Fraser Valley Regional District

Hazard Report

Fraser Valley Regional District

Prepared by
BGC Engineering Inc.

Executive Summary

BGC Engineering Inc. (BGC), Torpy Consulting (Torpy), and The Beacon Design Collective Inc. (Beacon) were retained by the Fraser Valley Regional District (FVRD, the District) to compile hazard information available in the eight electoral areas (A to H – the study area) of the FVRD and develop an associated emergency management (EM) plan. This report (Project 0409007) summarizes the hazard information for FVRD's electoral areas. The EM plan will be informed by this report and presented under separate cover.

The study area covers a large area (12,000 km^2) of the FVRD, encompassing a diverse physiography from sea-level lowlands to rugged mountains (up to 2,700 m). The area is susceptible to a range of geohazards, including landslides, flooding, bank erosion, debris flows, liquefaction, and snow avalanches. Climate change has the potential to greatly influence many of these geohazards with changes in types, amounts, and timing of precipitation. This report introduces each of these hazard types and provides examples of past events within the FVRD.

BGC assembled and compiled hazard mapping from FVRD, BGC's alluvial fan database, and a Canadian landslide database. This compilation was supported by 350 reports provided by FVRD, including geohazard assessments of varying scales conducted by consultants along with floodplain bylaws from the FVRD and its electoral areas and communities.

BGC compiled the provided hazard information but did not review the accuracy of any hazard information provided by third parties as part of this scope. Based on the compiled information, for each electoral area BGC developed summaries of the hazards and potential consequences in order to support EM planning and prioritization of future work to identify, assess, and manage risks from hazards. BGC also provided the compiled mapping to FVRD, Torpy, and Beacon in vector format. BGC completed this assessment before the Kookipi Creek fire in Electoral Area A in 2023 and as such, the impacts of the fire are not included in this report.

In support of ongoing hazard and risk management in the FVRD, BGC recommends that FVRD focus future work on hazard identification and assessment, development and maintenance of a hazard inventory, and communication of results to land owners and stakeholders within the FVRD.

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Glossary

Term	Definition
Alluvial fan	A low, outspread, relatively flat to gently sloping mass of loose rock material, shaped like an open fan or a segment of a cone, deposited by a stream at the place where it issues from a narrow mountain valley upon a plain or broad valley, or where a tributary stream is near or at its junction with the main stream, or wherever a constriction in a valley abruptly ceases or the gradient of stream suddenly decreases (Bates & Jackson, 1995).
Atmospheric river	Relatively long and narrow atmospheric systems that can carry large amounts of water vapour and cause extreme rainfall or snow as vapours rise and cool while moving overland (NOAA, 2023).
Avulsion	Lateral displacement of a stream from its main channel into a new course across its fan or floodplain. An avulsion channel is a channel that is being activated during channel avulsions (Oxford University Press, 2008).
Consequence	In relation to risk analysis, the outcome or result of a **geohazard** being realised. Consequence is a product of **vulnerability** (V) and a measure of the **elements at risk** (E) (Fell et al., 2005; Fell et al., 2007).
Elements at risk (E)	This term is used in two ways: » To describe things of value (e.g. people, infrastructure, environment) that could potentially suffer damage or loss due to a **geohazard**. » For risk analysis, as a measure of the value of the elements that could potentially suffer damage or loss (e.g. number of persons, value of infrastructure, value of loss of function, or level of environmental loss).
Geohazard	Geophysical process that is the source of potential harm, or that represents a situation with a potential for causing harm.
Geohazard inventory	Recognition of existing **geohazards**. These may be identified in geospatial (GIS) format, in a list or table of attributes, and/or listed in a risk register.
Risk	Likelihood of a **geohazard** scenario occurring and resulting in a particular severity of **consequence**. In this report, risk is defined in terms of safety or damage level.
Vulnerability	The characteristics and circumstances of an **element at risk** that make it susceptible to the damaging effects of a hazard. For example, vulnerability may be used to describe the likelihood that a fatality could occur due to hazard impact.

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1.0 Introduction

BGC Engineering Inc. (BGC), Torpy Consulting (Torpy), and The Beacon Design Collective Inc. (Beacon) were retained by the Fraser Valley Regional District (FVRD, the District) to compile natural hazard (geohazard) information available in the eight electoral areas (A to H) of the FVRD and develop an associated emergency management (EM) plan. This report summarizes the hazard information for FVRD's eight electoral areas (referred to hereafter as the study area). The EM plan will be informed by this report and presented under separate cover.

The study area covers 12,000 km^2 of the FVRD along the Fraser River valley, extending to the U.S. border to the south and beyond the Nahatlatch River to the north (FVRD, 2023a). Land use includes rural residential, agriculture, and forestry use, as well as major transport, utility, and telecommunications infrastructure. The District covers a diverse physiography, ranging from sea-level lowlands to rugged mountains (up to 2,700 m). This physiographic diversity, along with the coastal temperate rainforest and seismically active southwestern British Columbia, results in a range of geohazards, including landslides, flooding, bank erosion, debris flows, liquefaction, and snow avalanches. Climate change has the potential to greatly influence many of these geohazards due to changes in types, amounts, and timing of precipitation.

The FVRD electoral areas have a small, combined population (14,407 as of the 2021 census (Statistics Canada, 2023)) and a tax base proportional to the population that is required to support many competing priorities. Within the eight electoral areas are 24 designated places ("hamlets") separated by large distances. Some communities have access/egress limitations as well as other factors that may isolate residents from critical services and increase their vulnerability to the consequences of emergencies and disasters. There is a likelihood that multiple cascading incidents with diverse hazard events will occur in different parts of the region at the same time. There are a multitude of jurisdictions made up of municipalities, First Nations communities, governments, and private entities that all share authority over a vast landscape and a large network of transport and utility corridors, telecommunications, etc. All these factors will likely result in complex and coordinated response efforts.

1.1 Scope

BGC, Torpy, and Beacon's scope of work is outlined in the proposal (BGC, March 27, 2023). The project was carried out under the terms of professional services agreement between FVRD and BGC dated April 27, 2023.

The scope of work includes:

- Introduction to relevant hazard types with the potential to impact the FVRD electoral areas, including clear-water flood, steep creek, landslide, seismic, and snow avalanche hazards, along with a selection of relevant non-natural hazards.
- Compilation of existing geohazard information provided by FVRD supplemented with additional material as available, including published maps and recently available datasets.
- Development of electoral area summaries including:
  - Summary of geohazards affecting the electoral area and associated potential consequences.
  - Assessment of assets (properties, businesses, transportation infrastructure) exposed to mapped steep creek and flood hazards.
- Qualitative description of potential climate change impacts, non-natural hazards, and compounding risks across the FVRD.
- Recommendations for future work to improve understanding of hazards and risks across the study area.

The purpose of this study is to inform the development of the EM plan and communicate hazard information to a broad range of community members and stakeholders across the FVRD. The study focuses on the electoral areas and does not include municipalities (i.e. Abbotsford, Mission, Chilliwack, Harrison Hot Springs, Kent, Hope) or First Nations reserves within the FVRD.

1.2 Project Limitations

The current scope of work is limited to a compilation of existing hazard mapping. No additional project-specific desktop or field mapping was performed, and BGC did not verify the accuracy of third-party information. The scale of the hazard and qualitative risk-mapping is appropriate to inform EM planning for areas of increased hazard likelihood but is not appropriate for land use planning or the review of development applications which are important mechanisms to manage risks in a complex hazard landscape with a narrow tax base. The potential effects of climate change on geohazards are discussed at a high level, but a detailed characterization is outside of the current scope.

2.0 Hazard Type Summaries

The following sections describe the natural (geohazards) and non-natural hazards included in the scope of this report, the potential consequences of such hazards, and select examples of historical hazard events in the FVRD.

2.1 Geohazards

2.1.1 Clear-Water Flood Hazards

2.1.1.1 Overview

Clear-water floods occur when water overtops natural or artificial watercourses and lakes due to rainfall, snowmelt, and/or glacial runoff processes. Flooding can be seasonal and occur in the spring due to snowmelt. Flooding can also result from random storm surges, outburst floods from natural or human-made dams, unseasonably high temperatures, prolonged or high-intensity rainfall, or a complex mix of multiple processes.

The floodplain of a natural watercourse is defined as the spatial extent of land that is periodically flooded but not normally underwater. Repeated sediment deposition and erosion resulting from flooding creates features such as levees and bars, and can reroute river courses entirely. Post-flood floodplain mapping can further help describe the size and impacts of floods and inform where communities decide to develop land or mitigate existing risk due to floods.

Clear-water floods can be destructive to communities. Damage to roads, utilities, and critical facilities (e.g. Figure 2-1) incurs economic costs and risks to health and safety of those that have limited access to essential resources. Residential and commercial damage caused by flowing and standing water can translate to loss of life, income, and assets. Bank erosion associated with floods can undermine roads and building foundations. Environmental concerns include disruption to aquatic ecosystems and loss of habitat (Talbot et al., 2018).

Figure 2-1.

Damage associated with the Coquihalla River flooding its right bank near the Othello Interchange on Highway 5 in November 2021 (BC Ministry of Transportation, 2021).

2.1.1.2 FVRD Examples: Floods

The atmospheric river in southern B.C. in November 2021 caused widespread flooding in the FVRD, including of the Sumas Prairie (Figure 2-2). A state of local emergency was declared in response to the risk to life and property.

Figure 2-2.

Aerial view of the Fraser River valley looking east along Highways 1 and 7 in Electoral Area B during the November 2021 flood event in southern B.C. Photo: BGC, 2021.

Three prior major floods have been recorded on the Fraser River in the Lower Mainland, in 1894, 1948, and 1972 (Government of Canada, 2010). The 1948 flood resulted from a heavy snowpack and record warm temperatures. It inundated nearly one-third of the Fraser Valley, severed both transcontinental rail lines, and cost an estimated $20 million ($147 million in 1998 dollars) (Government of Canada, 2010; Figure 2-3).

Figure 2-3.

Aerial view of Mission to Barnston Island during the Fraser River flood in 1948 (Chilliwack Museum and Archives).

2.1.2 Steep Creek Hazards

2.1.2.1 Overview

Steep creek hazards are geohazards that involve a mixture of water and debris or sediment. These hazards typically occur on creeks and steep rivers with small watersheds (usually less than 100 km^2) in mountainous terrain, usually after intense or long rainfall events, and sometimes aided by snowmelt and worsened by forest fires.

Steep creek hazards span a continuum of processes from clear-water floods (flood) to debris flows (Figure 2-4). Debris flows and debris floods characteristically gain momentum and sediments as they move downstream and spread across an alluvial fan where the channel enters the main valley floor. Each watershed and fan are unique in the type and intensity of hazards and associated risks.

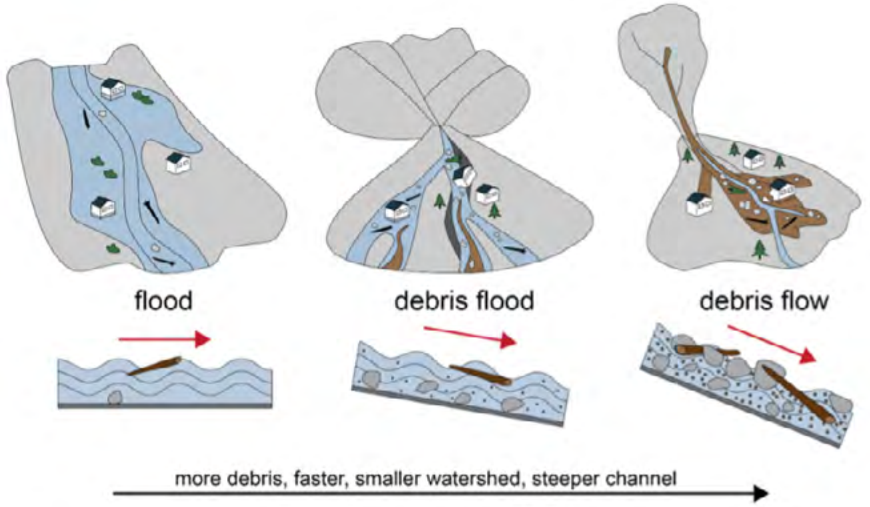


Figure 2-4.

Continuum of steep creek hazards (BGC).

2.1.2.2 Clearwater Floods

Clearwater floods (defined in Section 2.1) on alluvial fans can act differently than floods in riverine and lake environments. The avulsion potential of clearwater floods on alluvial fans is controlled by similar parameters as steep creek hazards, including evidence of previous avulsions and landslide dam outbreak floods. Steep creek floods should therefore be considered separately from riverine and lake flooding in hazard assessments.

2.1.2.3 Debris Floods

Debris floods represent flood flows with high transport of gravel to boulder-sized material. Debris floods typically occur on creeks with channel slopes between 3° and 17° (5% and 30%) but can also occur on lower-gradient (flatter) gravel bed rivers. Due to their initially relatively low sediment concentration, debris floods can be more erosive along low-gradient channel banks than debris flows. Debris floods introduce large amounts of sediment to the fan where they accumulate (aggrade) in channel sections with decreased slope. Debris floods can also initiate on the fan itself through rapid bed erosion and entrainment of bank materials, as long as the stream power is high enough to transport larger rocks.

2.1.2.4 Debris Flows

Debris flows originate from sediment mobilized by the influx of ground or surface water, and travel in confined channels bordered by steep slopes. Due to their high flow velocities, peak discharges during debris flows are at least an order of magnitude larger than those of comparable return period floods and can be 50 times larger or more (Jakob & Jordan, 2001; Jakob et al., 2016). The most severe damage caused by debris flows results from direct impact of large rocks or coarse woody debris against structures that are not designed for the impact forces (Jakob, Stein, & Ulmi, 2012). Similarly, linear infrastructure such as roads and railways may experience damage from debris flows due to direct impact or erosion (e.g. Figure 2-5). Buried infrastructure can be damaged by debris flows if it is exposed by erosion and then impacted by boulders or woody debris.

Figure 2-5.

Debris-flow deposit on Highway 5 following the November 2021 atmospheric river event (Jonathan Hayward/The Canadian Press, 2021).

