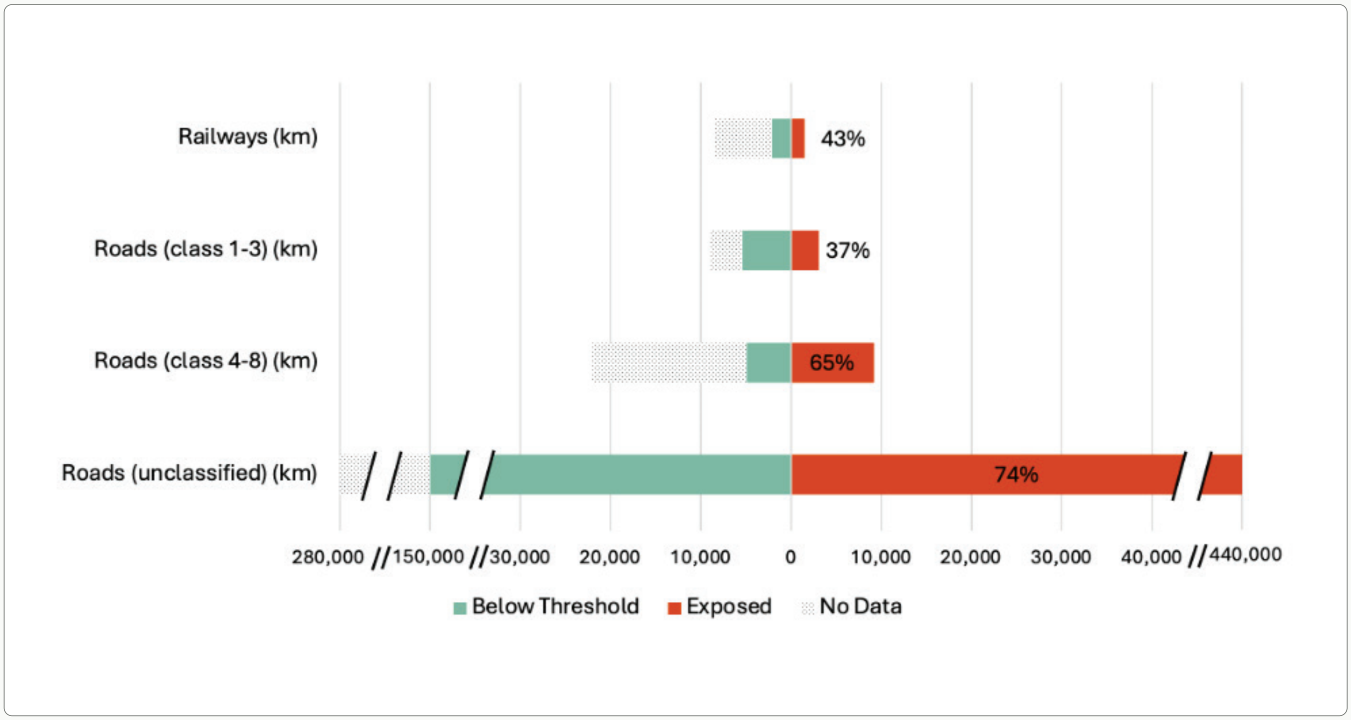
The Provincial DCRRA geospatial hazard exposure analysis identifies assets that are exposed to PSTA wildfire threat level 6 or higher. Due to gaps in data for the private lands, the Provincial DCRRA threat analysis is incomplete for understanding the exposure of people, buildings and most critical facilities to wildfire hazard. The graphs in Figure 2.6.2. show the proportion of population, assets in transportation (linear assets) and natural assets threatened by wildfire at the defined threshold. It's important to read the information in the graphs with the caveat of gaps in data for the private lands.

Land use planning in built areas historically has not recognized the hazards associated with building materials and surrounding vegetation; therefore, many communities are at high risk of wildfire impacting the community. The adoption of FireSmart principles can help to address these problems (construction and vegetation) in new home construction within identified hazard areas. In some cases, municipalities designate these hazard areas as development permit areas (DPA). It will take a sustained and long-term effort to reduce fire risk in built areas on the WUI. For many communities with an existing threat, the only option is to mitigate the fuel hazard through fuel treatments.

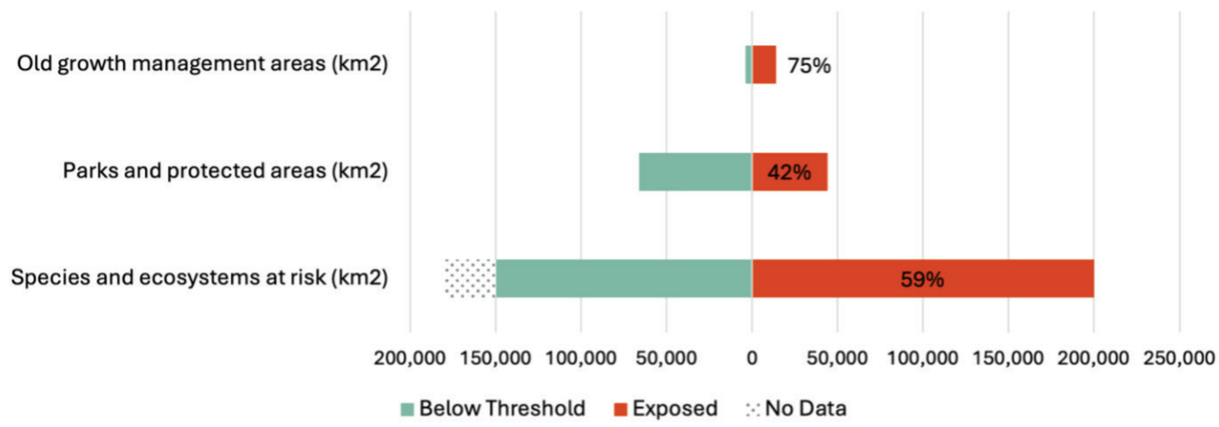
Figure 2.6.2: Graphs on assets threatened by wildfire areas where the wildfire threat rating is >= 6 (moderate threat).



Population: 12% of the population (150,000 people) are in areas classified as having a moderate or higher risk of wildfires within areas mapped by the Provincial Strategic Threat Analysis (PSTA).



Railways and roads: 43% of the railways (1,500 km), 37% of the roads class 1-3 (3,070 km), 65% of the roads class 4-8 (9,200 km), 74% of the unclassified roads (440,000 km) are in areas classified as having a moderate or higher risk of wildfires within areas mapped by the Provincial Strategic Threat Analysis (PSTA).



Old growth management areas: 75% of old growth management areas (14,000 km²) are in areas classified as having a moderate or higher risk of wildfires within areas mapped by the Provincial Strategic Threat Analysis (PSTA).

Parks and protected areas: 42% of parks and protected areas (44,000 km²) are in areas classified as having a moderate or higher risk of wildfires within areas mapped by the Provincial Strategic Threat Analysis (PSTA).

Species and ecosystems at risk: 59% of species and ecosystems at risk (220,000 km²) are in areas classified as having a moderate or higher risk of wildfires within areas mapped by the Provincial Strategic Threat Analysis (PSTA).

Past events

Past wildfire events in B.C. and their impacts can be viewed in terms of looking at both single devastating wildfire events and collectively at wildfire seasons. Understanding individual wildfire events informs how specific wildfires impact a community or affected area. Looking more broadly at a wildfire season helps inform how multiple wildfires affect populations and communities, landscapes, emergency response capabilities and resources.

For example, the 2023 wildfire season had multiple wildfires that were destructive based on size, amount of damage or both.[193] The lightning-caused Donnie Creek wildfire, which started near Fort Nelson, burned more than 600,000 ha, was B.C.'s largest wildfire in recorded history, and resulted in the shutdown of many natural gas operations. However, due to the northern location and low population density, the fire resulted in a very low number of structures impacted. Later that summer, the McDougall Creek wildfire started near West Kelowna. Although this wildfire burned a much smaller area (13,970 ha),[194] it had a significant impact due to its location in a highly developed area. Impacts included the evacuation of residents in West Kelowna and the neighbouring communities of Westbank First Nation, almost 200 homes that were damaged or destroyed, and long-term displacement of residents.[195] While these two wildfires illustrate individual differences across events, the entire 2023 wildfire season collectively resulted in more than 2.84 million hectares of forest and land burned; tens of thousands of people evacuated from their homes; hundreds of homes and structures destroyed or damaged; impacts to cultural values, ecological values and infrastructure; and long-term consequences to the economy and people's health and wellbeing.[196]

Table 1 summarizes the past ten years of wildfire seasons in B.C. and a general overview of their impacts in terms of fire size, management costs, people evacuated, structures lost, and fatalities. It's important to note that wildfire size is not always proportional to wildfire damage or impacts (for example, large fires do not necessarily result in more structures being damaged or destroyed).

Table 2.6.1: 10-year summary of wildfires in B.C. (2015–2024) – Source: B.C. Wildfire Service.

	Total fires	Total hectares	Total fires in the WUI	Fire management costs	People evacuated	Structures destroyed	Fatalities
2015	1,859	280,737	583	$277.1M	2,745	N/A	1 responder
2016	1,057	100,366	485	$129.1M	2,023	N/A	0
2017	1,350	1,216,053	472	$649.5M	65,000	502	0
2018	2,112	1,355,715	562	$571.9M	6,000	158	0
2019	828	21,138	392	$182.5M	<10	N/A	0
2020	670	14,536	333	$193.7M	N/A	N/A	0
2021	1,647	869,300	629	$718.8M	32,880	527	2 civilians
2022	1,803	135,235	556	$411.9M	1,960	8	0
2023	2,294	2,896,220	679	$1,094.8M	48,900	1,118	6 responders
2024	1,684	1,073,548	464	$621M	7,480	120 (estimated)	0

Additional information on wildfire season summaries including past wildfire events, individual wildfires and their impacts are available from the B.C. Wildfire Service.

Climate change influence

As discussed throughout this chapter, the size, severity, frequency, location and behaviour of wildfires are influenced by a complex set of variables. These variables include characteristics of fuels and fire regimes, ignition sources, weather conditions and topographical features, and are influenced by other factors such as land use, forest health conditions, forest and fire management policies, and even specific response and suppression tactics. Together, these complex dynamics shape the potential impacts and long-term consequences associated with wildfire.

Two of these variables—precipitation and temperature—are changing from within historical ranges due to climate change. Although there is still considerable variation across the province due to regional differences, the individual effects of precipitation and temperature, and the interaction between these two variables, can affect wildfires in B.C.[i] For example, heightened winter and spring precipitation promotes vegetation growth that can result in an abundance of flammable vegetation available to wildfires.[197] Prolonged periods of drought in many areas have significantly influenced the long-term soil moisture content and subsequent live vegetation moisture conditions. While warm-season extreme heat days combined with low relative humidity, low or absent precipitation results in low moisture content in organic soil layers, and dead plant material increases the potential for high fire danger in naturally vegetated areas (as measured by the Canadian Forest Fire Weather Index System).[ii] Other changes in precipitation and temperature can contribute to longer periods of wildfire activity ("fire seasons") due to low snowpacks, earlier snowmelt and warmer, drier spring and fall conditions.[198]

Multiple studies have directly attributed the increase in extreme wildfire events and seasons experienced in B.C. over the past decade to climate change. A study of the extreme conditions during the summer of 2017, during which an area of 1.2 million hectares burned in B.C., attributed the high fire weather and fire behaviour metrics to climate change and concluded that these conditions increased the area burned by a factor of 7–11.[199] The heat dome that occurred in 2021 over southern B.C. and the Pacific Northwest of the United States was found to have a pronounced effect on that summer's fire season, including the Lytton fire,

i. Appendix A, Hazard Exposure Geospatial Analysis – Methodology Report.