2.1.2.5 FVRD Examples: Steep Creek Hazards

Patterson Creek, located six kilometres northeast of Bridal Falls along Highway 1, has experienced at least 11 debris flows over the past approximately 140 years (Lau et al., 2022; BGC, December 11, 2018). The nature of debris-flow initiation at Patterson Creek includes both erosion of infilled channel sediment and debris slides in the upper watershed, often initiated by resource road failures (Figure 2-6). At least four events have deposited sediment onto Highway 1.

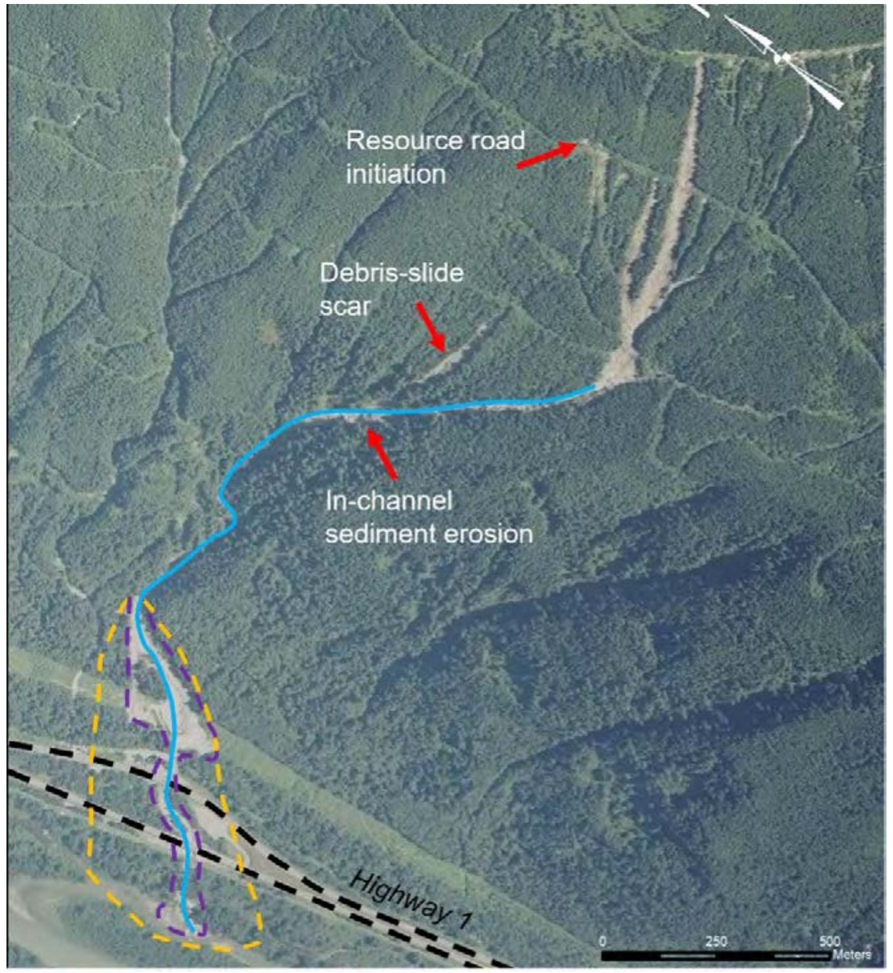


Figure 2-6.

Aerial photograph from 2002 showing the Patterson Creek alluvial fan (orange dash), a recent debris-flow deposit (purple dash), and sediment sources (red arrows) (Photo source: GeoBC).

2.1.3 Landslide Hazards

Landslides occur when ground mass (rock, debris, or earth) moves down a sloped surface by falling, toppling, sliding, spreading, flowing, or a combination thereof. Landslides are classified based on their geotechnical characteristics, geological causes, and dynamic behaviour (Hungr, Leroueil, & Picarelli, 2014). In general, bedrock failures are larger in magnitude (except for small, localized rock falls <1,000 m^3) and of low frequency (Thomson, 1998). These failures occur along structural weaknesses in the rock (Thomson, 1998). Surficial soil landslides are more common, move faster, and generally have less damaging impact forces. They occur when driving forces (often weight or a surcharge at the top of a slope) exceed the shear strength of the material. This is often triggered by precipitation or snowmelt.

Landslide types that may be experienced in the FVRD are shown in Table 2-1. The examples shown are not an exhaustive list of potential failure types within the FVRD; instead, they are provided to demonstrate that a range of failure mechanisms are possible.

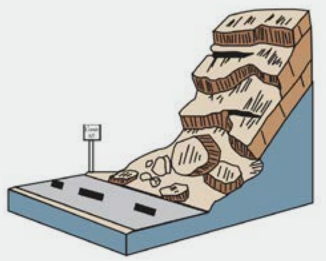
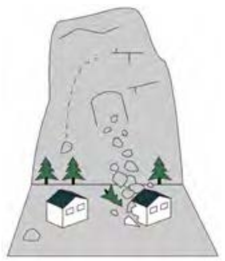
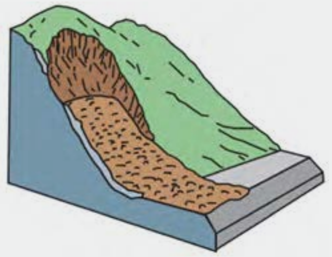
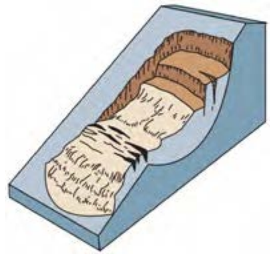
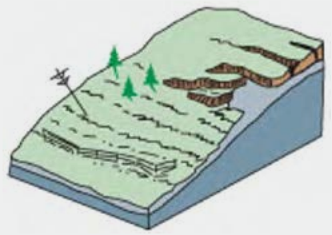
Landslide Type		Description	Causes
Rock fall		Rolling, sliding, and stopping of rock fragments falling off slopes. Occurs in mountainous regions and can form talus slopes due to repeated events. Can become rock avalanches as they erode.	Triggered by the effects of gravity, or precipitation causing an increase in pore water pressure or freeze-thaw cycles in colder months.
Rock slide, rock avalanche		Rapid movement of shattered and pulverized fragments of bedrock. Travels much faster and further than rock fall. Can block rivers and create landslide-generated waves.	Planar elements on a slope, such as jointing, bedding, and foliation, can form one or more surfaces that create a movement mechanism. Precipitation and groundwater levels in the slope influence movement.
Debris avalanche		Occurs when a slope failure consists of an unsorted mix of rock and soil, regardless of moisture (Schuster & Crandell, 1984). With the addition of water in a channel, can become debris flows.	Initiated by heavy rains and involves a relatively thin layer of colluvium.
Rotational landslide		Rock (and debris/earth) slides involve the movement of rock/debris/earth that largely remain on the sliding surface. Sliding (failure) surfaces can be planar (translational) or curved (rotational), and are often a combination.	Sliding movements can be initiated by failure in an internal plane of weakness in rock. Precipitation and groundwater levels in the slope influence movement.
Creep		Extremely slow movement of surficial soil layers on a soil (typically less than 1 m deep). Over time, material loosened by creep can become source material for shallow slides and debris avalanche.	Climate-driven volume changes associated with wetting and drying and freeze-thaw cycles.

Table 2-1.

Landslide types (Evans & Savigny, 1994; Hungr et al., 2014). Schematics from United States Geological Survey (USGS) (2004) or BGC.

2.1.3.1 Karst

Karst topography is caused by the dissolution of soluble rock such as carbonates and evaporites (British Columbia Ministry of Forests, 2003). The presence of karst causes can be signalled by the following landscape markers: fluted and pitted bedrock, karst sinkholes, subsurface openings (caves), sinking streams, and underground drainage systems (Stokes & Griffiths, 2019). Karst is typically more of a foundation concern but can trigger landslides by undercutting the surface or by weathering rock. Within the FVRD, reconnaissance-level karst mapping indicates potential for karst parallel and south of Highway 1 between Abbotsford and Harrison Hot Springs, and in additional localized areas south of Hope.

Figure 2-7.

Landslide-generated tsunami schematic (University of Hawaii, (n.d.)).

2.1.3.2 Landslide-Generated Waves

Landslides that deposit into a waterbody can create landslide-generated waves (Figure 2-7). Landslide-generated waves can damage properties on the shoreline of the waterbody. In the FVRD, the 2007 Chehalis Lake tsunami transported silt to boulder-sized sediment that modified the lake shoreline (Roberts, McKillop, Lawrence, Psutka, Clague, Brideau, Ward, 2013).

2.1.3.3 FVRD Examples: Landslides

Throughout the FVRD, there is a long history of landslides ranging from relatively small rock falls to the 47 million m³ 1965 Hope Slide. Rock falls are common in the steep, mountainous terrain of the FVRD, and are most reported along highway corridors that follow the steep valleys of the major river systems (Figure 2-8). Rock falls are more frequent in spring (snowmelt) and fall (heavy rainfall), with some attributed to freeze-thaw cycles and frost wedging in winter (Piteau & Peckover, 1978).

Figure 2-8.

Rock fall on Highway 1 near Yale (Evans & Savigny, 1994).

The 1965 Hope Slide in the Sunshine Valley (Figure 2-9) is one of the largest recorded rock avalanches in Canada. It occurred in two phases three hours apart and inundated several kilometres in the corridor with debris. After the failure, it was observed that multiple discontinuities dipped toward the valley (Evans & Savigny, 1994).

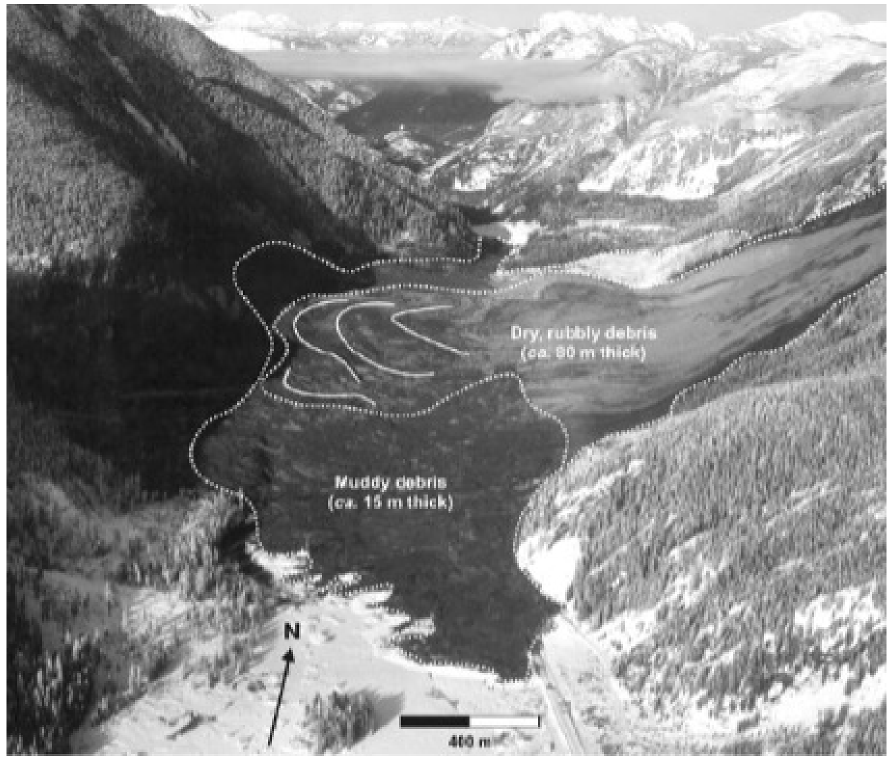


Figure 2-9.

Photo of the Hope Slide after event (Orwin, Clague, & Gerath, 2004). Sunshine Valley is 3 km south of this location.

2.1.4 Seismic Hazards

Earthquakes typically occur at tectonic boundaries and their size can be measured using their moment magnitude (M_w). Earthquakes can cause significant damage from ground shaking leading to building and other infrastructure failure. Smaller seismic events known as aftershocks can occur after an earthquake, leading to further damage.

Liquefaction occurs in loose saturated soils under strong earthquake ground motions (Figure 2-10). Liquefaction can lead to building damage and structure failure when the soil destabilizes. Liquefaction potential depends on geotechnical soil parameters, geological deposition setting, and the magnitude of the seismic load. Soil saturation is likely in active floodplains or soils in poor drainage conditions (BGC, November 28, 2013).

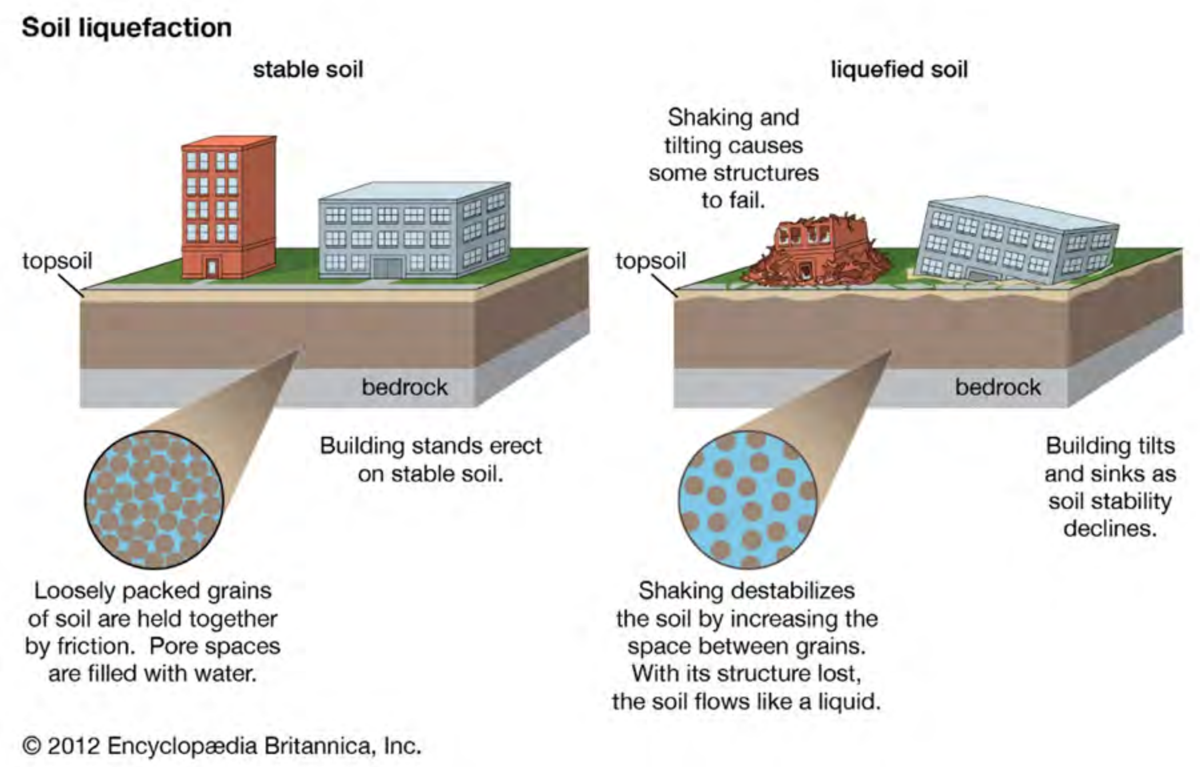


Figure 2-10.

Soil liquefaction schematic (Encyclopedia Britannica, 2012).

Earthquakes can also occur away from tectonic boundaries at shallow local faults. Glaciation may have concealed or removed evidence of these faults (BGC, November 28, 2013). These earthquakes can occur inland near population centres and infrastructure. In general, three types of earthquakes can be expected in the FVRD:

» **Crustal earthquakes** may produce high-intensity shaking at short periods (high frequencies) and can damage small, low-rise buildings. They may also cause widespread landslides and rock falls. Liquefaction will typically occur near the epicentre or causative fault. Local lateral spreading and flow failure can occur. A typical magnitude of M7 can be expected every 50 to 100 years.

» **In-slab earthquakes** are more frequent relative to other earthquake types. They produce high-intensity shaking at longer periods (lower frequencies) that can damage mid-high-rise buildings and bridges. Liquefaction is more widespread. Magnitudes typically range between M7 and M8 every 50 to 100 years.

» **Great subduction-interface earthquakes** are rarer. Longer duration (up to several minutes) strong shaking, particularly at longer periods (lower frequencies) can occur. Widespread liquefaction with the potential to result in supply-chain disruption due to effects on cities (settling foundations, bridge abutments, and pipeline crossings) is a primary concern. Magnitudes can reach M9 and potentially occur every 430 years.

BGC has estimated probable likelihoods for the types of earthquakes above. These return periods are estimations informed by research and experience, and are included for the purpose of communicating the relative likelihood; they should not be relied upon for design and need to be checked against the most recent seismic hazard model to inform design and planning decisions.

2.1.4.1 Historical Seismicity

The last great subduction-interface earthquake preceded the seismic record in 1850. Paleoseismology and historical records from First Nations and Japan indicate that the last great subduction earthquake probably occurred on January 27, 1700 (BGC, November 28, 2013).

The largest historical in-slab earthquake in the B.C.-Washington coast region occurred in 1949 beneath Olympia, Washington (M7.1). This earthquake was approximately 200-300 km away from the FVRD. BGC is not aware of any damage experienced in the FVRD as a result. Impacts from coastal earthquakes and the Boulder Creek fault zone in northern Washington are possible.

2.1.5 Snow Avalanche Hazards

Snow avalanches are a movement of snow and ice down a slope. Avalanches are heavily influenced by meteorological conditions, including snowfall, rain, wind, and fluctuating temperatures. Additional considerations include external forces such as human activities, seismic events, and loads applied by accumulated snowfall. Avalanches commonly form in steep-sloped valleys (generally slope angles greater than 25°), that are subjected to heavy snowfall and regular freeze/thaw cycles (Dynamic Avalanche Consulting Ltd. (Dynamic), 2020).

Loose avalanches and slab avalanches are two of the most predominant types of avalanche failure (McClung and Schaerer, 2006). Loose avalanches occur in light-packed snow where gravitational forces exceed frictional resistance. A loose avalanche starts from a point near the surface and progressively sweeps up more particles as it migrates downslope (Mellor, 1968). The likelihood of a loose avalanche increases when bonds between snow grains are weakened due to a rise in temperature.

Slab avalanches involve a cohesive slab of snow sliding along an underlying weak snowpack. These avalanches have a distinct, broad fracture line along their crown (Dynamic, 2020). Freeze/thaw cycles create a layer of distinct particle shapes of larger size that do not bond well with overlying snowfall. Larger grains create weaker bonds, as pore spaces dictate fewer bonds per unit area. This weaker crust cannot withstand shear forces perpetuated by accumulated snowfall, and failure occurs (Jamieson, 2006).

Figure 2-11.

Crown of slab avalanche (Jamieson, 2006).

Avalanches pose a hazard within glacial valleys with transecting infrastructure, such as transportation corridors and utilities, as the destructive force of the snow and ice mass can cause significant damage and alter landscapes (FVRD, 2006).

Luckman (1978) explains that a large majority of snow avalanches do not erode the underlying ground surface. However, where snow avalanches pick up the full depth of snow, debris will also be collected and redeposited downslope. The debris entrained (picked-up) is usually restricted to slopes above tree lines, in gullies, or areas of exposed loose rock, as vegetation cover can inhibit erosion. Avalanche debris can travel along major gullies and stream valleys, before depositing at the base of the mountain. Heavy avalanche erosion is evident at Terminal Mountain (Figure 2-12), where a cone of loose debris and rock has formed (Luckman, 1978).

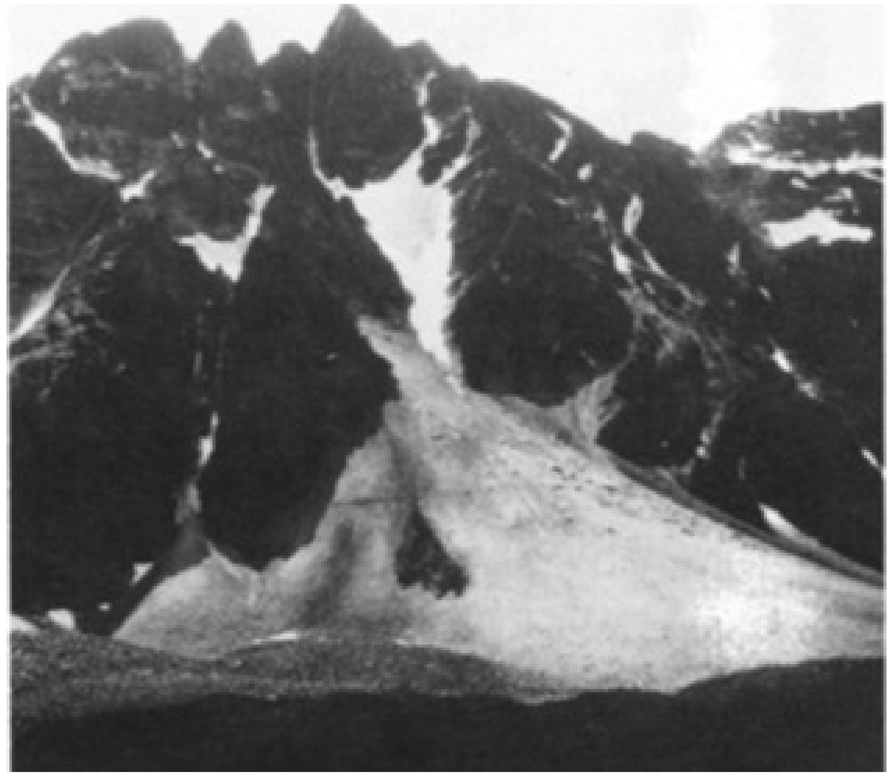


Figure 2-12.

Cone at Terminal Mountain, July 1970 (McClung et al., 2006).

2.1.6 Wildfire Hazards

Wildfires can cause significant economic, social, and environmental losses. They can move quickly and unpredictably, and block emergency access. Wildfires can also result in low visibility from smoke and poor air quality, along with associated health impacts to susceptible individuals.

B.A. Blackwell & Associates Ltd. (Blackwell) created Community Wildfire Protection Plans for FVRD (May 19, 2020; June 30, 2020a, b). These plans focus on fire risk in the wildland urban interface (WUI). Blackwell assessed that sixty to ninety per cent of land in the FVRD is susceptible to wildfires of moderate (20 to 1,000 hectares [ha]) size with an average return period of roughly 200 years. These fires typically occur after extended drought and the British Columbia Wildfire Service (BCWS) identified that most are human caused (camping, forestry activities, rail, and industry), with some areas susceptible to lightning-initiated wildfires.

During fire season (April to October) daily fire danger ratings are published by the B.C. government through the BC website. Ratings range from low to extreme and are provided to support decision-making by the general public. On the same site, detailed danger-class reports with estimated and forecast fire danger ratings are provided for specific weather stations.

Following wildfires, burned slopes are often more susceptible to steep creek and other slope hazards. The largest events are most often triggered by the first major storm following a wildfire, and the hazard remains elevated in the first two years following a fire (Cannon & Gartner, 2005; Staley et al., 2020; De Graff et al., 2015). Landscape recovery is usually reached after five to ten years, depending on the rate of vegetation regrowth (Bartels et al., 2016).

2.1.6.1 FVRD Examples: Wildfires

The largest recorded fires in electoral areas A and B happened in 1933 and 1936, and burned 2,900 ha and 1,190 ha, respectively (Blackwell, June 30, 2020a, b). The two largest wildfires in the region of electoral areas D, E, and H occurred in 1938 and burned a total of 11,517 ha. In summer 2021, the Mowhokam, Little, and Falls creek watersheds experienced moderate to high burn severity across approximately 20% of their area. Post-fire debris floods and debris flows resulting from these watersheds led to damage to Highway 1, railway, and additional infrastructure (Ministry of Forests, Land, and Natural Resource Operations (FLNRO), 2021).

2.1.7 Climate Change Considerations

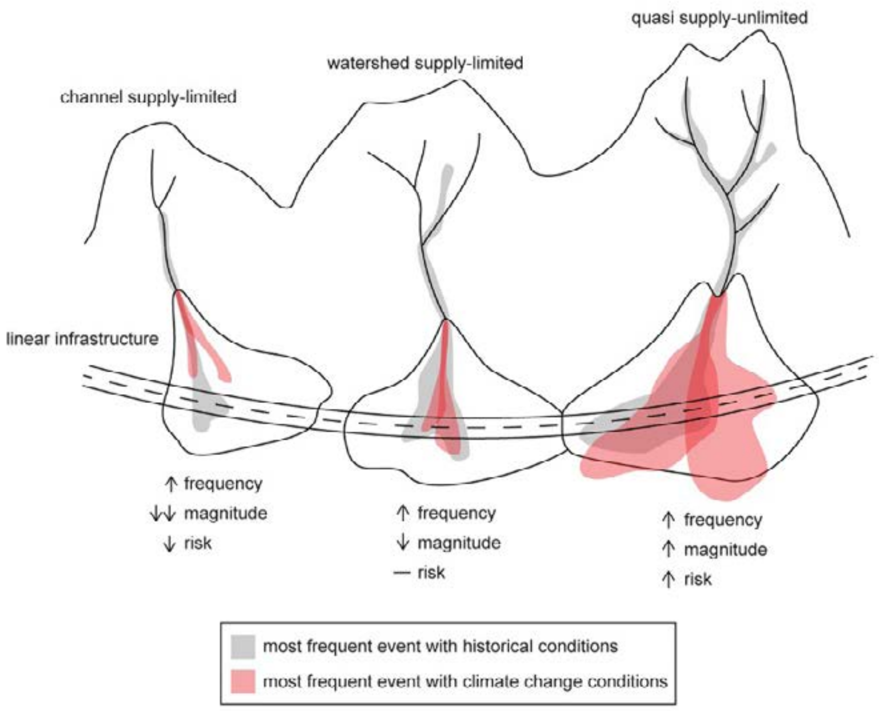
Climate change is a significant systematic shift in the long-term climate over several decades or longer due to natural or human-induced forces[2]. This shift in climate can impact the frequency, magnitude, and duration of extreme weather events, such as snow and ice storms, heavy rains, heat waves, and droughts. These events impact the frequency and magnitude of clear-water floods, steep creek events, landslides, wildfires, and snow avalanches in the FVRD.

Temperatures in the FVRD are projected to increase in all seasons in the 2020s (CCCMA, 2023). The cycle of warmer temperatures leading to earlier freshets (seasonal snowmelt) and more intense rain-on-snow events increases the potential for clear-water flooding and mobilization of surficial materials in steep slopes, causing more frequent landslides, debris flows, and debris floods. Depending on the sediment supply of a watershed, steep creek hazard magnitudes are expected to change as a result (Figure 2-13). Sediment supply in channel and watershed supply-limited watersheds require a recharge period for new sediment to become susceptible to mobilization, while quasi supply-unlimited watersheds do not need this time period and therefore have an "unlimited" supply of sediment.

2 According to the World Meteorological Organization, The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change in more specific terms as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."

Figure 2-13.

Frequency, magnitude, and risk changes by sediment supply (BGC).



Hotter and drier summers increase the risk and extent of wildfires due to factors such as decreased moisture content in the organic matter that burns and spreads wildfire (C2ES, n.d.). After a forested watershed has been burned, its hydrologic response is changed due to the loss of canopy, loss of organic matter binding the soil (e.g. tree roots), and the formation or enhancement of water-repellent soils (Cannon & Gartner, 2005). This increases the erodibility of soil and decreases its ability to absorb water, which causes an increase in overland water flow and channel runoff. These factors make sediment transport much more likely following rainfall on burned hillslopes, and, as a result, debris flows can occur at a higher frequency.

A warming climate can shift the temporal occurrence of avalanches (e.g. Jamieson, Bellaire, Sinickas, 2017; Hao et al., 2023). Temperature surges and changes in seasonal snowfall impact the expected "season" of avalanches in a region or hazard area, but there is less evidence suggesting overall frequency and magnitude of avalanches are decreasing due to warming temperatures.

2.2 Non-Natural Hazards

Non-natural hazards, like geohazards, have implications for community emergency management. The following sections provide a high-level, qualitative description of potential non-natural hazards and associated consequences.