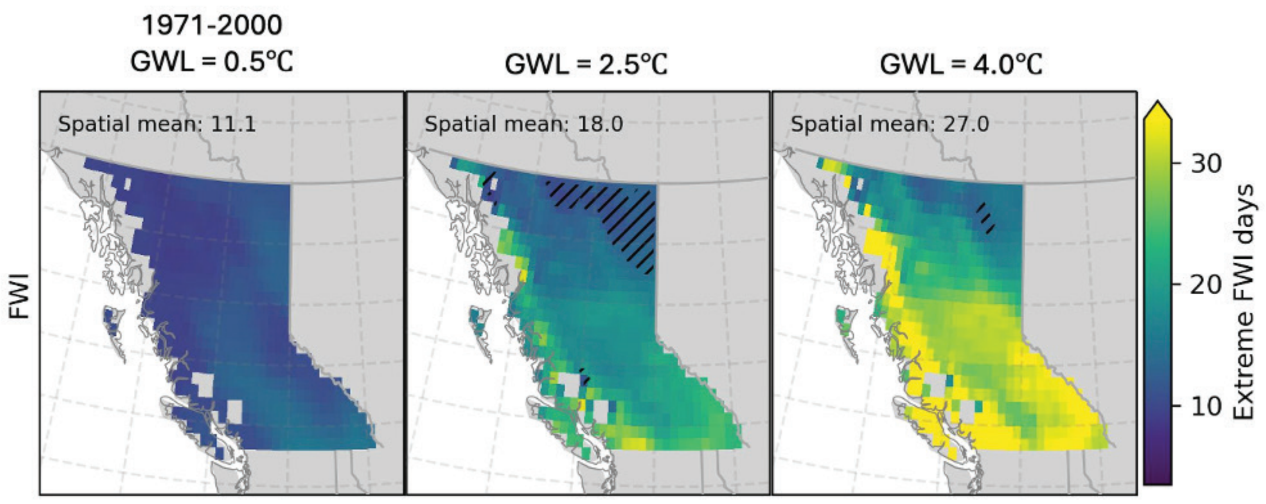
ii. Appendix B, BC Climate Change Overview.

due to conditions that enabled extreme fire behaviour (for example, frequent episodes of night-time burning, large pyro-cumulonimbus formations) and over fifty thousand cloud-to-ground lightning strikes.[200] Another study by Parisien et al. analyzed the potential effect of climatic moisture deficit (CMD), referred to as the sum of monthly evaporation minus precipitation, and the trends exhibited during the extreme wildfire seasons of 2017, 2018, 2021 and 2023.[201] This study found that the drying trend in recent decades (which has reversed from prior decades) may indicate that evaporative demand driven by increased warming has surpassed the effects of increased precipitation on moisture and may explain the dramatic increase in B.C. wildfire activity during those years.

Research indicates that climate change will continue to result in larger and more intense wildfires in B.C. in the future.[202,203,204,205] Several studies, using projections from a variety of climate models running different emissions scenarios, suggest overall drier land surface conditions and an increase in both future Canadian Forest Fire Weather Index (FWI) and fire season length, specifically in B.C.[206,207,208] Canadian Regional Climate Model simulations were recently used to calculate historic and projected FWI during the fire season (May–September), assuming a high-emissions scenario.[209, 210]

Figure 2.6.3 shows the count of days when the FWI is extremely high (exceeding the 95th percentile of FWI in a historical reference period). The figure shows that, averaged over B.C., about 11 such days occurred in the past. The number of extreme FWI days increases to 18 at a GWL of 2.5°C (the 2050s, under a high-emissions scenario; the 2080s, under a moderate scenario) and to 27 days at a GWL of 4.0°C (the 2080s, under high emissions). That is, according to these model projections, extreme fire weather conditions are projected to occur about 2.5 times as often by the end of the century, compared to the 1980s. The same simulations show that under all emissions scenarios, fire season length will increase everywhere in the province in all future 30-year periods (ClimateData.ca, 2024).

Figure 2.6.3: Count of days that exceed the historical 1971–2000 average May to September 95th percentile FWI value, FWIx95, in the historical period (left), at a future GWL of 2.5°C (centre), and at a future GWL of 4.0°C (right). The GWL values are relative to the preindustrial period (for example, 1850–1900 corresponds to a GWL of 0°C). Areas overlaid with cross-hatching in the future period maps are not statistically different from baseline values in the left-hand panel. Pacific Climate Impacts Consortium, 2025.



There are some uncertainties related to how different areas will be affected by wildfires due to: natural climate variability in regional ecosystems across the province[i]; climate models related to hydroclimate processes that may not accurately account for the link between climatic moisture deficit and wildfires[211]; and different greenhouse gas emissions scenarios.

Additional information on the influence of climate change on wildfire is included in Appendix B: B.C. Provincial Climate Overview, and the conclusions of an associated extreme event likelihood analysis are summarized in Chapter 5.

Strengths, gaps and uncertainties in understanding wildfire risk in B.C.

As noted throughout this chapter, wildfire hazard is unique in many respects from other hazards. Wildfires can occur simultaneously across multiple regions, their duration and intensity depend on many factors, and some of their impacts (such as smoke) can have broad effects on large areas of the population—even those outside of the immediate area of the hazard. Understanding strengths, gaps and uncertainties helps provincial and local agencies and communities to better plan and prepare for wildfires.

i. Appendix B, BC Climate Change Overview.

Strengths

- The PSTA provides a consistently applied process of threat assessment for public lands across the province and is available for public use
- The Community Resiliency Investment (CRI) program's investments at the provincial and local levels—including the FireSmart program, local government Community Wildfire Resiliency Plan development, fuel treatments and local government wildfire response training and readiness—help communities to prepare for the wildfire to increase the effectiveness of FireSmart activities
- The Wildfire Risk Reduction (WRR) funding program invests in strategic fuel treatments on provincial Crown lands and areas surrounding mountain resort communities
- Incorporation of Indigenous Traditional Ecological Knowledge into the management of ecosystems contributes to the increased long-term resiliency of the landscape
- Continued effectiveness of initial attack response, with a target of suppressing 94 percent of wildfires at four hectares or less, effectively reduces the total number of fires burning on the landscape
- Increased capacity and effectiveness of structure protection and structure defence response provides an additional response strategy
- Advances in tools and technology increase effectiveness in preparedness, response, and public information and public awareness (early detection, drones, mobile app, dashboard, etc.)

Gaps

- The BCWS Provincial Strategic Threat Assessment does not include private land
- The fuel (vegetation) inventory in many areas of the British Columbia landscape is not up to date, providing an inaccurate representation of the fuel conditions for wildfire behaviour modelling
- The Canadian Forest Fire Danger Rating System (CFFDRS) Fire Behaviour Prediction (FBP) fuel models do not accurately align with many of the corresponding Biogeoclimatic Ecosystem Classifications that are represented within British Columbia
- The knowledge of changing climatic conditions is not represented in the current CFFDRS models for predicting future wildfire conditions and effects with certainty
- There is a shortage in the expertise and capacity of workforce for wildfire research, preparedness, mitigation, response and recovery

- First Nations communities remain as some of the most threatened communities in British Columbia
- Necessary landscape-level fire management initiatives have been difficult to undertake due to the complexities of competing interests on the landscape
- Uptake of wildfire mitigation actions by individual residents and private landowners has been limited

Pop-up camp for kids impacted by the 2021 White Rock Lake fire

In the summer of 2021, Boys and Girls Club Okanagan partnered with United Way to provide a pop-up recreation program for children of families evacuated by the White Rock Lake Fire. The evacuation impacted members of the Okanagan Indian Band and residents on the west side of the lake in Vernon.

Because of the fires, many children had been stuck in hotel rooms for days on end—unable to play outside, due to poor air quality, or to access to indoor opportunities, due to unaffordability. Parents were faced with a high-stress situation, trying to call insurance companies and access resources, while keeping their children happy and occupied.

BGC's pop-up recreation program provided children with a safe and friendly environment to have fun, make friends and receive the help of supportive adults. The program was held at the BGC gym, adjacent to the Emergency Support Services (ESS) reception, so evacuees could drop their children off while receiving ESS support. The program was intentionally low-barrier—it didn't require any pre-registration or sign-up, provided breakfast and lunch, and was free to attend.

The program allowed children to play sports and games, make crafts, have glow stick parties, be taken on local walks, go rock wall climbing, watch movies and much more.

The staff at BGC witnessed many signs of the trauma and stress that children had experienced. A child referred by a local social worker had been struggling and couldn't leave his mom's side. Before long, the staff at BGC helped the child make friends with other children, allowing his mom to go and access ESS supports. Another family was new to the area and had been evacuated from their home after two weeks. The program helped turn a stressful and chaotic introduction into a new community into a safe, supportive and fun experience.

– Adapted from "2021 United for BC Wildfire Recovery Fund Report," with permission from United Way BC

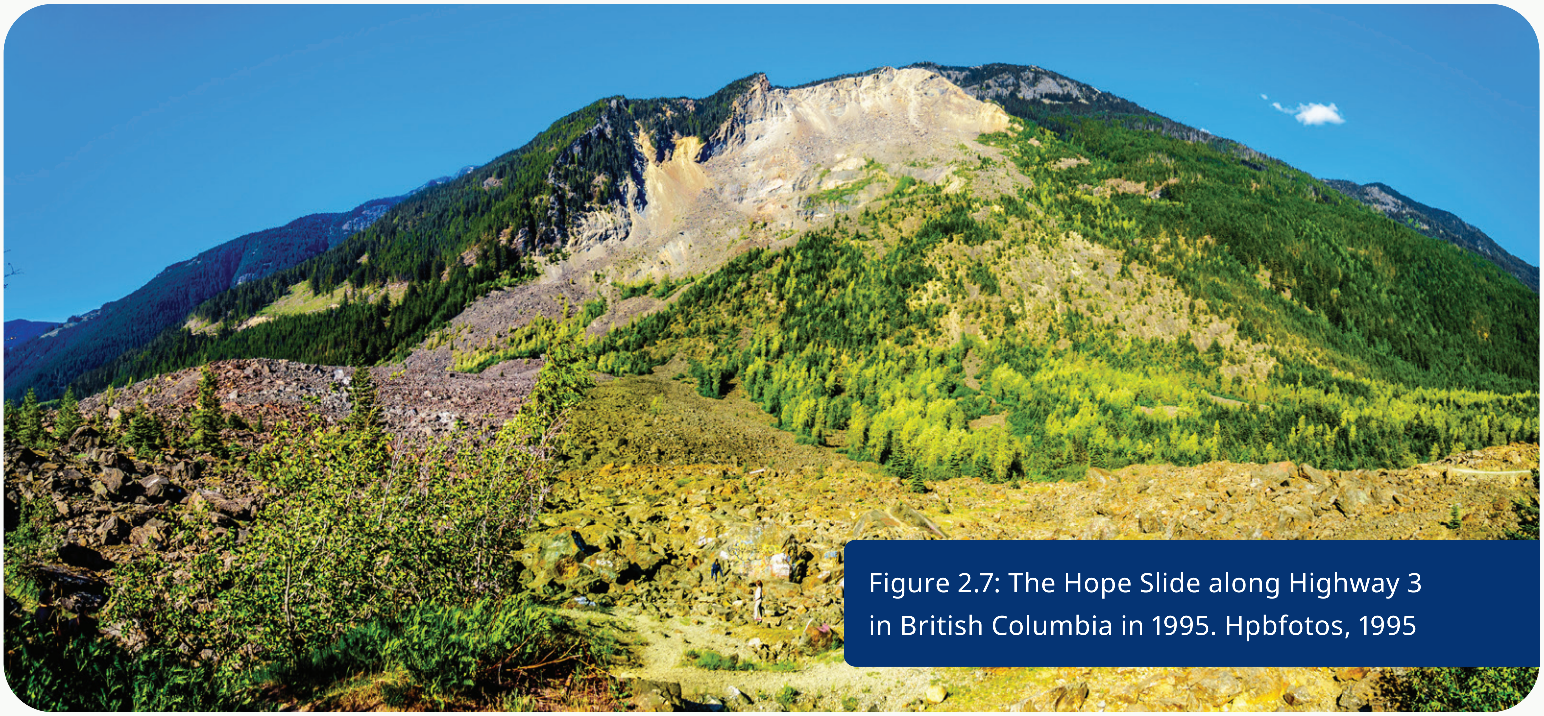


Figure 2.7: The Hope Slide along Highway 3 in British Columbia in 1995. Hpbfotos, 1995

2.7 Earthquakes

Hazard description

Earthquakes are the intense and sometimes damaging shaking of Earth's surface, as a result of fault rupture and stress release within the ground. The active plate boundary in western B.C. has generated some of the world's largest earthquakes. Although less frequent than some of the other hazards, a single magnitude 9 (M9) earthquake has the potential for human and economic losses that exceed the combined losses from all disasters experienced in B.C. over the past 200 years.[212]

Earthquakes on First Nations lands and waters

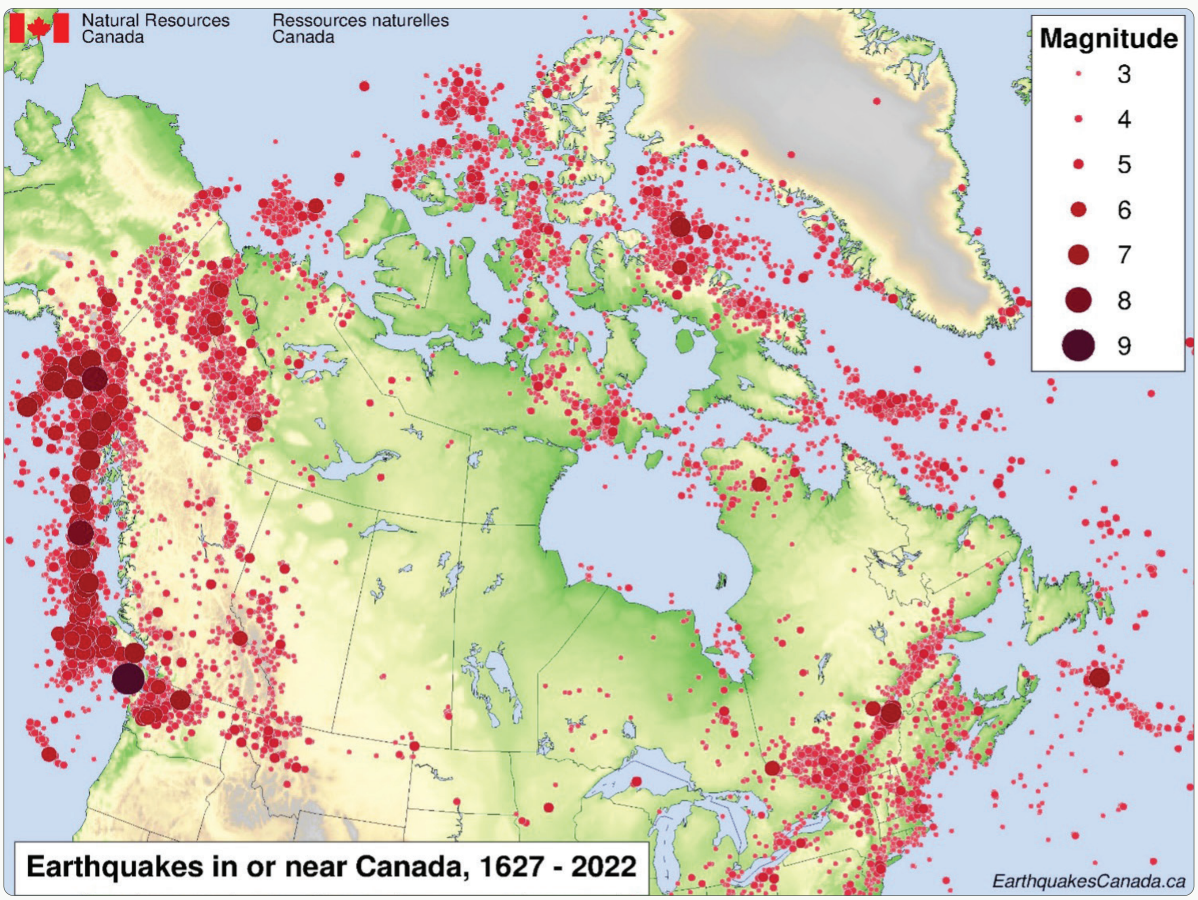
First Nations Knowledge and stories tell the history of earthquakes and are a potential source to inform risk and resilience. More education on earthquakes and alerts is needed in B.C. There are many different types of earthquakes that can occur, with varying degrees of impacts to the environment and infrastructure. Immense damage can occur from earthquakes and also from after-effects such as fires and tsunamis. Most earthquakes are a natural occurrence but can also result from human activities such as fracking.

– First Nations Committee

Seismic hazard is a function of the rate of earthquake activity, the size of earthquakes that can happen in a region (subduction zones usually generate larger magnitude earthquakes than other seismic sources), distance to the earthquake's rupture zone including depth of the earthquake (the strength of the seismic waves decay by distance), and the geologic conditions at the site where the shaking is observed (generally, soft sediments shake harder than stiff rock).

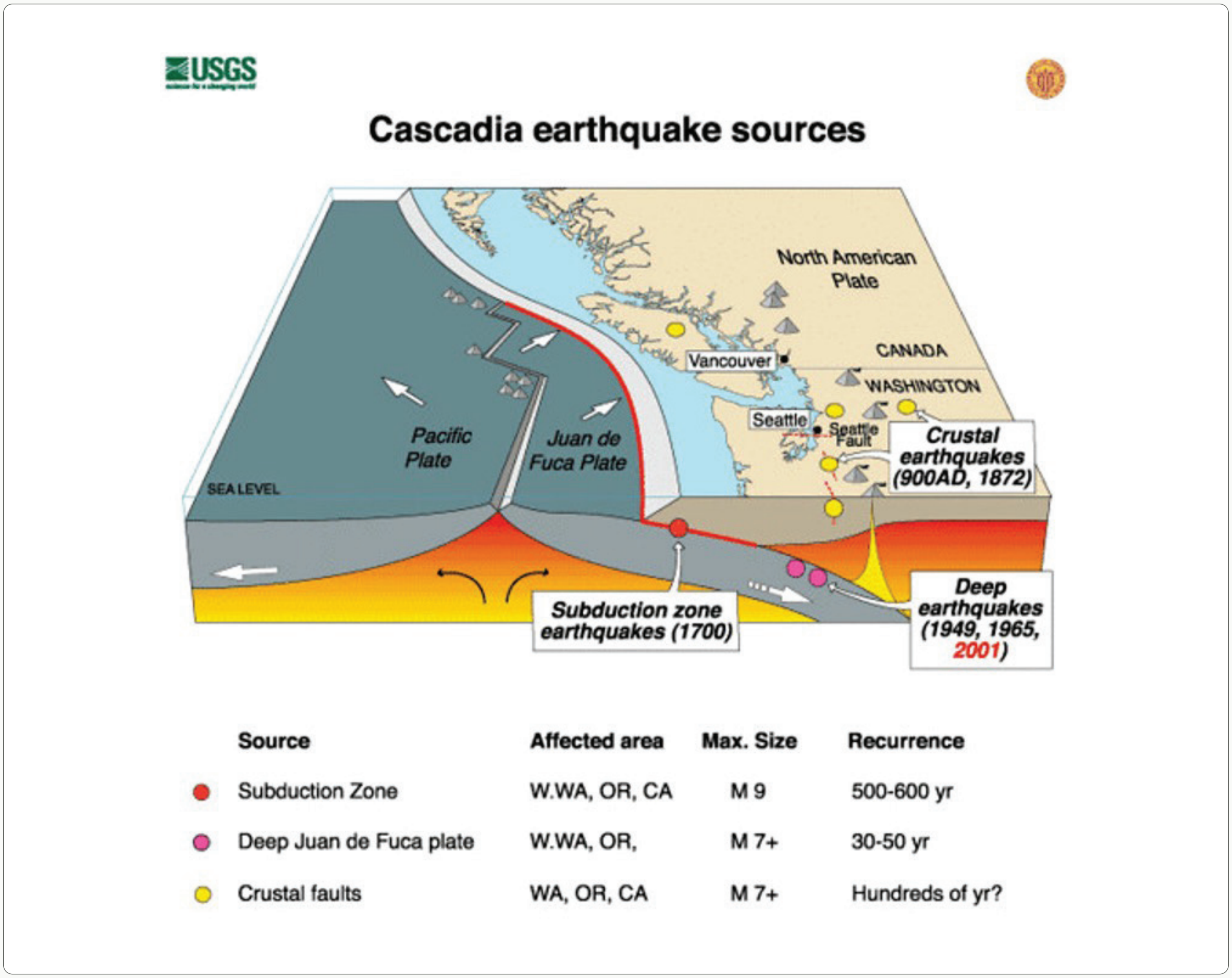
Seismic hazard is highest in western B.C. and generally decreases towards the east (Figure 2.7.1). Western B.C. is situated along an active tectonic plate boundary. In the south, the oceanic Juan de Fuca Plate (Cascadia Subduction Zone) and smaller Explorer Plate subduct beneath the North America Plate and are capable of generating magnitude ~9.0 and ~8.5 earthquakes (M~9.0 and M~8.5), respectively. In the north, two faults offshore of Haida Gwaii are capable of generating magnitude >7.5 earthquakes: Haida Gwaii Thrust (for example, an M7.8 earthquake in 2012) and Queen Charlotte Fault (for example, an M8.1 earthquake in 1949). The active plate boundary continues to the north along the Fairweather Fault and Alaska Subduction Zone.

Figure 2.7.1: Known seismic activity in Canada since 1627. Natural Resources Canada, 2023.



In this tectonic setting (Figure 2.7.2), several thousand earthquakes are recorded in B.C. annually, of which approximately 50 are felt. Southwest B.C., the most populated region of the province, is located in the Cascadia Subduction Zone, which can create three different types of earthquakes: shallow crustal earthquakes (for example, the 1946 M7.3 Vancouver Island earthquake), deeper in-slab earthquakes (for example, the 2001 M6.8 Nisqually earthquake) and megathrust earthquakes at the subduction interface (for example, the 1700 M9.0 Cascadia earthquake). Earthquake activity rates are lower in eastern B.C., but a major earthquake is possible anywhere in the province (for example, the 1918 M6.0 Valemount earthquake in the southern Rocky Mountains and the 1872 M7+ Entiat earthquake east of Seattle).

Figure 2.7.2: Three types of earthquakes that can affect southwestern B.C. US Geological Survey, 2011.



When a fault ruptures, seismic waves propagate through the earth, causing the ground to shake. The amplitude (intensity), vibration frequency and duration of the shaking vary from place to place, depending on the distance to the earthquake rupture and the ground conditions under the site. Generally, softer sediments amplify the ground-shaking effects, which is why earthquake damage is often amplified in river deltas, areas of human-made fill, and soft-sediment basins (such as the Fraser River Delta and False Creek in the Lower Mainland). These types of areas were delineated with microzonation studies in the two largest metropolitan areas of B.C.: Vancouver[213] and Victoria.[214]

Hydraulic fracturing, also known as "fracking"—the injection of pressurized liquids to fracture rock in the development of oil and gas wells—has caused induced earthquakes in northern B.C.[215] Recent studies indicate that hydraulic fracturing in a region can increase both the frequency of occurrence and the magnitude of earthquakes in that region.[216] The Montney field near Fort St. John has experienced hundreds of fracking-induced earthquakes, with the largest event reaching local magnitude 4.4. More research is needed to better quantify whether hydraulic fracturing can trigger larger, more damaging earthquakes.[217, 218]

Earthquake shaking causes buildings and infrastructure to vibrate, potentially causing damage or collapse. Damage is particularly severe to structures that have been built prior to seismic design codes; in particular, these are unreinforced masonry buildings, concrete structures built prior to the 1990s, and wood buildings constructed prior to the 1970s. Intense ground shaking can last from seconds (shallow crustal earthquakes and deeper in-slab earthquakes) to minutes (megathrust earthquakes), and major earthquakes may be followed by numerous aftershocks. Aftershock sequences may last for weeks or months and can extend well beyond the rupture region of the mainshock.

Secondary hazards

Secondary hazards can include (but are not limited to) landslides, liquefaction, tsunamis, floods and urban fires. In addition, aftershocks, particularly from shallow crustal and megathrust earthquakes, are of concern as they exacerbate the impacts to already damaged buildings and impede (and potentially reset or restart) the response and recovery efforts.

Damage to critical infrastructure causes disruption of essential services (transportation, water, power, communication, etc.) and has significant adverse impacts on lives, social structures, the economy and the environment.

Disruption of the transportation network impedes search and rescue efforts needed immediately after an earthquake, as well as movement of emergency supplies, rapid damage assessments, cleanup of debris and recovery efforts.

Earthquakes often cause cascading impacts and hazards. For example, damage to industrial facilities from earthquake shaking can lead to the release of chemical substances into built and natural environments. Impact from tsunamis triggered by earthquakes can surpass the shaking impact in coastal communities. And with the increase in intensity and frequency of hydro-meteorological events (such as floods, wildfires and extreme heat), there is a greater likelihood that a damaging seismic event will occur during a climate-related emergency which will intensify the impact of the earthquake and require emergency response to multiple events at the same time. Remote communities with a single access route are impacted disproportionately due to the likelihood of being completely cut off and the resulting delays in recovery.