2.2.1 Transportation Hazards

Transportation hazards in the electoral areas include motor vehicle accidents, train derailments, and, although interpreted to be less likely, aircraft crashes. There is limited public transportation in rural areas, so use of cars and motorcycles is common in the FVRD electoral areas. Motor vehicle accidents have the potential to result in injury and loss of life; affect access and egress for residents, visitors, and emergency vehicles; and cause ancillary emergencies, for example due to hazardous material spills. Highway 1 is an important transportation and shipping corridor for Canada within the FVRD.

Train derailments or crashes occur when a train derails or collides with an obstruction on the rail tracks. The Canadian Pacific Kansas City Ltd. (CPKC) railway and the Canadian National Railway Company (CN) run through the FVRD. These hazards likely pose low risk to the communities in the electoral areas where rail lines pass, but this would depend on the severity and proximity of the incident to assets.

2.2.2 Industrial Hazards

Industrial hazards are related to commercial, industrial, and transport operations in an area. These include explosions or gas leaks associated with pipelines, utility ducts, mines, or gas stations, as well as hazardous material accidents. Westcoast natural gas pipelines and TransMountain petroleum pipelines are within the FVRD. Gas stations that service the communities across the FVRD are also distributed throughout the area. Explosions or gas leaks are interpreted to be low likelihood scenarios.

Hazardous material accidents can occur where transport of dangerous goods occurs. Impacts of hazardous material accidents depend on the material type and volume of material released. Damage to the environment, wildlife, and communities are all possible, and the degree of severity is dependent on the circumstances of the event and proximity to elements at risk.

2.2.3 Infrastructure Hazards

Infrastructure to manage hazards (e.g. dikes, dams, and bank erosion protection) that is appropriately designed is intended to reduce risk to communities and downstream areas. However, if infrastructure is not adequately designed, maintained, or experiences a hazard larger than it was designed for, it has the potential to not perform as intended, or even increase risk to downstream areas. BC Hydro operates the Wahleach Dam upstream of Laidlaw and has published an EM guide in the extremely unlikely event that the dam fails (FVRD, 2007).

Orphan dikes are dikes that are not owned or maintained by any party. Failure of these non-standard infrastructures may lead to increased consequences due to failure. More information can be found in the Province's Risk Assessment of BC's Orphan Dikes Summary Report[3]. In the FVRD, Slesse Park Dike and Revetment, Wilson Road Mud Berm, Slesse Slide Erosion Protection in Area E, and Norrish Creek Dike in Area G are all classified as orphan dikes and should be considered in EM planning (FVRD Engineering, May 6, 2021).

Improvement districts are incorporated public local bodies governed by a board of elected trustees. Improvement districts provide services such as dike protection, water, and fire protection services (also known as "objects") for the benefit of landowners within their boundary. Improvement districts are not the same as municipalities or regional districts, as improvement districts may only provide the services authorized in their letters patent. There are three diking improvement districts: North Nicomen Diking District (Area G), Dewdney Area Improvement District (Areas C, F, G), and Nicomen Island Improvement District (Area G). While these are outside of FVRD's authority, they should be considered in EM planning.

3 https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/integrated-flood-hazard-mgmt/kwl_riskassess_orphandikes-summaryreport-20201209.pdf

2.2.4 Health Hazards

Health hazards result from natural illness or contamination resulting in adverse effects, and can be compounded by limitations on access to appropriate health facilities. Risk to life and quality of life caused by pandemics disproportionally affects rural communities with limited access to goods and essential services. Similarly, health risks from wildfire smoke and consequential impacts to rural communities is higher than in urban areas because these populations tend to have access to fewer medical facilities and staff per capita while being in closer proximity to fires.

The spread of disease through contaminated water supply is another threat faced by communities that rely on few or small sources of water. Limited water supply due to contaminated systems and/or drought needs to be accounted for in emergency planning.

2.2.5 Societal Hazards

Social hazards in a community can include socio-economic disparity and lack of or poor educational resources and critical facilities. These factors can amplify the impacts of other hazards by increasing the number and/or severity of adverse consequences. Emergency response takes into consideration the ability of community members to respond to a hazard, natural or not, and the ability of community resources to support people during an emergency.

3.0 Data Compilation

In support of this hazard assessment, BGC assembled and compiled hazard mapping from BGC's alluvial fan database, a Canadian landslide database, and FVRD-mapped hazards.

3.1 Alluvial Fan Database

BGC maintains a database of alluvial fans, which currently includes 271 fans mapped in the FVRD. BGC delineated fans based on interpretation of available aerial and satellite imagery, lidar-derived or publicly available digital elevation models (DEMs), and review of previous fan mapping. The fan inventory is not exhaustive, and fans likely exist in some developed areas that have not been mapped. BGC notes that it is possible for steep creek geohazards to extend beyond the limit of the fan boundary in some cases due to factors such as:

- Localized flooding, where the fan is truncated by a lake or river.
- Young landscapes where fans are actively forming (e.g. recently deglaciated areas).
- Where large landslides (e.g. rock avalanches) trigger steep creek hazards larger than any previously occurring.
- Where human modifications result in changes to flow paths (e.g. construction of dykes and bridges, dredging).

Assessment of such scenarios could form part of more detailed study, discussed in Section 7.0. The limits of geohazard areas identified in this assessment (the alluvial fan boundary) should be treated as transitions, not exact boundaries.

3.2 Canadian Landslide Database

A preliminary Canadian landslide database compiled by Brideau, Lipovsky, and Brayshaw (2023) contains point features of landslide occurrences with information on landslide and material type and, where known, date, trigger, and reference. There are 298 mapped events within the study area, including debris flows and debris floods. This database only includes recorded landslides or those identified in post-event terrain mapping. For this reason, the database is not exhaustive and likely underrepresents the presence of landslides in less-densely populated areas or areas without elements at risk.

3.3 FVRD

FVRD provided BGC with spatially referenced hazard data, including alluvial fan, floodplain, and floodplain setback polygons, as well as cadastral, administrative, land improvement, service area, transportation, and utility extents. FVRD also provided 350 reports that include geohazard assessments of varying scales conducted by consultants along with floodplain bylaws from FVRD and its electoral areas and communities. Hazard mapping included in the provided geohazard reports was used to inform the qualitative risk assessment and mapping. Where there was overlap of the hazard mapping provided and detailed mapping in BGC's inventory, BGC's mapping was relied on for this assessment. BGC did not review the technical quality of hazard delineations provided by FVRD as part of the scope of this report.

4.0 Electoral Area Hazard Summaries

4.1 Introduction

BGC reviewed and summarized the compiled hazard mapping and provided it to FVRD for display on the FVRD Web Map. For each electoral area, BGC summarized the main hazards and potential consequences. Elements at risk are grouped as shown in Table 4-1.

Hazard Exposure Group	Description	Elements at Risk
Community	Group of assets typically existing in populated, settled areas.	People, buildings, critical facilities, businesses and environmental values.
Lifelines	Group of linear infrastructure and critical infrastructure assets.	Roads, highways, railways, petroleum, natural gas, electrical, communication, water, sanitary, or drainage infrastructure.

Table 4-1.

Element at risk groupings.

Qualitative risk mapping, as presented in this report, is appropriate to inform EM planning, and to support land use planning by identifying areas that warrant further review as part of development applications. More detailed assessments should be undertaken to inform site-specific planning and decisions.

4.2 Steep Creek and Flood Hazard Intersects

BGC identified elements at risk within steep creek and flood hazard areas, represented by mapped alluvial fans and floodplains respectively. Business point locations were obtained in GIS format (point shapefile) and used to identify the location of businesses within hazard areas (Precisely, 2021). Transportation infrastructure (highways, railroads, and roads) data and property boundaries were provided by FVRD. The asset data and hazard mapping used are not exhaustive and could be supplemented in the future with population, BC Assessment, and mapped utility data, as well as additional and refined hazard mapping.

4.3 Seismic Hazards in the FVRD

The FVRD is an area of relatively high seismic activity due to its proximity to the Cascadia Subduction Zone (NRCan, 2015). The magnitude of the impacts felt by a large coastal earthquake within the electoral areas is dependent on:

» **Proximity:** Areas furthest from the coast are less likely to be catastrophically impacted by ground shaking caused by seismic loading during an earthquake.

» **Geologic conditions:** Soft soils, such as fine grained deltaic and fluvial deposits, generally experience higher intensity ground shaking during an earthquake than areas underlain by bedrock (PNSN, n.d.). This is relevant for communities in floodplains at risk of liquefaction due to ground shaking. Electoral areas with developed land in high liquefaction hazard zones (lowland fluvial and alluvial sediments of the Fraser, Harrison, Chilliwack, and Hatzic valleys) include Areas C through H (GSC, 1998).

» **Population density:** Rural areas generally lack high-rise buildings due to smaller populations and are less likely to face significant property damage than urban areas.

4.4 Electoral Area A

Area A has a population of 495 people and 287 private dwellings as of 2021 (Statistics Canada, 2023). Boston Bar, North Bend, and Canyon Alpine are located along Highway 1 which parallels the Fraser River (Figure 4-1). CPKC and CN railways parallel the east and west sides of the river, respectively. The Fraser Valley is bounded by mountainous slopes on either side and marks the division of the Cascade Mountains (east) and the Coast Mountains (west). Other developed areas include properties along Nahalatch Road at Hannah Lake.

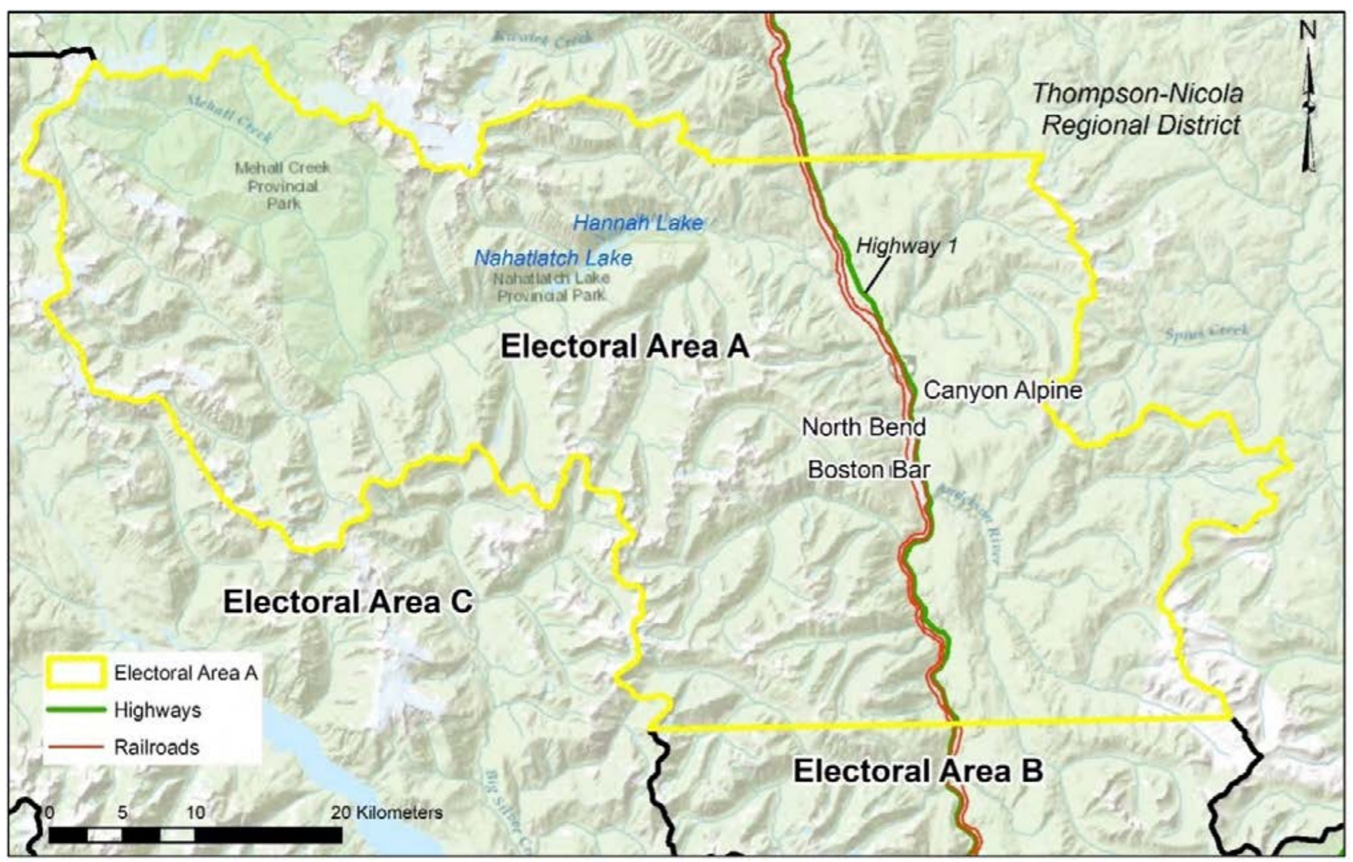


Figure 4-1.

Electoral Area A site overview.

4.4.1 Description of Hazards

4.4.1.1 Clear-Water Floods

Localized flooding along the Fraser River valley is often associated with intense rainfall and snowmelt in mountainous watersheds. The communities of Boston Bar, North Bend, and Canyon Alpine are located atop terraces above the floodplain where flooding due to surface runoff and steep creek flows is possible, especially in localized depressions. Drainage systems can become blocked or damaged by sediment contributing to flooding. There is limited floodplain mapping of the Fraser River in Area A, but erosion of steep slopes along the floodplain extents during high flow is possible, which can cause loss of land and property.

4.4.1.2 Steep Creeks

Mapped steep creek hazards are concentrated along the main transportation corridor, but numerous steep channels exist throughout the mountainous terrain of Area A. Creeks and associated alluvial fans that cross the highway and railways pose a hazard to infrastructure as well as persons and transported goods present during an event. Interruptions to service on the highway or railways could lead to significant economic losses for asset owners, corridor users, and, in larger events, to the regional economy.

North Bend has several steep creeks that flow through the community which pose steep creek hazards to property and infrastructure within the mapped hazard extents (Thurber, February 2, 2018). Both Boston Bar and Canyon Alpine are similarly bordered by bedrock-controlled, steep forested slopes, but there is limited evidence of recent steep creek events. Historical logging records were not reviewed as part of this assessment, but intense rainfall could trigger debris flows or debris floods along old resource roads and in watersheds that have been logged.