The recovery process following earthquake damage can be prolonged, leaving communities vulnerable to extreme weather conditions for extended periods. Rebuilding infrastructure, homes and essential services often takes months or even years, depending on the extent of destruction. During this time, residents may be forced to live in temporary shelters or damaged structures, exposing them to harsh weather elements. This prolonged exposure can lead to additional health risks, economic hardships and psychological stress. Moreover, the disruption of normal protective systems and infrastructure can exacerbate the impact of subsequent extreme weather events, creating a cycle of vulnerability that further complicates and delays full recovery.

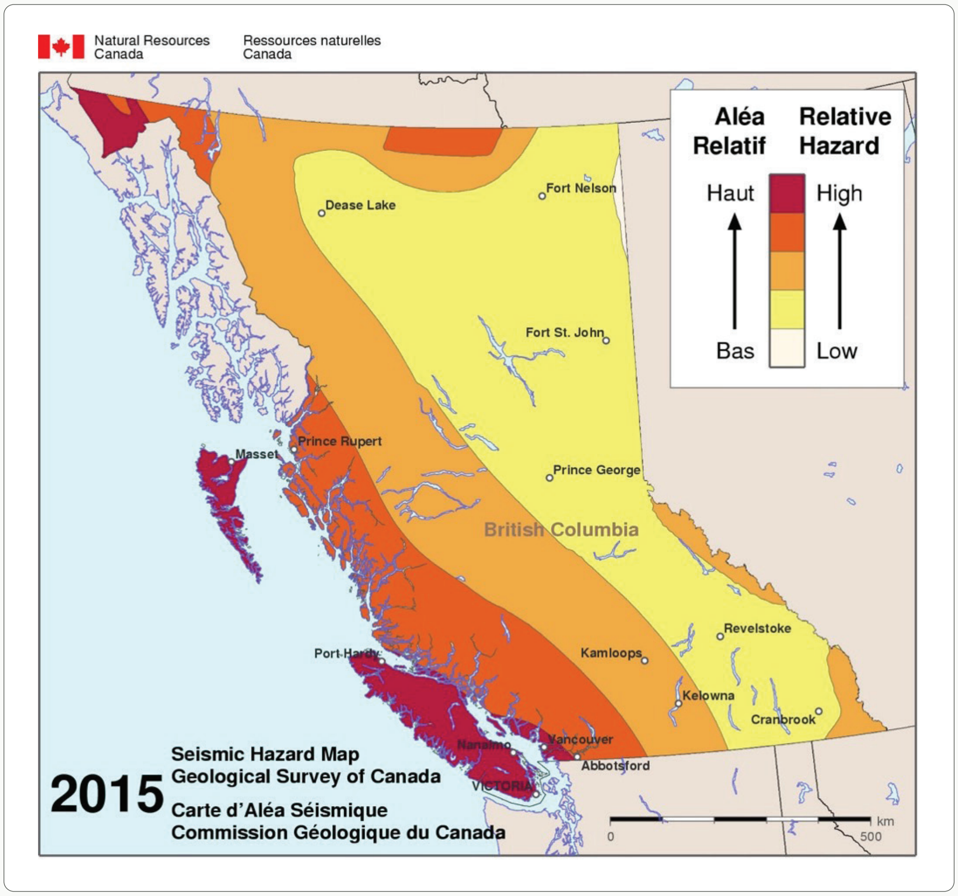
Hazard distribution

Earthquake hazard in B.C. is highest near major tectonic boundaries along the coast, where large earthquakes occur frequently, and generally lessens towards inland B.C. In addition to proximity to major tectonic features, strong ground shaking hazard is tightly correlated with ground conditions (Figure 2.7.3).

All other factors being equal, areas of soft sediments shake harder, longer and at a lower frequency of vibration, translating to a higher chance of resonance with most structures (and consequently, more damage) than stiff rock sites. All structures have natural frequencies of vibration as they oscillate back and forth. During earthquakes, if the dominant frequency of the ground shaking matches a structure’s own intrinsic natural frequency, resonance occurs. Resonance amplifies the movement of the structure, potentially causing severe structural damage. This effect varies based on structural characteristics such as material and height, the ground conditions under the structure, and the earthquake's location and size.

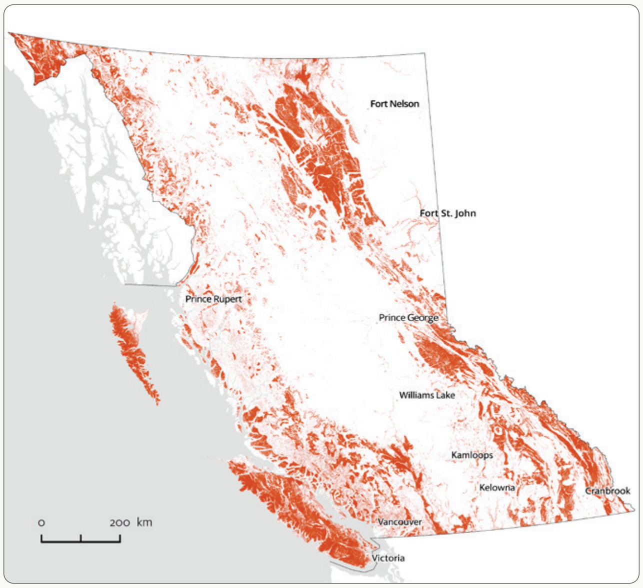
In addition, liquefiable sites (saturated loose granular soils such as sandy deposits) and areas with landslide susceptibility (relatively loose material on steep slopes) are at higher risk.

Figure 2.7.3: Simplified qualitative seismic hazard map for B.C. for uniform firm ground conditions. Natural Resources Canada, 2015.

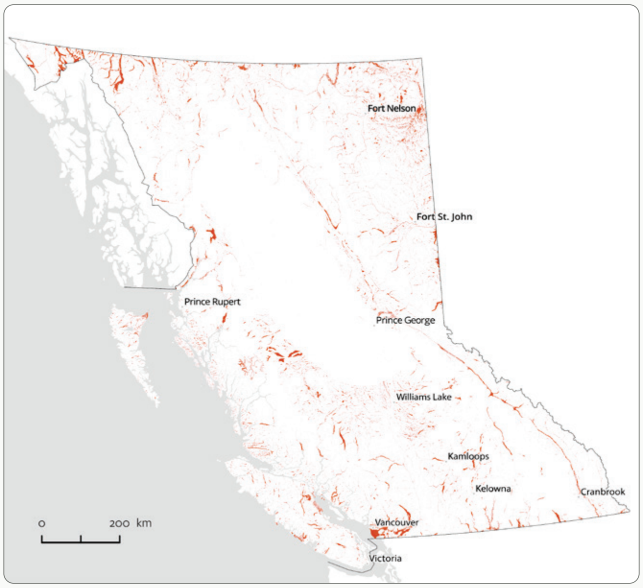


Soft sediments are found in many places: where rivers form deltas as they flow into the ocean, in areas of human-made fill, around lakes, and in other areas of recent sedimentary deposition (since the last major ice age). Landslide susceptibility is generally higher in mountainous areas with steep slopes and may be exacerbated in wet (rainy) conditions or following wildfire events that strip the ground bare. Most communities in B.C. have some parts of their urban area exposed to at least one of these conditions. See Figure 2.7.4 for the areas of B.C. with potential co-seismic landslide and liquefaction hazards (for more details, see Appendix A: Hazard Exposure Geospatial Analysis – Methodology Report).

Figure 2.7.4: Areas with potential co-seismic landslide hazards for the 2,475-year ground shaking (Map a) and areas exceeding liquefaction hazard threshold (potentially liquefiable soils with peak ground acceleration >0.09 g) for the 2,475-year ground shaking (Map b).



Map a – Seismically triggered landslide



Map b – Liquefaction

Earthquakes cause strong ground shaking and permanent ground displacement due to liquefaction, landslides and fault rupture. The most common of these is the ground shaking hazard, which can be expressed in terms of qualitative (Modified Mercalli Intensity, MMI) or quantitative (peak ground acceleration, PGA; peak ground velocity, PGV) parameters. Earthquake shaking hazard is broadly a function of the magnitude of the earthquake, distance to the earthquake, ground conditions at the site of interest, and broad tectonic characteristics of the region. It should be noted that just considering ground shaking hazard for earthquakes would lead to an incomplete analysis. It is also important to identify areas with liquefaction and landslide potential, which are integral parts of the earthquake hazard. Where known active faults exist on land, they should be identified—and the deformation zone should be mapped to assess risk due to permanent displacement induced by fault rupture.

Offshore earthquakes of certain fault types can cause tsunamis. Low-lying coastal areas are more susceptible, but all coastal communities in B.C. are exposed to this hazard to varying degrees.

Hazard exposure

Earthquake hazard poses a threat to human life through damage to buildings and infrastructure. Southwestern B.C. has a high concentration of assets, services, conditions and populations at earthquake risk, and B.C. bears the largest burden in Canada with estimated total economic losses from a magnitude 9 Cascadia earthquake valued at about $128 billion and 43,700 jobs lost over the 10 years following the earthquake.[219]

In general, older buildings that were constructed before significant earthquake provisions were put in place in building codes (generally pre-1990) are expected to fare worse. Among these, certain types of buildings, such as unreinforced masonry, will suffer the most amount of damage, but serious damage to concrete high-rise buildings also poses a significant threat as these buildings typically have a high occupancy rate. The 2011 Christchurch, New Zealand, earthquake caused two such non-ductile concrete buildings to collapse, accounting for more than 90 percent of the deaths from that earthquake. Other past earthquakes, such as the 1989 Loma Prieta and 1994 Northridge, both in California, have highlighted how vulnerable to collapse or partial collapse buildings are if they have a soft storey (a common example of this is tuck-under parking in some multi-family wooden apartment buildings). These examples are drawn from jurisdictions with similar construction practices to B.C.

In B.C., the building code's performance goal for most buildings is "life safety" through "collapse prevention," with the exception of higher importance buildings (such as schools, hospitals, fire stations, etc.), from which a better performance ("immediate occupancy") is expected. This means that any level of damage short of collapse can be expected in ordinary buildings, even in buildings that are built to the latest building code. Older buildings have progressively less seismic resistance capacity. This translates to a large number of buildings that will need to be assessed for safe use after a major earthquake in B.C. This is particularly important as large numbers of people will have to be sheltered until their buildings can be assessed to be safe for re-entry and occupation.

Currently, there are no "mandatory retrofit" requirements for older buildings in B.C. Existing buildings are required to consider seismic retrofitting only in the case of major alterations to the building.

Damage to infrastructure after a major earthquake poses additional challenges for recovery. Disruption to transportation networks will be caused both by damage to transportation structures (roads, bridges, railways, ports, airports, etc.) and by debris from damage to other structures (buildings, power poles and lines, etc.) that is blocking roads. Canadian Highway Bridge Design Code (CHBDC) adopts performance-based seismic design principles for bridge design. Bridges are designed to different performance levels (immediate service/ minimal damage, limited service/ repairable damage, or service disruption/ extensive damage) depending on the importance categories (Lifeline, Major-route or Other) and the probability of seismic ground motion exceedance.

If the transportation networks cannot be reopened quickly, all recovery efforts will be hampered (search and rescue as well as restoration of utilities such as power, communication, water, wastewater, heating and fuel distribution). B.C.'s largest airport is on liquefiable ground, and all coastal ports are susceptible to tsunami damage; therefore, the restoration of land transportation routes will be a high priority. Some communities with only a single point of access will be cut off from assistance until their access route is opened to traffic.

The massive amount of debris generated in a large, damaging earthquake will require designated dump sites, vehicles to get them to those sites, and machinery to tear down buildings that are not possible to repair. After the initial phases of recovery, these materials will have to be disposed of carefully and recycled where possible. Damage to older buildings will expose asbestos, requiring caution during the cleanup of debris from these buildings. The implications of asbestos release in terms of public health also need to be considered.

B.C.'s dike infrastructure is aged and many of the dikes have little or no seismic design. If a major earthquake occurs during the rainy season, in addition to the earthquake damage, communities may experience major flooding at the same time.

Urban fires can be a significant portion of the earthquake losses in southwestern B.C. Depending on the damage to the natural gas system, fire department response, water system damage, weather and other conditions, the losses can range from upwards of $150 million from an M9 Cascadia Subduction Zone earthquake to more than $10 billion if an M7.3 shallow crustal earthquake happens in the Georgia Strait.[220]

About the Provincial DCRRA geospatial analysis of earthquake hazard exposure at the provincial scale

For this provincial-scale hazard exposure analysis, seismic hazards are based on 2,475-year return period ground motions (2 percent chance of exceedance in 50 years) from Canada's sixth-generation seismic hazard model.[221] The 2,475-year return period shaking intensity is used as the design earthquake for building structures adopted by the National Building Code of Canada.

Peak ground acceleration (PGA) greater than 0.09 g was used as an indicator of the hazard threshold for the "built form" (such as buildings) and anything contained by or related to the built form (such as population, critical facilities and businesses); PGA of 0.09 g roughly corresponds to a Modified Mercalli Intensity (MMI) of VI (Strong), which is the level of ground shaking expected to start causing some building damage. PGA greater than 0.28 g was used as an indicator of the hazard threshold for surface infrastructure such as roads, rail and electrical or communications utilities; PGA of 0.28 g roughly corresponds to VII (Very Strong) on the MMI scale.[222]

Peak ground velocity (PGV) values were used as an indicator of the hazard threshold for buried infrastructure for screening pipelines following earthquakes; PGV greater than 125 mm/s was used as an indicator of the hazard threshold for brittle pipe (typically segmented) such as water pipelines, and PGV greater than 250 mm/s was used as an exposure indicator for ductile pipe (arc-welded steel) such as oil and gas pipelines.

Figure 2.7.5 and Figure 2.7.6 show the spatial distribution and proportion of assets, services, conditions and populations across the province threatened by the seismic hazard thresholds used in the Provincial DCRRA geospatial analysis, which is defined as areas that are directly affected by significant ground motion and ground failure (liquefaction and landslides) caused by earthquakes. See Appendix A: Geospatial Analysis – Methodology Report for further details on the thresholds and asset data layers used in the analysis.

Figure 2.7.5: Built form improvement value (top) and population (bottom) exposed to seismic hazards across B.C. with 2% chance of exceedance in 50 years (2,475-year return period).

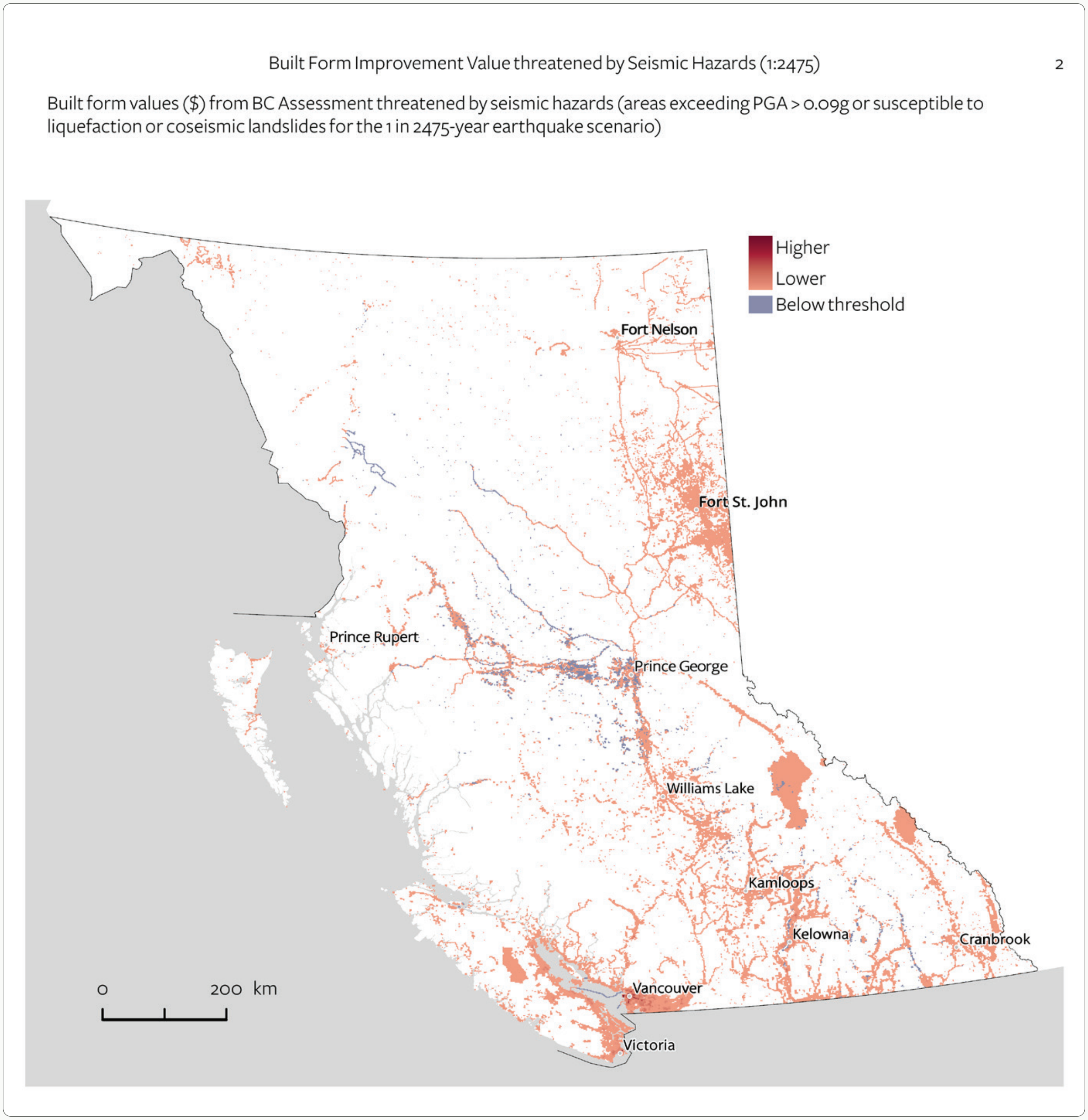
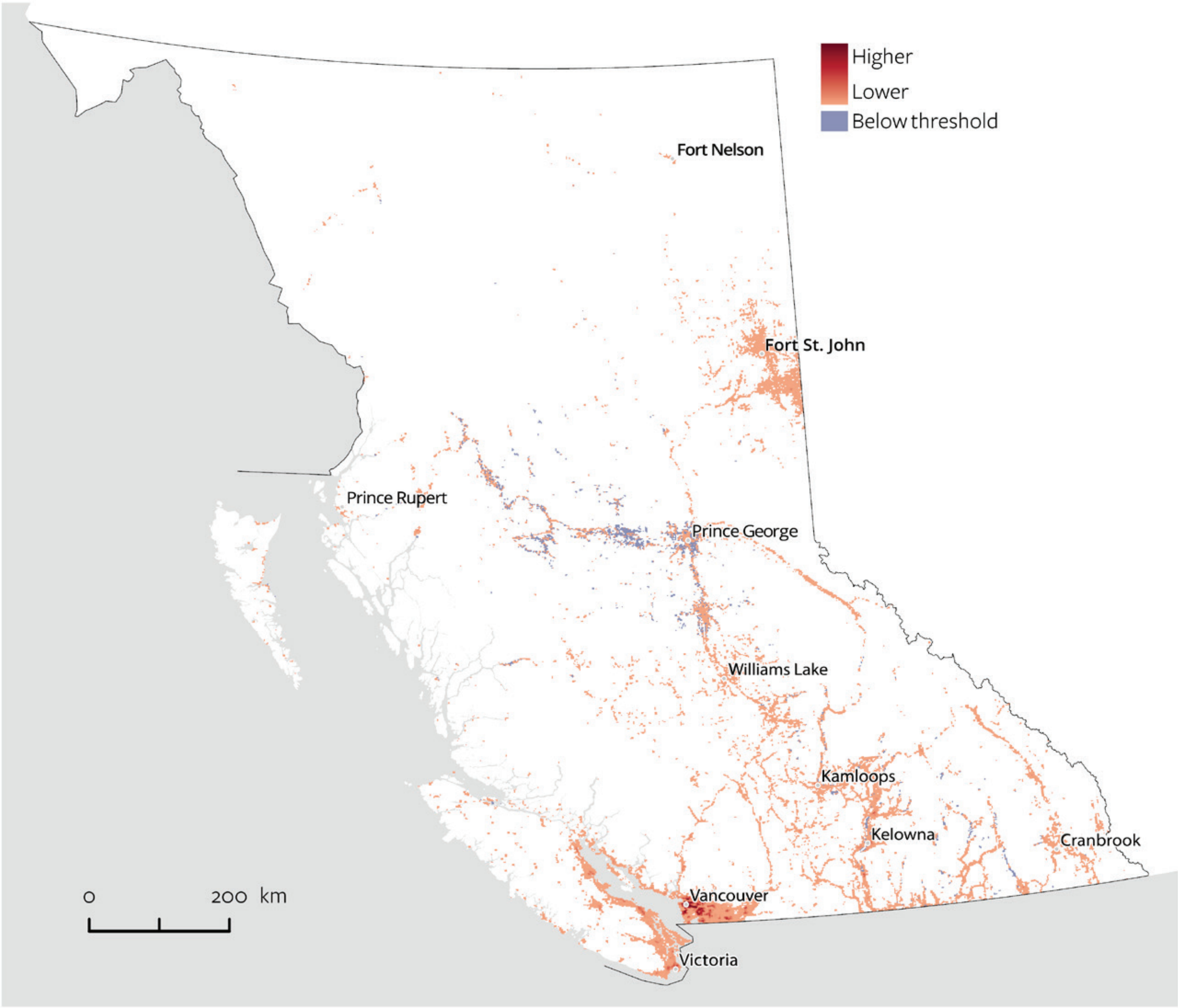
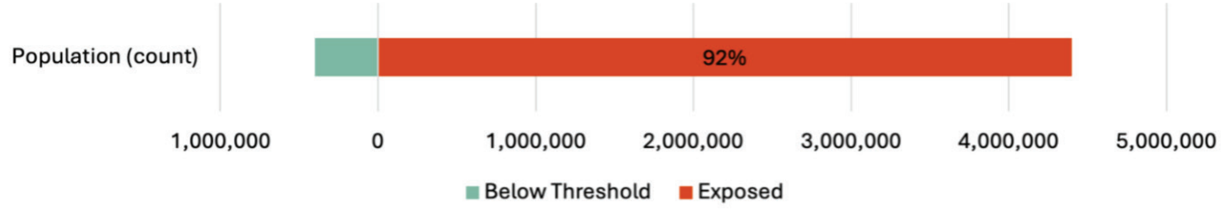
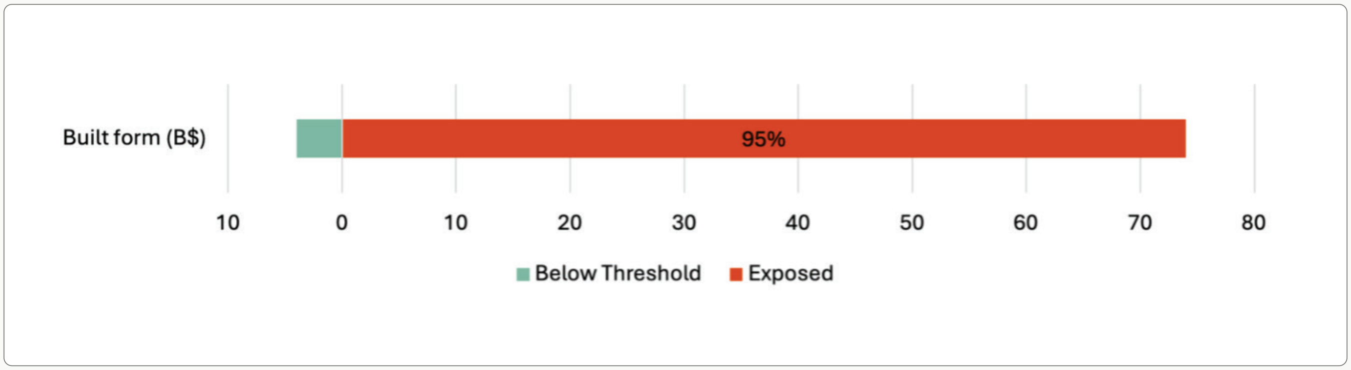


Figure 2.7.6: The proportion of assets, services, conditions and populations exposed to significant seismic risk.