At Nahatlatch Lake, multiple steep creeks intersect the Nahatlatch forest service road, including Squakum Creek. Properties at the west end of Hannah Lake are susceptible to infrequent debris flows, but changes in frequency and magnitude of intense rainfall events due to climate change may cause future events across the entire electoral area (Thurber, November 2, 1992).

4.4.1.3 Landslides

Recorded landslides have occurred predominantly on the mountainous slopes adjacent to the Fraser River. The landslides include debris flows, surficial soil slides, and rock falls.

Numerous historic landslides in the electoral area intersect or are located upslope of property and development permit areas. These areas may pose a hazard to downslope assets. The communities of Boston Bar, Canyon Alpine, and North Bend are developed at the base of steep slopes that are susceptible to shallow slope failures and, less likely, rock falls. Residences and businesses at the base of these slopes, especially where undercut, should be aware of potential upslope hazards (Thurber, January 12 1989a, b, c). Landslides are more likely to be recorded in developed areas, so there are likely many undocumented historic landslides.

4.4.1.4 Seismic

Historically, earthquakes in Area A have been low magnitude (2 or lower) (Halchuk et al., 2015; NRCan, 2022). However, due to proximity to the Cascadia Subduction Zone (NRCan, 2015), Area A may experience ground shaking and associated effects from a coastal earthquake.

4.4.1.5 Snow Avalanche

Snow avalanche hazard mapping is usually constrained to developed areas in the alpine, such as ski resorts, and therefore limited detailed mapping is available in the electoral area. Snow avalanches have occurred along Highway 1, and while they may cause disruption to transportation between communities along the corridor, they are unlikely to cause severe damage to assets within the communities in Area A due to proximity of infrastructure to slopes.

4.4.1.6 Wildfires

The 2019 Provincial Strategic Threat Analysis (PSTA) identified the Fraser Valley in Area A as moderate to extreme wildfire threat, while Blackwell assessed the fire behaviour threat rating at low to extreme, with a predominance of the area north of Tsileuh Creek as high with high to extreme WUI threat (Blackwell, June 30, 2020a). Nahatlatch Valley is one of two locations in the FVRD where the BCWS identified lightning-caused wildfires as a concern (Blackwell, June 30, 2020a). In 2016, a wildfire caused property damage to Boston Bar.

4.4.2 Consequences

A summary of elements at risk susceptible to steep creek and flood hazards, based on the boundaries of existing mapped alluvial fans and floodplains, is provided in Table 4-2. No floodplain mapping was available in Electoral Area A and therefore no elements are identified. This should not be interpreted to indicate that there is no risk from flooding in this area, and instead indicates that additional mapping is required (Section 6.0). Potential consequences of hazards in Electoral Area A are summarized in Table 4-3.

			Steep Creek	Floodplain
Number of Mapped Hazards			17	-
Mapped Hazard Area (km²)			1.8	-
Community	Property	Total No. of Properties	117	-
		No. of Registered Businesses	1	-
Lifeline	Transportation	Length of Highway (km)	0.3	-
		Length of Railway (km)	2.4	-
		Length of Roads (km)	6.0	-

Number of floodplains represents the number of individual mapped water courses.

Table 4-2.

Elements within mapped steep creek and flood hazard areas in Electoral Area A.

Type	Element at Risk	Consequence
Community	People	» Loss of life is a potential consequence to persons hit by landslide, snow avalanche, and steep creek hazards, or trapped by wildfires. » Indirect consequences of disrupted access to transportation corridors include elevated risk to community members reliant on goods and services (e.g. food, water, medical services, school, banking, etc.). Damage to utilities can similarly elevate risk if water, power, and/or communications are cut off or de-energized during disasters. » Private property located in hazard zones, including at the base of steep slopes and in areas of low elevation, is susceptible to damage by landslide and steep creek hazards. Standing water damage due to clearwater flooding is also possible in localized depressions.
	Critical Facilities	» Boston Bar Elementary, Boston Bar Health Centre, Boston Bar North Bend Firehall, and Boston Bar Royal Canadian Mounted Police (RCMP) are in the community of Boston Bar. These facilities are located a minimum of 100 m from the base of steep slopes on the east side of the community and increased offset distance reduces risk from landslides.
	Environmental Values and Areas of Cultural Significance	» Disruption to and destruction of ecosystems and/or areas of cultural significance are potential consequences of flooded or washed-out land, forests burned by wildfire, landslides, and unseasonal occurrences of atmospheric events. Areas of critical habitat are especially susceptible to the impacts of geohazards. » Impacts to utilities (listed below) may have environmental consequences.
Lifeline	Transportation	» Damage, destruction, and/or closure to Highway 1 and rail due to 1) erosion of steep channel banks and standing water during riverine flooding; 2) landslide and debris-flow/debris-flood impact forces and debris deposition. This incurs repair, mitigation, and rerouting costs depending on the duration of closure. » Closure of Highway 1 and rail due to snow avalanche deposition, in which significant damage is unlikely but closure costs are incurred. » Closure of Highway 1 due to wildfires may cut off emergency access.
	Utilities / Infrastructure	» Water intakes located in steep creeks with frequently occurring events may be damaged due to sediment infill and/or impact forces. » Linear infrastructure, including sewer, powerlines, petroleum and natural gas lines, water supply, and communications, is susceptible to damage from impact forces of landslides and steep creek events.

Table 4-3.

Potential consequences of hazards in Electoral Area A.

4.5 Electoral Area B

Electoral Area B has a population of 869 people and 598 private dwellings as of 2021 (Statistics Canada, 2023). Three major river systems transect the Area: the Fraser, Nicolum, and Coquihalla rivers (Figure 4-2). Spuzzum, Yale, Choate, Dogwood Valley, Emory Creek, Ruby Creek, and Laidlaw are located along the Fraser River and Highway 1.

Developed land is mostly concentrated along these valleys, except for properties along Silverhope Creek south of Hope. CN and CKPC railways follow the Fraser River valley through the Electoral Area. Westcoast natural gas pipelines and TransMountain petroleum pipelines run through the Area.

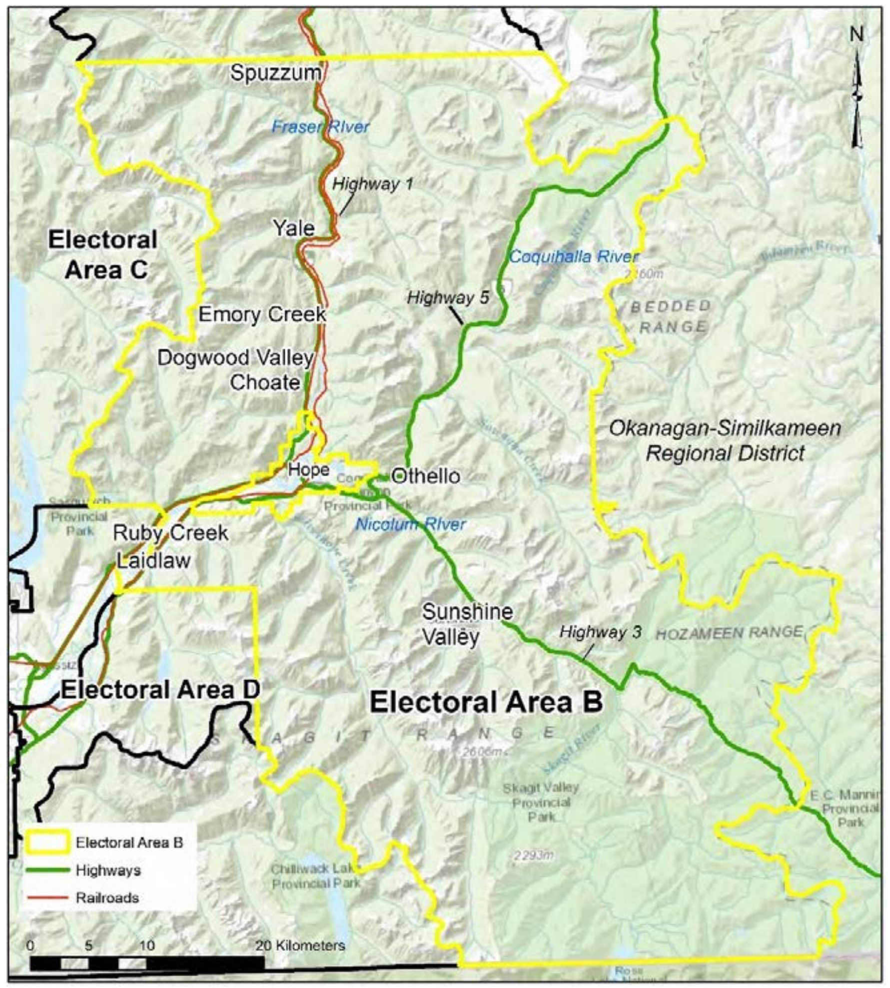


Figure 4-2.

Electoral Area B site overview.

4.5.1 Description of Hazards

4.5.1.1 Clear-Water Floods

Laidlaw and Ruby Creek are in the Fraser River floodplain and are susceptible to flooding as they are not currently protected by dikes. Some structures and access roads at Laidlaw are below the Fraser River design flood elevation, suggesting flood mitigation strategies are needed (Water Management Consultants, June 17, 2009).

Communities north of Hope are generally above the Fraser River floodplain, but flooding is possible during intense rainfall, when creeks and surface runoff flow into low-lying areas. Sunshine Valley is located at the confluence of several creeks and gullies. The area southwest of Highway 3 is in the Sumallo River floodplain, and most recently flooded in November 2021.

Sediment transport along Dewdney Creek, a tributary of the Coquihalla River located east of Highway 5, poses a hazard to utilities that cross under the creek (Dobson Engineering, June 1, 1998). Channel destabilization and scour is especially a concern at the mouth of Dewdney Creek, and increased sediment could impact infrastructure downstream along Coquihalla River.

4.5.1.2 Steep Creeks

Mapped steep creeks hazards in Area B are numerous along the mountainous slopes that border the main highway corridors. Infrastructure and community assets transected by steep creeks are susceptible to damage and closure during extreme rainfall.

The steep slopes along Highway 1 near Laidlaw experience frequent debris flows and debris floods, and have been the subject of many hazard assessments. In the November 2021 atmospheric river, floods and debris floods on Lorenzetta and Wahleach creeks caused private property and infrastructure damage due to sediment and water (Statlu, January 24, 2022).

4.5.1.3 Landslides

Landslides recorded Area B include a spectrum of types in both surficial material and rock. Landslides have caused highway closures, especially during months of highest precipitation (October through February). Large, deep-seated post-glacial rock fall deposits have been identified on either side of the Fraser River between Hope and Yale (Friele, 2017). The Graveyard Creek, Kuthlalth, Katz, and Lake of the Woods landslides are examples of major rockslides that occurred thousands of years ago originating in poor quality bedrock (Friele, 2017; Evans and Savigny, 1994). Due to the regional bedrock geology and fault systems, Yale is in a potential rock fall hazard zone (QCD, April 18, 2008). Rock falls and avalanches have been recorded on the mountainous slopes of the lower Fraser River valley, including in Area B.

Areas of Dogwood Valley, located at the toe of steep forested slopes, are susceptible to slow-moving surficial landslides (Thurber, January 4, 1990). Other communities along the lower Fraser River valley may be susceptible to these hazards where geologic conditions are similar.

The 1965 Hope Slide is an example of instability of the rock slopes in the Sunshine Valley area. Similar geologic conditions have been observed from the crest of the slide across the upper mountain slope to Huckleberry Creek canyon, and while the probability of a destructive slide is uncertain, the potential consequences are high (Thurber, May 26, 2006). Flooding and resulting erosion and debris flows on the Sumallo River and Cedar Creek fans are likely to have a much higher occurrence than a large bedrock landslide (Thurber, March 7, 2003).

4.5.1.4 Seismic

Historically, earthquakes in Area B have been low magnitude (70 recorded earthquakes M4.5 or lower between 1627 and 2020) (Halchuk et al., 2015; NRCan, 2022). Area B may experience ground shaking and associated effects from a coastal earthquake. Liquefaction potential along Coquihalla, Nicolum, and Fraser Rivers should be considered as part of land use planning.

4.5.1.5 Snow Avalanche

Small snow avalanches have occurred in the steep valley slopes of the Sunshine Valley area. Continued deforestation of steep slopes will likely increase the number of active avalanche sites (Thurber, August 5, 1977). Avalanches along Highway 5 can cause highway closures.

4.5.1.6 Wildfires

The Fraser Valley north of Hope to Yale is identified as moderate to extreme wildfire threat in the 2019 PSTA, while Blackwell assessed fire behaviour threat rating at low to extreme with high to extreme WUI threat at communities in this valley (Blackwell, June 30, 2020a). Sunshine Valley is one of two locations in the FVRD where the BCWS identified lightning-caused wildfires are a concern (Blackwell, June 30, 2020a).

4.5.2 Consequences

A summary of elements at risk susceptible to steep creek and flood hazards, based on the boundaries of existing mapped alluvial fans and floodplains, is provided in Table 4-4. Existing floodplain mapping does not extend along the Fraser River north of Hope, and the summary may underestimate risk from flooding. Table 4-5 summarizes the potential consequences of geohazards described by community and lifeline assets.

			Steep Creek	Floodplain
Number of Mapped Hazards			169	10
Mapped Hazard Area (km²)			12.2	20.5
Community	Property	Total No. of Properties	637	740
		No. of Registered Businesses	4	19
Lifeline	Transportation	Length of Highway (km)	9.5	14.6
		Length of Railway (km)	4.0	12.5
		Length of Roads (km)	36.4	75.8

Number of floodplains represents the number of individual mapped water courses.

Table 4-4.

Elements within mapped steep creek and flood hazard areas in Electoral Area B.