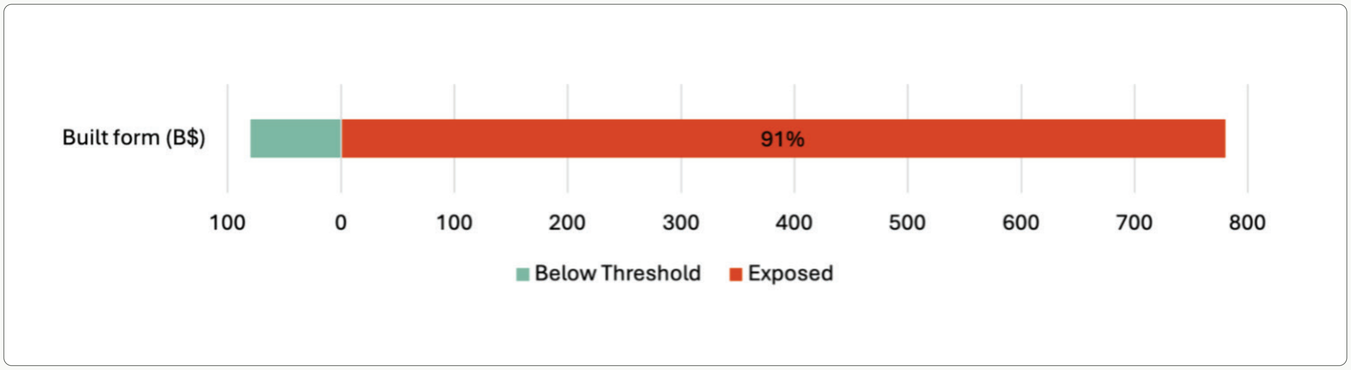




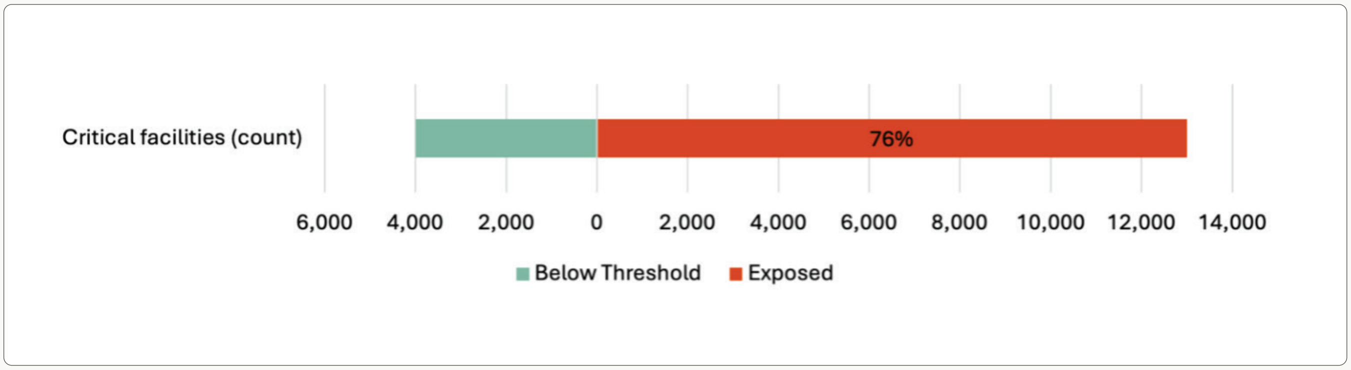
Population: 92% of the population (4,400,000 people) is within areas exposed to significant ground motion and ground failure.



Built form, replacement value: 95% of the built form in First Nations reserves ($74B) is within areas exposed to significant ground motion and ground failure.



Built form, parcel improvements assessed value: 91% of the built form (parcel improvement value) ($780B) is within areas exposed to significant ground motion and ground failure.



Critical facilities: 76% of the critical facilities (13,000) are within areas exposed to significant ground motion and ground failure.

Past events

Information on the events described below is available from NRCan's Earthquakes Canada website.[223] When considering the impacts from these earthquakes, it should be noted that many of them happened in remote areas with very little exposure, or in the past when the exposed population was much smaller.

M7.8 Haida Gwaii thrust earthquake in 2012 (crustal)

This earthquake occurred offshore of Haida Gwaii and caused strong shaking throughout the area. A tsunami alert was issued following the earthquake, and the residents of Masset, Skidegate, Sandspit and Queen Charlotte City were evacuated to higher ground. Minor shaking was also felt in Prince Rupert and in other cities of B.C.'s interior such as Prince George, Quesnel and as far away as Kamloops.

M6.8 Nisqually earthquake in 2001 (in-slab)

This earthquake occurred south of the border near Olympia, Washington. It was felt in Victoria and Vancouver. It caused damage to unreinforced masonry buildings in Olympia and Seattle. Property damage was about US$2–3 billion. The earthquake caused hundreds of injuries[224] and heavily damaged the air traffic control tower at Seattle-Tacoma International Airport. Following the earthquake, many structures in the epicentral area were closed temporarily for inspection. This included several bridges, schools, all state offices in Olympia, and Boeing's factories in the Seattle area. One bridge in downtown Olympia was heavily damaged and was later torn down and rebuilt. In Seattle, the Alaskan Way Viaduct was closed for about 24 hours for emergency repairs due to damage, disrupting transportation.

M7.9 earthquake near the Alaska–B.C. border in 1958 (crustal)

This earthquake caused a massive rockfall (over 30 million m^3) into Lituya Bay, causing a mega-tsunami that caused destruction as high as 200 m above the surface of the water, completely scouring the land of all trees and vegetation. This event happened in a remote area and five people lost their lives.[225]

M8.1 Queen Charlotte Fault earthquake in 1949 (crustal)

This is Canada's largest recorded earthquake and one of the world's largest crustal earthquakes ever recorded. Occurring on the Queen Charlotte Fault, the shaking was so severe on Haida Gwaii that cows were knocked off their feet, and a geologist with the Geological Survey of Canada working on the north end of Graham Island could not stand up. Chimneys toppled and an oil tank at Cumshewa Inlet collapsed. In Terrace, on the mainland, cars were bounced around, and standing on the street was described as “like being on the heaving deck of a ship at sea.” In Prince Rupert, windows were shattered and buildings swayed.[226]

M7.3 Central Vancouver Island earthquake in 1946 (crustal)

This is Vancouver Island’s largest recorded earthquake. This earthquake caused two deaths[227] and considerable damage on Vancouver Island and was felt as far away as Prince Rupert and Portland, Oregon. The earthquake knocked down 75 percent of the chimneys in the closest communities—Cumberland, Union Bay and Courtenay—and did considerable damage in Comox, Port Alberni and Powell River (on the eastern side of the Georgia Strait). A number of chimneys were shaken down in Victoria, and people in Victoria and Vancouver were frightened—many running into the streets.

M7.2 West Vancouver Island earthquake in 1918 (crustal)

This earthquake occurred in the early instrumental era when not many seismometers were installed on the West Coast. Therefore, its exact location is uncertain, but it occurred near the west coast of Vancouver Island and was felt very strongly at Estevan Point lighthouse and at Nootka lighthouse on the southern tip of Nootka Island. Some damage occurred to the Estevan Point lighthouse and to a wharf at Ucluelet. This earthquake awakened people all over Vancouver Island and in the greater Vancouver area. It was felt in northern Washington state and as far east as Kelowna, in the interior of B.C.

M7.4 earthquake near the Washington–B.C. border in 1872 (crustal)

This earthquake occurred before the instrumental era in a relatively unpopulated area at the time, so the exact location is uncertain, but it appears to have been in northern Washington State, about 100 km or more south of Hope, B.C. The strongest shaking and most of the aftershocks were reported in the Lake Chelan area in Washington State, suggesting that this region was the closest populated area to the epicentre. The shaking was strong enough to frighten people and cause them to run out of buildings in Victoria, New Westminster and Yale, and in Seattle, Washington. The earthquake was reported as felt from central B.C. in the north (Quesnel) to central Oregon in the south (Salem) and east into Alberta and Montana.

M9.0 Cascadia Subduction Zone earthquake in 1700 (subduction interface)

This is one of the world’s largest earthquakes. The shaking collapsed houses of the Cowichan Peoples on

Vancouver Island and caused numerous landslides. The shaking was so violent that people could not stand and so prolonged that it made them sick. On the west coast of Vancouver Island, the tsunami destroyed the winter village of the Pachena Bay people, with no survivors.[228] These events are recorded in the Oral Traditions of Indigenous communities on Vancouver Island. If this event occurred today, it would impact all of Vancouver Island and much of the Lower Mainland, where the population and urban and economic development is now much higher.

Climate change influence

While tectonic processes that induce earthquakes are not influenced by weather conditions, the occurrence of an earthquake during hazard season (for example, wildfire or flood seasons) greatly affects its impact and the potential for triggering secondary hazards. Climate change models indicate that as global warming raises temperatures and modifies precipitation patterns, B.C. will experience more frequent extreme climate events, potentially occurring over a longer period of the year. Specifically, the occurrence of longer, hotter and dryer warm seasons exacerbating drought, extreme heat and wildfires, and larger amounts of precipitation during storms increasing the likelihood of flooding, will increase the likelihood that an earthquake will coincide with a climatic hazard and an existing emergency. Such co-occurrence enhances the likelihood of an earthquake or its resulting damage triggering secondary hazards such as landslides, floods and fires.

Strengths, gaps and uncertainties in understanding earthquake risk in B.C.

Strengths

- The seismic provisions in building codes, bridge codes and the underlying seismic hazard maps are regularly updated (generally every five years).
- The Province has an immediate response strategy[229] and emergency management system[230] that are relatively up to date.
- The Risk Profiler[231] developed by Natural Resources Canada presents the results of quantitative risk assessments for various earthquake scenarios and probabilistic earthquake losses in B.C.
- The two largest metropolitan areas in B.C. (Vancouver and Victoria) have reliable microzonation studies[232] and professional practice guidelines for assessing the impacts of near-surface geology on earthquake hazard and risk.

- The Province benefits from tsunami and earthquake early warning systems that provide alerts to citizens, facilities, organizations and authorities to take potentially immediate (and sometimes automated) protective actions.
- Earthquake insurance take-up rates are high in southwestern B.C., compared to the rest of Canada.
- BC Housing is considering “immediate occupancy” instead of “life safety” as a target for building performance for some of its new building projects. This will help to increase shelter capacity and reduce the number of people in need of shelter after a major earthquake.
- Recent code changes for “housing and small buildings” (as defined in part 9 of the building code) are coming into force in March 2025 and intend to better align it with Part 3 of the code (engineered buildings). Such buildings built to comply with previous code versions are not as well protected from earthquakes as engineered buildings.
- Education and awareness strategies are at work in First Nations communities and other communities to improve preparedness and include the use of Indigenous Knowledge, annual drills such as ShakeOut B.C., high-ground hikes, tsunami zone signage, and early warning systems and sirens.

Gaps

- More earth science information and seismic monitoring is needed for better assessment of earthquake hazard, for example:
    - Current knowledge of active faults in B.C. is incomplete (very few active faults have been mapped so far). Where active fault location and their potential to create large earthquakes are unknown, seismic hazard assessments are general in nature and may miss significant hazard zones.
    - The ground motion models used in hazard assessment are from global recordings of earthquakes. Insufficient local ground motion data limits current characterization of local ground shaking characteristics, and more reliable calculation of seismic hazard.
    - Microzonation studies delineating potential site amplification, liquefaction and landslide are needed, and where available, should be incorporated into hazard assessments (see case study 2 in Appendix C).

- Seismic wave amplification patterns are not well determined in key sedimentary basins in B.C. Significant basin effects could increase the hazard and need to be incorporated into hazard models and future risk assessments (see case studies 3 and 4 in Appendix C).

- More engineering information is needed related to seismic damage potential of buildings and infrastructure, for example:
  - The structural vulnerability of the different types of existing structures in B.C. is not well resolved. Improving our understanding of vulnerability; considering codes, regulations, practices and how they evolved over time; and considering structural irregularities such as soft storeys would improve our understanding of seismic risk and capacity for a reliable assessment of building safety post-disaster.[233] Additionally, there is a gap in methods for quantifying structural vulnerability of previously damaged buildings, which is important for risk assessment of combined events (such as earthquake and tsunami or mainshock and aftershocks).
  - Much of earthquake engineering research in B.C. is based on earthquakes in California and lacks long-duration subduction interface earthquake data.
  - Much focus is given to damage to buildings. Risk studies also need to consider damage to critical infrastructure (transportation network, power, water, communication, hospitals etc.) and their interdependencies to properly assess the risk (see case study 4 in Appendix C).
  - More effective and cost-efficient engineering solutions are needed to mitigate the liquefaction-induced damage on the transportation network.