Type	Element at Risk	Consequence
Community	People	» Loss of life is a potential consequence to persons hit by landslide and steep creek hazards, or trapped by wildfires. » Indirect consequences of disrupted access to transportation corridors include elevated risk to community members reliant on goods and services (e.g. food, water, medical services, school, banking, etc.). Damage to utilities can similarly elevate risk if water, power, and/or communications are cut off or de-energized during disasters. » Private property located in hazard zones, including at the base of steep slopes and in areas of low elevation, is susceptible to damage by landslide and steep creek hazards. Standing water damage due to clearwater flooding is also possible in localized depressions.
	Critical Facilities	» Yale Fire Halls #1 and #2 are located outside the currently mapped Fraser River floodplain and alluvial fan extents. They are interpreted to have low risk of damage due to flood and steep creek hazards based on the information presently available; however, floodplain mapping in this area is limited and should be reviewed.
	Environmental Values and Areas of Cultural Significance	» Disruption to and destruction of ecosystems and/or areas of cultural significance are potential consequences of flooded or washed-out land, forests burned by wildfire, landslides, and unseasonal occurrences of atmospheric events. » Areas of critical habitat are especially susceptible to the impacts of geohazards. » Impacts to utilities (listed below) may have environmental consequences.
Lifeline	Transportation	» Damage to and/or closure of Highways 1, 3, and 5, and rail due to erosion of steep channel banks and standing water during riverine flooding, and due to impact or deposition from landslides, steep creek hazards, and snow avalanches.
	Utilities / Infrastructure	» Water intakes located in steep creeks may be damaged due to sediment infill or impact from landslides and steep creek hazards. » Linear infrastructure, including powerlines, petroleum and natural gas lines, water supply, and communications, is susceptible to damage from impact of landslides and steep creek hazards.

Table 4-5.

Potential consequences of hazards in Electoral Area B.

4.6 Electoral Area C

Electoral Area C has a population of 1,133 people and 894 private dwellings as of 2021 (Statistics Canada, 2023). It is in the Coast Mountains on the north side of the Fraser River and is bordered to the north by the Squamish-Lillooet Regional District (SLRD) (Figure 4-3). Major waterways include the Lillooet River that flows southeast into Harrison Lake which outlets into Harrison River, a tributary of the Fraser River.

Harrison Mills, Lake Errock, and Weaver Creek are located southwest of Harrison Lake. Hemlock Valley is in the southwestern slopes adjacent to Harrison Lake. While most developed land is concentrated in the southern communities, there are properties along Harrison Lake and the Lillooet River. Highway 7 and CPKC rail cross in the south.

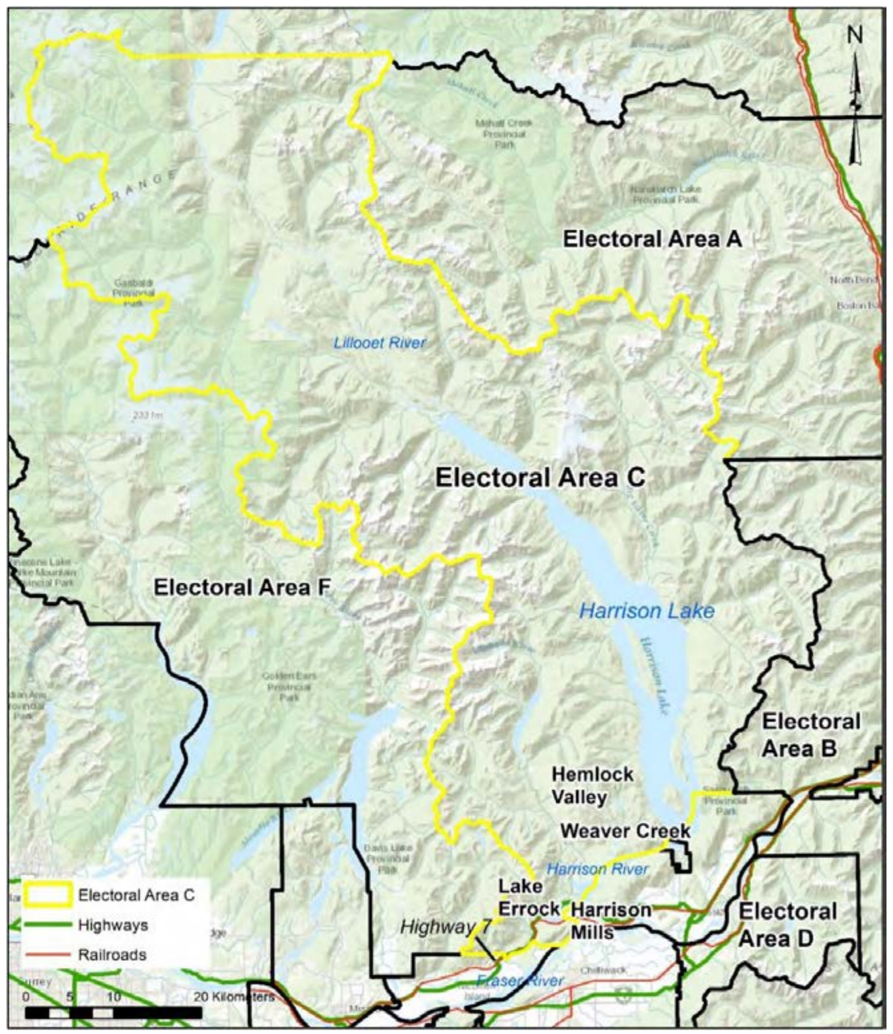


Figure 4-3.

Electoral Area C site overview.

4.6.1 Description of Hazards

4.6.1.1 Clear-Water Floods

Due to their low-lying locations along the Fraser/Harrison River floodplain, Weaver Creek, Harrison Mills, and Lake Errock are susceptible to flooding during high flows. Numerous creeks and gullies outlet from the steep slopes that border the communities and can cause localized flooding during intense rainfall.

The northern area of Harrison Mills is on the Elbow Creek alluvial fan and is subject to the impacts of channel flooding (NHC, February 3, 1997). At Hemlock Valley, some properties are within the mapped floodplain setback of Sakwi Creek, and a maintenance yard and nearby buildings, including the community fire hall, are built in a gravel pit susceptible to water ponding. Flood mitigation could be beneficial for buildings in these areas (Thurber, February 1999).

4.6.1.2 Steep Creeks

Many active creeks along south-facing steep slopes north of the Fraser River and Highway 7 have been the subject of hazard assessments. These creeks pose debris-flow, debris-flood, and erosion hazards to infrastructure within and potentially downstream of their alluvial fans.

Cordilleran (April 29, 2012) conducted a hazard assessment for fan and flood hazards in Lake Errock, noting that Siddle and Holacthen creeks have a frequency of overbank flows. Cordilleran identified existing developments within the creek fans and floodplains as safe for residential use with implementation of protective works. Cordilleran recommended detailed hazard assessment to support development in the area at the top of the fans of Siddle, Squakum, and Holachten creeks, and where development involves a general increase in risk exposure (i.e. subdivision of lots) (Cordilleran, April 29, 2012). Potential channel capacity and erosion concerns were also noted at the Highway 7/CPKC rail crossing of lower Holachten Creek. Elbow Creek has a history of significant sediment transport and deposition in developed areas (NHC, February 3, 1997). A dike parallels the north side of the creek by Eagle Point Estates.

4.6.1.3 Landslides

Landslides have been recorded in the mountainous slopes across Area C, including rock falls and surficial slides at Elbow Creek, Echo Lake, Holachten Creek, and in the gullies along the eastern slopes of Harrison Lake. Slides along Highway 7 have caused road closures in the past.

Continued landslide activity at Mount Breakenridge Slide, on the east side of Harrison Lake, could generate flood waves that impact low-lying areas near Harrison Bay at Lake Errock (Thurber, September 3, 1998). The Mount Douglas and Silver Mountain landslides are additional potential sources of landslide-generated floods at Harrison Lake (Hughs et al., 2021).

Landslides in the Sakwi Creek watershed may initiate debris flows and debris floods that may impact property within hazard zones, mainly along Edelweiss Drive (Thurber, February 1999).

4.6.1.4 Seismic

Area C may experience ground shaking and associated effects from a coastal earthquake. The south portion of Area C bordering the Fraser River floodplain is mapped as gravel and sand sediments with low liquefaction hazard (GSC, 1998). Liquefaction potential along the Lillooet River was not evaluated as part of this scope and should be reviewed during land use planning.

4.6.1.5 Snow Avalanche

Dynamic (October 6, 2020) summarized snow avalanche data for Hemlock Valley and identified numerous "moderate" hazard paths (estimated 300-year return period) along Edelweiss Drive. They noted that forest loss in colluvial ground conditions encourages avalanche activity and areas that experience forest growth will likely experience reduced avalanche activity.

4.6.1.6 Wildfires

Developed areas on the shores of Harrison Lakes are identified as low to moderate wildfire threat with isolated areas of extreme threat in the 2019 PSTA. South-facing slopes north of the Fraser River are identified as moderate to extreme threat in the 2019 PSTA. Blackwell assessed fire behaviour threat rating at moderate to extreme, with high WUI threat in both areas (Blackwell, June 30, 2020a).

The two largest fires in Area C occurred along the Harrison Lake shoreline in 1958 (lightning) and 2015 (cause unknown). BCWS note that high recreational use along with forestry, railways, and other industrial uses contribute to fire risk in the area (Blackwell, May 19, 2020b).

4.6.2 Consequences

A summary of elements at risk susceptible to steep creek and flood hazards, based on existing mapping is provided in Table 4-6. Existing floodplain mapping in Area C does not extend north of Harrison River, and the summary may underestimate flood risk. Table 4-7 summarizes the potential consequences of geohazards in Area C described by community and lifeline assets.

			Steep Creek	Floodplain
Number of Mapped Hazards			35	2
Mapped Hazard Area (km²)			28.1	28.0
Community	Property	Total No. of Properties	1,106	587
		No. of Registered Businesses	12	6
Lifeline	Transportation	Length of Highway (km)	4.9	3.0
		Length of Railway (km)	3.2	0.3
		Length of Roads (km)	56.9	28.1

Number of floodplains represents the number of individual mapped water courses.

Table 4-6.

Elements within mapped steep creek and flood hazard areas in Electoral Area C.

Type	Element at Risk	Consequence
Community	People	» Loss of life is a potential consequence to persons hit by landslide and steep creek hazards, or trapped by wildfires. At Harrison Lake, landslide-generated waves are a possible secondary hazard that may cause injury or death to persons and damage to property within proximity of the impact zone. Recreational day visitors without lodging options need to be considered when planning emergency response in this area. » Indirect consequences of disrupted access to transportation corridors include elevated risk to community members reliant on goods and services (e.g. food, water, medical services, school, banking, etc.). Damage to utilities can similarly elevate risk if water, power, and/or communications are cut off or de-energized during disasters. » Private property located in hazard zones, including at the base of steep slopes and in areas of low elevation, is susceptible to damage by landslide and steep creek hazards. Standing water damage due to clearwater flooding is also possible in localized depressions.
	Critical Facilities	» Hemlock Valley Fire Department is exposed to the impacts of landslides and snow avalanches. Damage and/or loss of access to North Fraser Fire Hall #2 due to steep creek hazards.
	Environmental Values and Areas of Cultural Significance	» Disruption to and destruction of ecosystems and/or areas of cultural significance are potential consequences of flooded or washed-out land, forests burned by wildfire, landslides, and unseasonal occurrences of atmospheric events. » Loss of recreational areas is a potential consequence of flood, steep creek, and landslide hazards. Recreational trails that cross steep slopes may be susceptible to snow avalanches during winter months. » Impacts to utilities (listed below) may have environmental consequences.
Lifeline	Transportation	» Damage to and/or closure of Highway 7 and the CPKC railway line due to flooding within the Harrison River floodplain. » Damage to and/or closure of roads and Highway 7 due to impact or deposition from landslides and steep creeks along the slopes north of the Fraser River.
	Utilities / Infrastructure	» Water intakes located in steep creeks with frequently occurring events may be damaged due to sediment infill and/or impact. » Linear infrastructure, including powerlines, water supply, and communications, is susceptible to damage from landslides and steep creek events.

Table 4-7.

Potential consequences of hazards in Electoral Area C.

4.7 Electoral Area D

Electoral Area D has a population of 2,092 people and 735 private dwellings as of 2021 (Statistics Canada, 2023). It is on the southeastern side of the Fraser River and Highway 1. Popkum and Bridal Falls are located off Highway 1 near the western boundary of the electoral area and are bordered by the steep slopes of the northern Cascade Mountains.

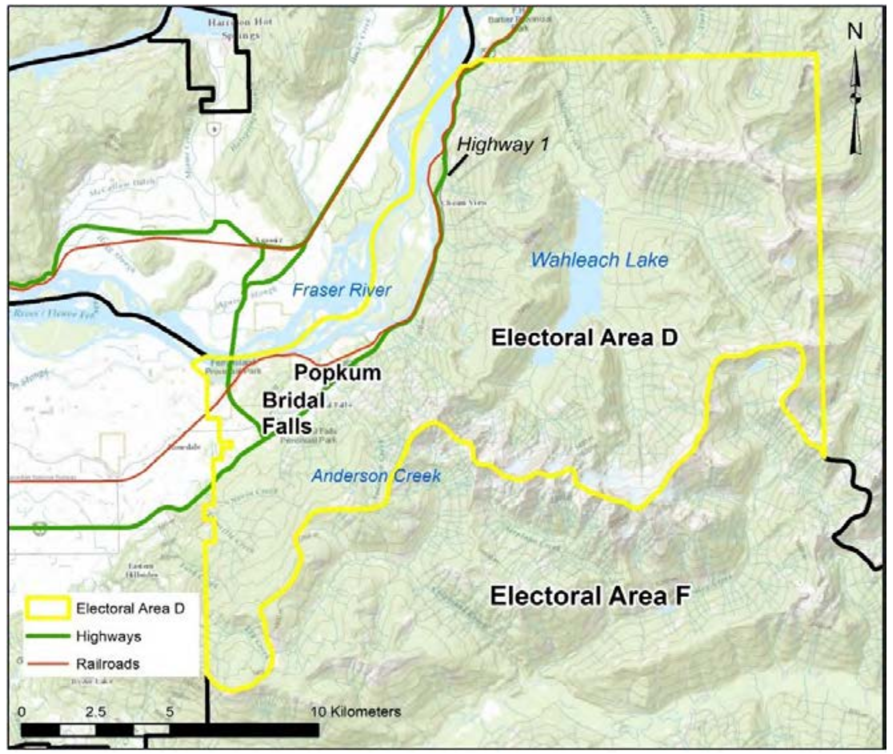


Figure 4-4.

Electoral Area D site overview.

4.7.1 Description of Hazards

4.7.1.1 Clear-Water Floods

Riverine flooding is unlikely to affect communities as most residences are above the Fraser River floodplain. Mountain creeks prone to flooding transect populated areas. In 2021, Anderson and Waterslide creeks flooded several properties and roads (Statlu, December 20, 2021).

4.7.1.2 Steep Creeks

Active steep creeks in the area include, but are not limited to, Popkum, Bridal Falls, Ted, and Cheam East and West creeks. Agricultural and residential lands in debris runout extents are susceptible to sediment and debris impact and deposition. Cordilleran and Braun Geotechnical Ltd. (Braun) mapped the area immediately south of Highway 1 as potential to significant hazard (Cordilleran & Braun, 2014). Within Area D, 24 alluvial fans have been mapped along Highway 1, and at least 46 debris flows and debris floods have deposited onto the highway (BGC, April 21, 2023).

4.7.1.3 Landslides

Debris avalanches and rock slides are common along the slopes bordering communities in Area D. BGC assessed landslide hazards for Bridal Falls (BGC, February 1, 2018). Golder (January, 1984) observed a significant rock fall west of Bridal Falls with boulders up to 5 m in diameter. Popkum Slide is a historic landslide estimated at 10 to 50 million m3 or more (Hardy, October 17, 1991). It may have occurred at the time of an M7.4 earthquake in 1872. Cheam Slide is estimated to have been up to 150 million m3 (Orwin et al., 2004). Golder (January, 1984) estimated runout from Cheam Slide extended 2.5 km north into the Fraser River.

4.7.1.4 Seismic

Area D may experience ground shaking and associated effects from a coastal earthquake. The northwest portion of Area D within the Fraser River floodplain is mapped as a combination of peat, silt and clay, and gravel and sand with moderate to high liquefaction hazard (GSC, 1998).

4.7.1.5 Snow Avalanche

Thurber (1999, May 25) assessed a snow avalanche on Mount Cheam near Anderson Creek.

4.7.1.6 Wildfires

Blackwell assessed the fire threat behaviour class along Highway 1 within Area D as low to extreme, with highest ratings on north-facing slopes south of the highway and the west side of Herrling Island and high WUI threat east of Bridal Falls Provincial Park (Blackwell, June 30, 2020b).

4.7.2 Consequences

Table 4-8 summarizes elements at risk from steep creek and flood hazards. The summary may underestimate flood risk, as existing floodplain mapping does not extend south of the Fraser River. Table 4-9 summarizes the potential consequences of geohazards in Area D.

			Steep Creek	Floodplain
Number of Mapped Hazards			24	1
Mapped Hazard Area (km²)			5.8	15.5
Community	Property	Total No. of Properties	279	128
		No. of Registered Businesses	6	3
Lifeline	Transportation	Length of Highway (km)	7.5	1.4
		Length of Railway (km)	6.4	4.9
		Length of Roads (km)	26.9	8.1

Number of floodplains represents the number of individual mapped water courses.

Table 4-8.

Elements within mapped steep creek and flood hazard areas in Electoral Area D.

Type	Element at Risk	Consequence
Community	People	» Loss of life is a potential consequence to persons hit by landslide and steep creek hazards, or trapped by wildfires. Indirect consequences of disrupted access to transportation corridors include elevated risk to community members reliant on goods and services (e.g. food, water, medical services, school, banking, etc.). Damage to utilities can similarly elevate risk if water, power, and/or communications are cut off or de-energized during disasters. » Private property located in hazard zones, including at the base of steep slopes and in areas of low elevation, is susceptible to damage by landslide and steep creek hazards. Standing water damage due to clearwater flooding is also possible in localized depressions.
	Critical Facilities	» Loss of access to Popkum Fire department and other facilities due to steep creek and landslide hazards depositing on access roads may increase risk during emergencies.
	Environmental Values and Areas of Cultural Significance	» Disruption to and destruction of ecosystems and/or areas of cultural significance are potential consequences of flooded or washed-out land, forests burned by wildfire, landslides, and unseasonal occurrences of atmospheric events. » Bridal Veil Falls Provincial Park is near steep slopes and mapped as a "significant hazard" area by Cordilleran and Braun (2014). Loss of recreational areas is a potential consequence of steep creek and landslide hazards. Recreational trails that cross steep slopes may be susceptible to snow avalanches during winter months. » Impacts to utilities (listed below) may have environmental consequences.
Lifeline	Transportation	» Damage to and/or closure of Highway 9 and the Agassiz-Rosedale Bridge due to flooding in the Fraser River. » Damage to and/or closure of Highway 1 due to rock falls along slopes and steep creek hazards near creeks and on alluvial fans. » Damage to and/or closure of the CN railway due to flooding in the Fraser River floodplain and steep creek hazards near creeks and on alluvial fans.
	Utilities / Infrastructure	» Water intakes located in steep creeks with frequently occurring events may be damaged due to sediment infill and/or impact forces. » Linear infrastructure, including powerlines, petroleum and natural gas lines, water supply, and communications, is susceptible to damage from impact forces of landslides and steep creek events.

Table 4-9.

Potential consequences of hazards in Electoral Area D.

4.8 Electoral Area E

Electoral Area E has a population of 1,568 people and 724 private dwellings as of 2021 (Statistics Canada, 2023). The area is north of the U.S. in the northern Cascade Mountains (Figure 4-6). Chilliwack River valley transects the area and includes Baker Trails, Bell Acres, Slesse Park, and Post Creek. Access is by Chilliwack Lake Road on the north side of the river.

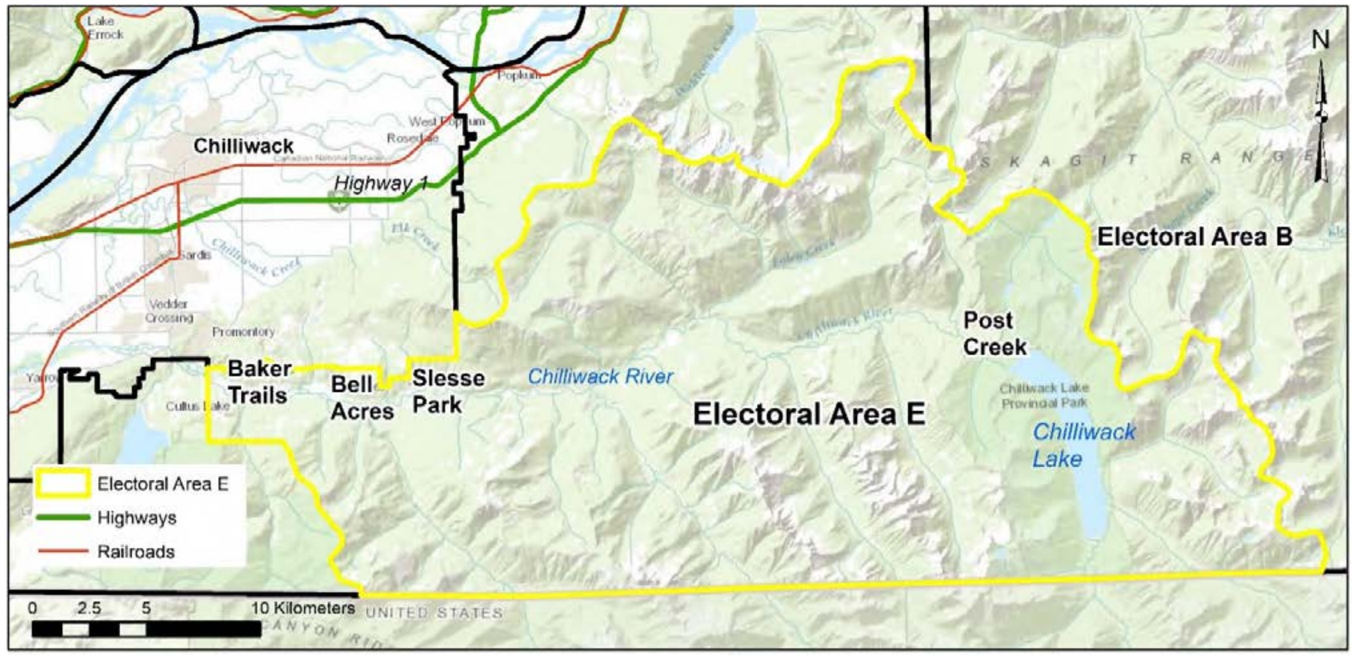


Figure 4-5.

Electoral Area E site overview.

4.8.1 Description of Hazards

4.8.1.1 Clear-Water Floods

Communities within the Chilliwack River floodplain may be susceptible to flooding during high flows. NHC (March 1991) noted that the Chilliwack River channel shifted and widened during flooding in 1989 and 1990, causing erosion along the high terraces that may affect the hazard level. Golder (April 12, 2002) discussed flooding during December 1975 and 1980, and January 1984. Ongoing loss of land is expected along the river due to the erosion (Thomson, 1998).

4.8.1.2 Steep Creeks

Baker Trails is constructed on the alluvial fans of Tank, Guy, Briar, and Wash creeks. Golder characterized these creeks as susceptible to debris flows and debris floods. McKelvie Creek is on the southeast of the village and is susceptible to debris floods (Golder, May 21, 2004).

Golder (March, 1993) identified the area between Slesse Park and Vedder Crossing as susceptible to destructive debris flows and debris floods. Slopes in this area are steep and have abundant erodible material. The presence of alluvial fans is evidence of historical debris flows.

4.8.1.3 Landslides

In December 2015, several large landslides occurred in the Slesse Park clay slides area (Statlu, January 27, 2016). This area is characterized by thick silt and clay deposits that have been eroded by a large bend in the river (Fletcher, 2000). Other landslides (i.e. the Tolmie Slide on the south bank) and debris flows have occurred in these deposits. The Ryder Creek watershed is prone to landslides. Expected runout from future landslides is unlikely to impact downslope assets (Thurber, February 26, 1998). Landslides at Anderson Run and Allison Run due to beaver ponds at the top of these slides resulted in bank erosion.

4.8.1.4 Seismic

Area E may experience ground shaking and associated effects from a coastal earthquake. The Chilliwack River floodplain east of Cultus Lake is mapped as moderate to high liquefaction hazard (GSC, 1998).

4.8.1.5 Snow Avalanche

Limited snow avalanche mapping is available for Area E. Avalanches are likely possible along the slopes and in watersheds above community assets.

4.8.1.6 Wildfires

Blackwell (June 30, 2020b) assessed fire threat behaviour along the Chilliwack River Valley as low to extreme, with highest ratings on south-facing slopes immediately west of Chilliwack Lake. Chilliwack Lake Road is the only egress route for riverside communities and is a vulnerability.

4.8.2 Consequences

Table 4-10 summarizes elements at risk from steep creek and flood hazards. The summary may underestimate flood risk, as existing floodplain mapping does not extend to the eastern side of the Area. Table 4-11 summarizes the potential consequences of geohazards in Area E.

			Steep Creek	Floodplain
Number of Mapped Hazards			20	1
Mapped Hazard Area (km²)			2.8	6.0
Community	Property	Total No. of Properties	313	210
		No. of Registered Businesses	3	2
Lifeline	Transportation	Length of Highway (km)	0	0
		Length of Railway (km)	0	0
		Length of Roads (km)	10.7	12.4

Number of floodplains represents the number of individual mapped water courses.

Table 4-10.

Elements within mapped steep creek and flood hazard areas in Electoral Area E.

Type	Element at Risk	Consequence
Community	People	» Loss of life is a potential consequence to persons hit by landslide and steep creek hazards, or trapped by wildfire. Indirect consequences of disrupted access to transportation corridors include elevated risk to community members reliant on goods and services (e.g. food, water, medical services, school, banking, etc.). Damage to utilities can similarly elevate risk if water, power, and/or communications are cut off or de-energized during disasters. » Private property located in hazard zones, including at the base of steep slopes and in areas of low elevation, is susceptible to damage by landslide and steep creek hazards. Damage due to standing water and bank erosion during riverine flooding is also possible.
	Critical Facilities	» Reduced or complete loss of access to the Chilliwack River Valley Fire Department due to flooding in the Chilliwack River. » Ford Mountain Correctional Centre is located on the eastern end of the Chilliwack River valley and may lose access to major transportation routes during a flood event.
	Environmental Values and Areas of Cultural Significance	» Disruption to and destruction of ecosystems and/or areas of cultural significance are potential consequences of flooded or washed-out land, forests burned by wildfire, landslides, and unseasonal occurrences of atmospheric events. Shifts in vegetation caused by wildfires may move species northward and higher in elevation. » Chilliwack River Provincial Park and other parks are susceptible to flooding from the Chilliwack River. Critical fish-bearing habitat disturbed by clay and silt deposits into the Chilliwack River due to landslides and steep creek hazards. » Impacts to utilities (listed below) may have environmental consequences.
Lifeline	Transportation	» Damage to and/or closure of the Chilliwack Lake Road due to flooding in the Chilliwack River floodplain and/or landslides adjacent to slopes, and steep creek hazards on alluvial fans or creeks. Closure of Chilliwack Lake Road due to wildfires blocking egress, and/or increased accidents due to limited visibility. » Bench/Army Forest Service Road is seasonally passable for emergency egress and affected by high water.
	Utilities / Infrastructure	» Water intakes located in steep creeks with frequently occurring events may be damaged due to sediment infill and/or impact forces. Slesse Park Dike and Revetment, Wilson Road Mud Berm, and Slesse Slide Erosion Protection are orphan dikes within the Area that could increase downstream impacts if one or more fail. » Linear infrastructure, including powerlines, water supply, and communications, is susceptible to damage from impact forces of landslides and steep creek events.

Table 4-11.

Potential consequences of hazards in Electoral Area E.

4.9 Electoral Area F

Electoral Area F has a population of 1,384 people and 783 private dwellings as of 2021 (Statistics Canada, 2023). The area makes up the northwest portion of the FVRD bordered by the Metro Vancouver Regional District (MVRD) to the west and SLRD to the north.

Large waterways include the Stave and Pitt river systems that ultimately outlet into the Fraser River. Most developed land is located northeast of Mission in the areas of Miracle Valley, McConnell Creek, Durieu, and Hatzic Prairie (collectively called the Hatzic Valley), and is primarily characterized by agricultural and rural-residential property.