- A greater understanding of risk and exposure to risk is needed, for example:
  - While Canada is fortunate to have the National Seismic Risk Model, higher resolution exposure databases are needed at the municipal level, and a greater variety of results (probabilistic and scenario-based) could provide important risk insights.
  - Direct losses from secondary hazards and direct losses to

structures other than buildings are currently not included in the National Seismic Risk Model. Similarly, indirect losses are not covered by this model. These are very significant seismic risk factors.

- Exposure and risk of post-earthquake fire at major energy facilities and gas storage and distribution networks is not well studied and understood.[234]
- Quantitative seismic risk assessments often focus on the “3 Ds”: deaths, damage and dollar losses. Currently, these do not provide a comprehensive quantitative assessment of significant impacts on vulnerable populations, health, food, energy, water availability and quality, natural ecosystems (including fisheries) and more (see case study 8 in Appendix C).
- Large earthquakes may impact multiple communities at the same time, with lasting impacts. Such large-scale, compounding events challenge the ideal span of control in the British Columbia Emergency Management System, and could challenge existing plans and the means to transfer information, resources and essential needs to and from communities.

- Better transfer of information is needed, for example:
  - Better translation of scientific knowledge into plain language would allow governments and citizens to make more informed decisions about their seismic safety.
  - Comprehensive and consistent hazard and exposure information is needed to standardize risk assessment and management. Some key information, such as microzonation studies, needs to be integrated in hazard and risk assessments. Meaningful use and interpretation of such resources depend on clear communication of data use (and exclusion), analysis limitations, intent and guidelines for appropriate use.
- Governance and regulation that manage risk through land use and building design and retrofit are needed, for example:
  - The existing building stock in B.C. includes many vulnerable buildings at significant seismic risk. Current regulations only require retrofit when a building is significantly renovated, and the number

and rate of retrofits are still low compared to the risk.

- The vast majority of existing buildings in B.C. were built to life-safety standards, ensuring that occupants can leave the building safely after an earthquake—with only a small portion designed for post-earthquake performance to allow the buildings to be reoccupied and functional. Designing more buildings to post-disaster standards would increase construction costs but would also increase the resilience of communities.
- Long-term risk reduction plans and land-use planning need to explicitly acknowledge and address inevitable extreme events such as an M9 megathrust earthquake scenario, which constitutes a provincial-scale multi-hazard event. The risks from an M9 earthquake seem overwhelming, but taking steady steps to reduce and prepare for the risks will not only pay off for such a major event but will also build resilience to all smaller earthquakes and many other hazard events.

Community resilience to seismic events: A case study of Haida Gwaii

Small, remote communities situated along the Pacific Northwest coast of British Columbia are vulnerable to seismic events, including earthquakes and near- and far-field tsunamis. Haida Gwaii is a seismically active archipelago of ~150 islands, with a population of ~4,500 people spread across six small communities. On October 27, 2012, a 7.8 M earthquake occurred. The epicentre was approximately 80 km seaward off the west coast of Haida Gwaii. This was the second largest earthquake recorded in Canadian history, and tremors were strong enough to be felt up to 1,500 km away.

Although this was a large seismic event, injuries to people and damage to infrastructure were minimal, likely in part because the epicenter was remote from communities and the resultant tsunami occurred when boaters and tourists were not typically present. The seismic disturbance did however result in psychosocial impacts to community members, and provide an opportunity to reconsider hazard preparedness on Haida Gwaii.

Despite legislative requirements to be prepared for hazard events, there has been a long-standing concern regarding earthquake preparedness in B.C. It is especially important for rural and remote communities to plan and prepare for hazard events, because their unique characteristics render them particularly vulnerable to disaster impacts and outcomes.

Due to the remote location, development in low-lying areas and socioeconomic challenges, Haida Gwaii communities are highly vulnerable to seismic events. However, prior to the 2012 earthquake, community and emergency planning for seismic events was not a priority and as such, citizens, stakeholders and local authorities were not well prepared for a significant seismic event. Low levels of awareness, limited capacity and resources inherent to small remote communities, and lack of policy direction from senior levels of government led to planning that was limited in scope and quality. Policies were found to be heavily focused on response activities, and few strategies were implemented to reduce vulnerability as well as and short- and long-term risks. As well, response planning was not robust and plans were not fully exercised, evaluated or maintained. The lack of preparedness in place for the 2012 earthquake, inadvertently contributed to the vulnerability of these small, remote, coastal communities.

The resilience of Haida Gwaii citizens, stakeholders and local authorities was tested by the 2012 earthquake. The event provided the impetus for local authorities and emergency managers to obtain capacity and resources, and improve education programs, community warning systems, and evacuation and response plans. As well, citizens have gained knowledge and have become engaged as active participants in emergency planning, which helps to build capacity and resilience in the community. It is expected that the new community-based Emergency Response Plans that align with local knowledge, skills, capacity and resources will help to improve response efficiency and build capacity.

The communities of Haida Gwaii are deeply connected to the land and waters, and living “on the edge” has taught the people and communities how to make do with less, navigate challenges and change, and work together to sustain their way of life and their communities. The strong social capital resources on Haida Gwaii were embodied in the statement “our people are our strongest thing,” which perhaps shows the true extent of Haida Gwaii’s resiliency and adaptive capacity.

– Adapted from Community Resilience to Seismic Events: A case study of Haida Gwaii (Thesis) by Deborah Pearson

Research highlight: Deep sedimentary basin amplification of earthquake ground motions

Metro Vancouver lies above the Georgia Sedimentary Basin. Such basins have been shown to amplify seismic shaking, particularly enhancing ground motions of long periods. Historically, deep basin amplification effects have not been explicitly accounted for in seismic hazard models and in building codes. In 2018, the United States Geological Survey included basin effects in the U.S. National Seismic Hazard Model and, as a result, basin effects are now included in U.S. building codes. While progress has been made in the U.S., Canada's 6th Generation Seismic Hazard Model (2020) doesn't explicitly account for these effects. This highlights a critical gap in our understanding of the seismic hazard in the region.

Researchers of the University of British Columbia are currently using new 3D physics-based ground motion simulations of M9 Cascadia earthquakes to quantify the amplification effects of the Georgia Sedimentary Basin, and to develop site-specific basin-amplification factors that can be applied to existing seismic hazard estimates in southwestern B.C.

The study found that basin amplification varies spatially across sites within Metro Vancouver and generally correlates well with basin depth. For instance, the average basin amplification factor for Metro Vancouver locations with a basin depth of 1–2 km is 1.7 at a two-second period, and it is 2.63 at the same period for sites with a basin depth of 3–4 km. When basin amplification effects are integrated into the calculation of Uniform Hazard Spectra (UHS), a design tool used to characterize earthquake ground motions, this results in higher seismic design forces, particularly for taller buildings (with periods of vibration of one to three seconds).

For further details on this research study, see case study 3 in Appendix C.

Figure 2.8.1: Sumas Prairie in November 2021. Tamsin Lyle, 2021

2.8 Multi-hazards

Hazard description

"Multi-hazards" is an overarching term describing the interaction of multiple hazards that may occur simultaneously or cumulatively over time, and that create interrelated effects between the hazards or the consequences.

Interconnected hazards and the cascading consequences represent a critical dimension of disaster and climate risk, where the interconnected nature of Earth systems and societal systems can turn a natural event into a complex set of hazards and consequences that escalate into a major crisis. Understanding these chains of events is essential for a comprehensive understanding of risks, as it enables better anticipation of potential crises and the development of more resilient strategies to manage and mitigate the far-reaching impacts of hazard events in a changing climate.

Hazards and hazard assessments are often developed with a singular focus and an assumption that hazards are independent events. However, some hazards are innately tied together (for example, a tsunami following an earthquake). Further, some hazards may occur simultaneously by chance, especially when considering longer duration hazards. For example, because a drought may last for years, there is a significant chance that another related hazard (such as a wildfire) or an unrelated hazard (such as an earthquake) may occur over this period.

Multi-hazards on First Nations lands and waters

All hazards are related—they are interconnected, part of one entity, and all go back to the Earth. Multi-hazards result from interdependencies between systems and subsystems of coupled natural and socioeconomic pathways, in response to changes. Multiple and compounding hazards are exacerbated by resource extraction systems and climate change impacts, and First Nations are disproportionately impacted by compounding events exacerbated by climate change influence. At a community level, complex hazards can cause inequities and trauma, impacting First Nations abilities to lead sovereign lives. First Nations-driven holistic climate change solutions and processes are essential for addressing multi-hazards, and this knowledge must be passed on to future generations.

– First Nations Committee

For singular events, there are relatively well-documented processes for analyzing hazards such as riverine floods,[235] landslides[236] and avalanches.[237] However, multiple hazards may interact in complex ways, with unexpected effects. Understanding the interaction of multiple hazards and their consequences is essential to addressing systemic risk, avoiding maladaptation and enabling comprehensive risk assessment, resilience planning and resource allocation.[238]

Definitions

Most efforts in understanding hazards and risks occur for each hazard independently. This is largely because technical expertise and programs and policies for risk management are usually hazard specific. The field of understanding multi-hazards is, therefore, less advanced and evolving, and there are, as yet, no standardized international definitions for terms. The following section represents agreed-upon definitions for this project.[239]

Multi-hazards:

Multiple major hazards and the specific contexts where these hazardous events may occur simultaneously or cumulatively over time, taking into account the potential interrelated effects. “Multi-hazards” is an overarching term, and the following terms define the different ways that hazard events may occur and their potential interactions.

Triggered hazards:

Where one hazard causes another to occur. This can result in cascades of hazards. For example, a heavy rain (convective storm) that triggers steep creek geohazards (debris flow, debris flood).[240,241,242]

Amplified hazards:

Where one hazard increases the likelihood or magnitude of a future hazard. For example, a multi-year drought creates conditions for a wildfire, and a wildfire occurs.[243]

Coinciding hazards:

Where two or more dependent hazards (for example, storm surge and rain, both caused by the same storm) or independent hazards (for example, earthquake and flood) impact the same place at the same time and where the combined consequences are greater than their sum.[244,245]

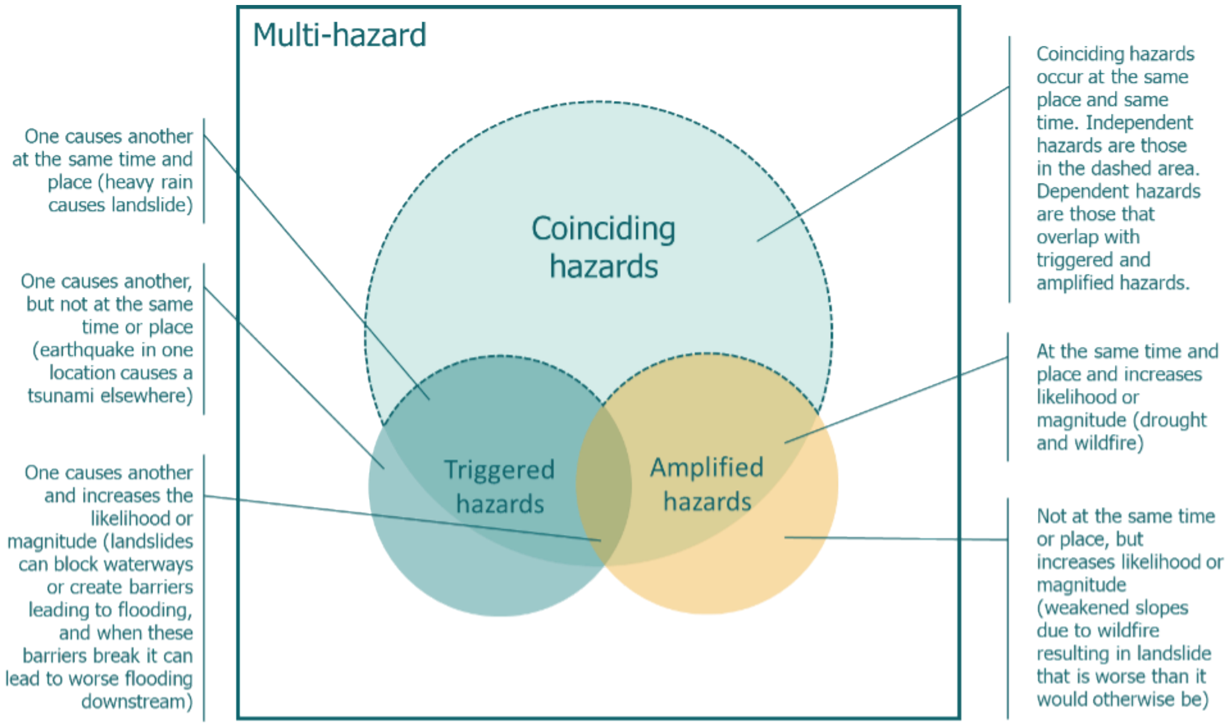
Cascading hazards:

Progression of hazards and consequences that produce more than two cause-effect chains, including human-caused hazards. A commonly cited example is the 2011 Tohoku Cascade Chain, which started with a seismic event that triggered a tsunami, followed by a nuclear hazard.[246] Another example is a seismic event that triggers a landslide, leading to blocked waterways that result in the flooding of adjacent areas. (Cascading consequences are discussed in Chapter 3 and in case study 5 in Appendix C.)

Any of the above can have compounding consequences if the impacts are greater than their sum. Building on the example of the Tohoku Cascade Chain above, the hazards from this event combined and compounded to create widespread and cascading impacts including electrical supply disruption, widespread nuclear contamination, short- and long-term damages to environmental and agricultural systems, and related challenges to health and wider governance systems.[247]

Figure 2.8.2 shows the interactions for coinciding hazards, triggered hazards, and amplified hazards, and provides examples for each. The dependent coinciding hazards are those that are also triggered or amplified hazards. However, there are also triggered or amplified hazards that are not coinciding hazards, meaning that they can happen at a different time or place.

Figure 2.8.2: Pairs of hazards can interact in different ways by being independent or dependent coinciding hazards. Hazards can also be triggered or amplified hazards or both. Not all triggered or amplified hazards occur at the same time or place.



Common multi-hazard pairs in B.C.

Infinite combinations of B.C.'s diverse hazards can occur, with some hazards triggering or amplifying others. The potential for a region to experience two or more hazards is generally related to its geologic and physiographic properties. For example, steeply sloped areas that are also forested will be prone to both wildfire and landslides.

In addition to examples where hazard-prone areas are simply coincidental, an important consideration for multi-hazard events is when a primary hazard can trigger or amplify the likelihood or severity of a secondary hazard. The landscape of British Columbia makes certain pairs of the six priority hazards possible, as described in Table 2.8.1.

Table 2.8.1. Priority hazard pairs in B.C.

Priority hazard and hazard pair		Description	Regions affected
Earthquake	**Tsunami**	Earthquakes centred off the coast can trigger a tsunami wave, meaning that coastal communities will face both shaking and damage from the primary earthquake, as well as the impacts of coastal flooding when the tsunami wave hits the coast.	Coastal areas adjacent to the Cascadia Subduction Zone (the west coast of Vancouver Island and portions of the mid-coast)
Earthquake	**Riverine flood**	Earthquake events, ranging from moderate to extreme, are anticipated to cause severe or extreme damage to the Lower Mainland diking infrastructure—which, if followed by a moderate- to high-flow event, will mean widespread flooding on the land side of the currently "protected" floodplain.	Southwestern portion of B.C. where earthquake hazard exists
Extreme heat	**Wildfire**	Extreme heat for prolonged periods can amplify wildfire hazards when they occur by creating the conditions for ignition and fire spread.	All parts of B.C.

Priority hazard and hazard pair		Description	Regions affected
Water scarcity	**Wildfire**	Water scarcity and drought change land cover conditions such that they amplify the likelihood and magnitude of wildfire.	All parts of B.C.
Wildfire	**Riverine flood**	Wildfires will amplify the severity of floods. Wildfires within a watershed will change the land cover as vegetation and soils are burned. When wildfire is followed by intense precipitation, flows within the watershed can behave differently than for an unburned landscape, with water not being absorbed as effectively in the soil and instead flowing quickly overland, causing flooding and erosion.	All parts of B.C.

Multi-hazard events are not limited to natural hazards. The damages and disruption they cause to the built environment can create additional hazards. For example, an earthquake may trigger widespread structure fires, which then become a hazard themselves. Damages and disruption to infrastructure, such as power outages and disruption to drinking water and waste management, can have vast impacts on people's health and wellbeing and other aspects of society.

In B.C., with consideration of 30 natural hazards, almost 100 pairs of interactions are possible (Table 2.8.2). The hazards most likely to trigger or amplify secondary hazards are sub-surface geophysical processes (earthquakes and volcanic eruptions), storms (convective with lightning, high winds, tornadoes), as well as riverine floods, wildfires and land subsidence and liquefaction. These hazards can amplify or trigger approximately 20 secondary hazards. Those natural hazards most likely to be triggered or amplified are generally local surface processes such as landslides, avalanche, submarine slides, wildfire and riverine flooding.

Table 2.8.2: Hazard pairs in B.C. The primary hazards are shown in each row, and the secondary hazards are shown in each column. This diagram is intended to illustrate potential interactions between primary and secondary hazards. It is not based on an exhaustive analysis of all possible relationships.

	Landslide and Debris Flows	Wildfire (incl. Wildland Urban Interface Fire, High Intensity Residential Fire)	Submarine Slides	Riverine Flooding: Lake, River Stream	Avalanche	Air Quality	Land Subsidence (and Sinkholes)	Human Disease (Pandemic and Epidemic)	Plant Disease and Pest Infestation	Animal Disease	Drought	Public Health Crisis	Storm - Convective Storms and Lightning	Storm - Tornado	Volcanic Activity	Coastal Storm Flooding	Extreme Temps - Cold	Storm - High-Wind Event	Stormwater Flooding (includes Flash Flooding)	Severe Winter Conditions - Snowstorms and Blizzards
Earthquake	●	●	●		●		●	●	●	●		●			●					
Volcanic Activity	●	●		●	●	●							●				●			●
Drought	●	●		●		●	●	●	●	●		●								
Wildfire (incl. Wildland Urban Interface Fire, High Intensity Residential Fire)	●			●		●					●		●					●	●	
Extreme Temps - Heat		●				●					●		●	●				●		
Riverine Flooding: Lake, River, Stream	●		●				●	●	●	●										
Ash Fall		●		●		●					●						●			
Extreme Temps - Cold	●																			●
Storm - High-Wind Event		●			●									●		●				
Storm - Convective Storms and Lightning		●												●					●	
Animal Disease								●	●			●								
Landslide and Debris Flows			●	●											●					
Liquefaction	●		●				●													
Tsunami (Telegenic and Terrestrial)	●		●													●				
Stormwater Flooding (includes Flash Flooding)								●	●	●										
Severe Winter Conditions - Snowstorms and Blizzards				●	●															
Plant Disease and Pest Infestation		●									●									
Avalanche	●			●																
Land Subsidence (and Sinkholes)	●		●																	
Submarine Slides	●						●													

Many communities in B.C. have been experiencing multi-hazards, at times simultaneously. Below are a few examples from recent years:[248]

- City of Penticton: A landslide and a fire in three months (August 2020–October 2020)
- Shackan Indian Band: A fire and a flood in six months (June 2021–November 2021)
- City of Merritt: A fire and a flood in one year (June 2021–June 2022)
- City of Williams Lake: A flood and a landslide in one-and-a-half years (April 2020–December 2021)
- Cooks Ferry Indian Band: Two fires and a flood in four-and-a-half years (August 2018–December 2021)
- Nazko Nation: Two fires and a flood in five-and-a-half years (April 2018–September 2023)
- Lower Similkameen Indian Band: Four floods, three fires and a landslide in five-and-a-half years (May 2018–November 2023)
- Okanagan Indian Band: Three floods and a fire in six years (May 2017–May 2023)
- Village of Cache Creek: Four floods and two fires in six years (July 2017–June 2023)

Research highlight: High-consequence rapid movement of landslides

Fast-moving landslides that run into rivers or lakes can create a cascade of hazard events extending much farther than the landslide footprint. A recent example is the 2024 landslide that completely blocked the Chilcotin River. Earthquakes can trigger fast-moving landslides, such as the 1946 Mount Colonel Foster rockslide on Vancouver Island, which generated a wave with a 51 m high run-up in a lake. However, other poorly understood conditions can trigger fast-moving landslides, such as the 2020 Elliot Creek rockslide that generated a 100 m wave run-up, extensive erosion and loss of salmon spawning habitat. Much larger landslides exist along the Columbia River Valley behind BC Hydro's Revelstoke and Mica dams, which generate approximately half of BC Hydro's power. These landslides are slow moving but could accelerate into the reservoir and generate waves that could overtop the dams. The situation could be similar to the 1963 landslide behind the Vajont dam in Italy, which created a large wave that killed over 2000 people in less than 15 minutes.

Ongoing research at the University of British Columbia, Okanagan, seeks to understand the conditions conducive to rapid landslide movements and the potential for a damaging landslide on Dutchman's Ridge behind the Mica dam. Advanced numerical modelling is being used to evaluate the shear-dependent loss of strength within the landslide materials. The work suggests that deep-seated rockslides in foliated metamorphic rock masses are characterized by significant internal fracturing and distortion. Rapid failure occurs more commonly in slopes with multiple shear zones, and earthquakes are a common trigger. Dutchman's Ridge landslide (115 million m^3) is only 1.2 km from the Mica dam and exhibits slope movement that is influenced by seasonal groundwater fluctuations. The findings are vital to better understand landslide mobility and manage the risks associated with this class of landslide.

For further details on this research study, see case study 5 in Appendix C.

Climate change influence

Climate change is a catalyst for many hazard events, generally making them more frequent and severe. Nearly all climate change model projections over all emissions scenarios indicate that B.C. will experience hotter, drier summers with more frequent heatwaves and longer dry spells. These models project more precipitation in the fall, winter and spring; warmer winters with fewer days below freezing; and increased severity of precipitation and storm events. Due to climate change, hazards that trigger or amplify secondary and additional hazards will become more frequent and severe. Examples include the 2021 heatwave that likely amplified ongoing wildfires in southern B.C., and the November 2021 atmospheric river that triggered widespread landslides and floods.

Climate change is also affecting the seasonality and duration of many hazards, which increases the likelihood of both related and coincidental hazard occurrence. Extended periods of below- or above-normal behaviour can prompt and intensify hazards such as flood, drought and wildfire. In addition, the lengthening of drought periods and wildfire season, as well as more frequent storms and floods, increase the statistical chance that an earthquake or other hazard event will overlap with these hazards.

Strengths, gaps and uncertainties in understanding multi-hazard risk in B.C.

Strengths

- Ministry of Emergency Management and Climate Readiness (EMCR) is developing a Comprehensive Emergency Management Plan (CEMP), which will in a future iteration explicitly consider multi-hazard interactions.
- Understanding multi-hazard interactions is encouraged (even if only qualitatively) by the Provincial guidelines and framework, including the Strategic Climate Risk Assessment Framework for British Columbia (2019)[249] and this work.
- Metro Vancouver recently developed preliminary multi-hazard mapping for its jurisdiction to support long-term planning. This work highlighted the challenges in gathering comprehensive and consistent data, which is required for quantitative analyses of multi-hazards.
- BC First Nations Climate Strategy and Action Plan amplifies First Nations voices as the original caretakers and rights holders and identifies pathways to address climate change (including 20 calls to action).
- First Nations Knowledge systems and place-based understanding of the land and water are an essential strength to understanding and addressing multi-hazards.
- First Nations' Emergency Services Society's spatial data platform, Lightship, supports timely emergency management responses for First Nations.

Gaps

The field of understanding multi-hazards, especially quantitative and statistical analysis, is in its infancy. At this time, most work in the field relies on empirical experience and expert judgments. This provides a base for understanding what may have occurred in the past but biases the science against potential hazards and multi-hazards that B.C. has not yet experienced. There are many gaps and uncertainties in understanding, including:

- Incomplete information on all hazards that may occur in the province. There has been a focus, including in this report, on priority hazards that have either been recently experienced (floods) or are likely to be extremely catastrophic (earthquakes). There are dozens of hazards present across the province, many of which are poorly studied or understood (such as volcanic eruptions and windstorms). Not having information on each of these individual hazards limits our understanding of how they may interact with other hazards. This also presents a challenge in identifying the most damaging or concerning hazards.

- Hazard information, when available, is rarely comprehensive and consistent across the province, and is therefore difficult to overlay in pairs or multiple hazards to understand where they overlap in space (and time).
- Methods to systematically consider multi-hazards and their potential impacts are in their infancy, including illustrative scenarios showing connections between hazards, exposure and vulnerabilities, and including the hazards pairing matrix approach shown here. Fully systematic reviews of all potential hazard interactions and cascading consequences are novel, and they are not available in B.C.
- There is incomplete provincial government understanding, in terms of First Nations capacity and strengths for planning, adapting and responding to climate change through culturally appropriate practices that honour land and water relatives.

Chapter 2 Endnotes

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