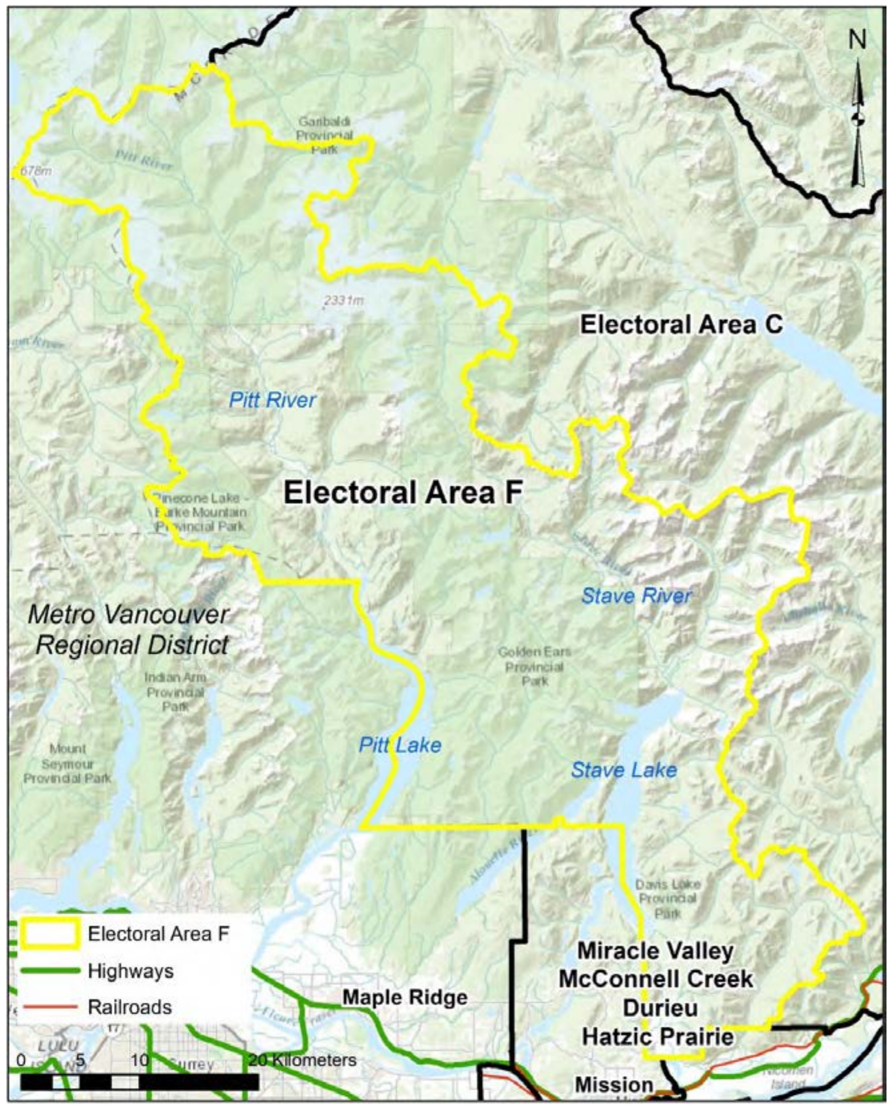


Figure 4-6.

Electoral Area F site overview.

4.9.1 Description of Hazards

4.9.1.1 Clear-Water Floods

The southern portion of the Hatzic Valley up to Durieu is within the Fraser River floodplain. Numerous creeks run along the valley floor and are often susceptible to flooding, including the Pattison and Lagace creek system which flows from Miracle Valley south into Hatzic Lake. Flooding of Lagace Creek has historically caused sediment deposition on adjacent properties (NHC, March 1985).

In November 2021, flooding on several creeks in Hatzic Prairie, including Lagace, North and South Herford, MacNab, Eng, Davies, and Pattison, caused channel bank erosion, flooding, and sediment deposition on agricultural lands and roads (Stirling Geoscience, December 2021).

The northern area of the valley is susceptible to flooding from Stave Lake and Cascade Creek. Intense rain caused flooding of the prairie at Cascade Creek in 1961 (Septer, 2007). A report by the Province of British Columbia (March, 1983) found that logging and clearing for transmission lines has increased the frequency of flooding in the Cascade Creek watershed.

4.9.1.2 Steep Creeks

BGC (March 1, 2004) assessed steep creeks on the east ridge of the Hatzic Valley. Field, Eng, MacNab, Dale, and Carratt creeks are active debris-flow prone creeks that pose a moderate risk to assets developed on the creek fans. In 2003, a major storm caused extensive damage in the valley when debris flows on Field, Carratt, and Eng creeks, and debris floods on McNab, Saporano, Pattison, and Dale creeks caused widespread flooding and debris deposition, with minor property damage due to boulder impacts (Septer, 2007; BGC, April 27, 2023).

4.9.1.3 Landslides

Several watersheds in the Hatzic Valley are prone to landslides. Fifty-five landslides greater than 0.1 ha have been recorded in the Hatzic Lake watershed (FLNRO, 2013). A farmer was killed by a landslide in 1961 following intense rain (Septer, 2007). Pattison Creek experienced two landslides in 1990, which infilled the creek and nearly impacted two homes (Septer, 2007).

North of the Hatzic Valley, landslides have been recorded along the Pitt River and Stave River forest service roads (Brideau et al., 2023). Property along these roads may be susceptible to rock and debris runout from slope failures.

4.9.1.4 Seismic

Area F may experience ground shaking and associated effects from a coastal earthquake. Hatzic Prairie north of Hatzic Lake is mapped as sand and silt with moderate to high liquefaction hazard transitioning to gravel and sand then silt and clay northward with low liquefaction hazard (GSC, 1998). Floodplain sediments along the Pitt and Stave rivers may similarly have liquefaction potential.

4.9.1.5 Snow Avalanche

No detailed snow avalanche mapping is available in this area. As Area F is frequented for recreational purposes, people should be aware of potential avalanche terrain before traversing steep snow-covered slopes.

4.9.1.6 Wildfires

Blackwell (May 19, 2020) assessed fire threat behaviour along the western shore of Pitt Lake as low to extreme, with highest ratings near the south side of the lake. A human-caused wildfire between Alouette river and Pitt Lake in Golden Ears Provincial Park burned over 3,000 ha in 1931 (Blackwell, May 19, 2020).

4.9.2 Consequences

A summary of elements at risk susceptible to steep creek and flood hazards, based on the boundaries of existing mapped alluvial fans and floodplains, is provided in Table 4-12. Existing floodplain mapping in Electoral Area F does not extend north of Davis Lake Provincial Park, and the summary may underestimate risk from flooding. Table 4-13 summarizes the potential consequences of geohazards in Electoral Area F described by community and lifeline assets.

			Steep Creek	Floodplain
Number of Mapped Hazards			22	2
Mapped Hazard Area (km²)			9.8	10.5
Community	Property	Total No. of Properties	236	251
		No. of Registered Businesses	2	14
Lifeline	Transportation	Length of Highway (km)	0	0
		Length of Railway (km)	0	0
		Length of Roads (km)	19.1	16.2

Number of floodplains represents the number of individual mapped water courses.

Table 4-12.

Elements within mapped steep creek and flood hazard areas in Electoral Area F.

Type	Element at Risk	Consequence
Community	People	» Loss of life is a potential consequence to persons hit by landslide and steep creek hazards, or trapped by wildfires. » Indirect consequences of disrupted access to transportation corridors include elevated risk to community members reliant on goods and services (e.g. food, water, medical services, school, banking, etc.). Damage to utilities can similarly elevate risk if water, power, and/or communications are cut off or de-energized during disasters. » Private property located in hazard zones, including at the base of steep slopes and in areas of low elevation, is susceptible to damage by landslide and steep creek hazards. Standing water damage due to clearwater flooding is also possible in localized depressions.
	Critical Facilities	» Loss of access and/or damage to North Fraser Fire Hall #3 in Pattison Creek alluvial fan due to steep creek hazards.
	Environmental Values and Areas of Cultural Significance	» Disruption to and destruction of ecosystems and/or areas of cultural significance are potential consequences of flooded or washed-out land, forests burned by wildfire, landslides, and unseasonal occurrences of atmospheric events. » Golden Ears Provincial Park has steep slopes and numerous creeks which may lead to landslides and steep creek hazards that could affect recreational users. Historically wildfires have occurred. » Impacts to utilities (listed below) may have environmental consequences.
Lifeline	Transportation	» Damage to and/or closure of roadways in the Hatzic valley due to flooding in the Fraser River floodplain. » Damage to and/or closure of Stave Lake Road due to Kensworth Creek would block access to the City of Mission. » Sylvester Road to the east of the prairie provides access to Electoral Area G and is built on an unknown alluvial fan, which could have been a historical debris flow or debris flood.
	Utilities / Infrastructure	» Water intakes located in steep creeks with frequently occurring events may be damaged due to sediment infill and/or impact forces. » Linear infrastructure, including powerlines, water supply, and communications, is susceptible to damage from impact forces of landslides and steep creek events. » Infrastructure foundations within high liquefaction hazards zones are susceptible to damage during an earthquake.

Table 4-13.

Potential consequences of hazards in Electoral Area F.

4.10 Electoral Area G

Electoral Area G has a population of 1,692 people and 897 private dwellings as of 2021 (Statistics Canada, 2023). Hatzic Island, Dewdney, Nicomen Island, and Deroche are on the north bank of the Fraser River (Figure 4-7). Highway 7 connects the communities, and CPKC rail is at the base of the slopes on the north side of the Fraser River.

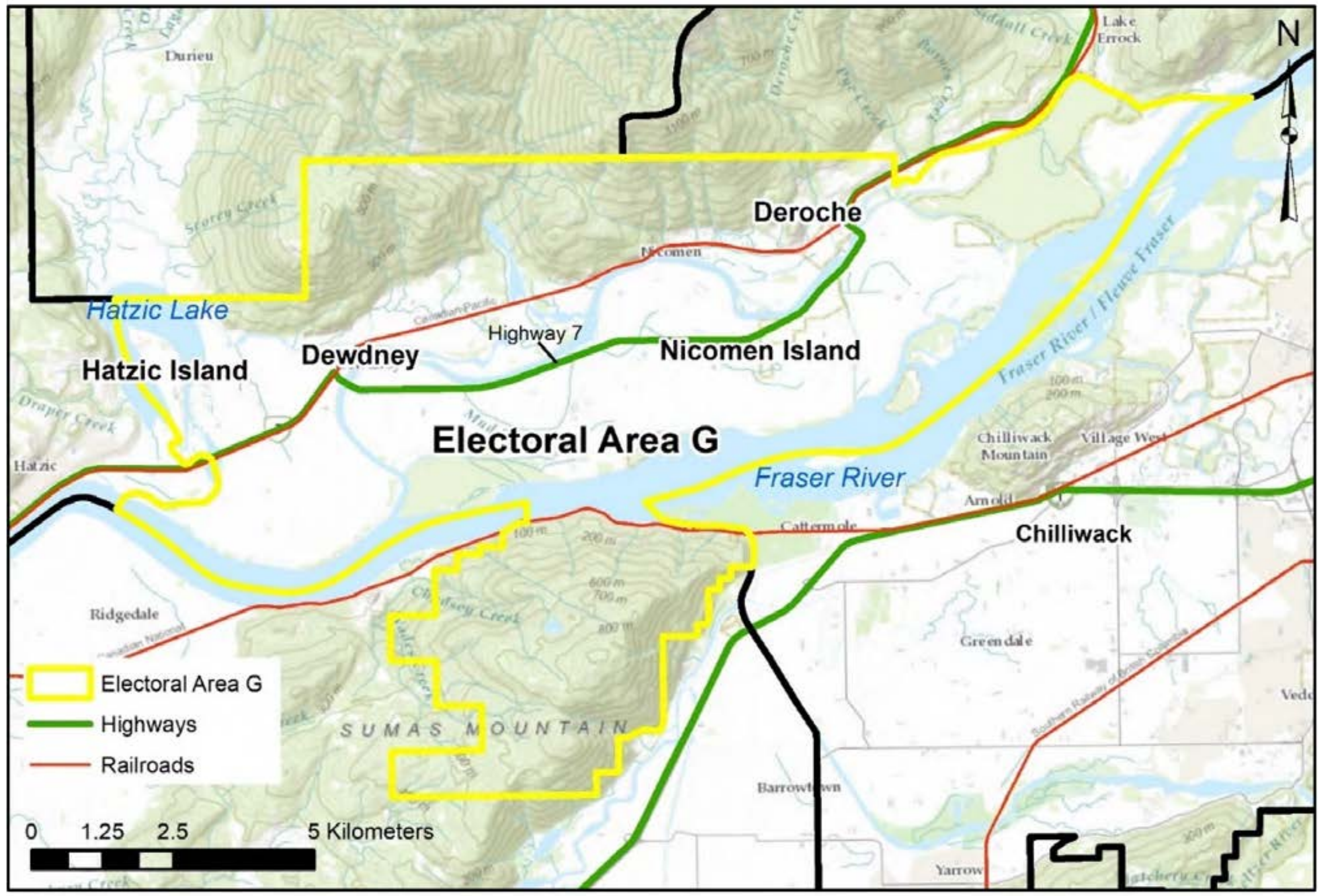


Figure 4-7.

Electoral Area G site overview.

4.10.1 Description of Hazards

4.10.1.1 Clear-Water Floods

Areas protected by the Dewdney, Nicomen Island, and North Nicomen dikes are susceptible to flooding. This infrastructure is owned, managed, and maintained by Improvement Districts. Dike failure due to stability issues poses the greatest flood hazard, and dike failure and overtopping by the Fraser River at sections of the Dewdney and Nicomen Island dikes below the design flood elevation is possible (Water Management Consultants (WMC), June 17, 2009). Golder (October 30, 2015) recommended flood mitigation improvements at Nicomen Island and noted that the impacts of climate change will increase this need. Hatzic Island is at risk of flooding when Hatzic Lake levels rise (FVRD, 2023b).

Deroche and Norrish creeks are prone to flooding during intense rainfall (KWL, June 24, 2008; NHC, August 1999). The 2006 Deroche Creek flood caused aggradation, bank erosion, and avulsion. Construction of an orphan dike3F on the west bank of Norrish Creek lowered flood potential; however, the dike has been structurally damaged by ongoing bank erosion (Westrek, April 30, 2013).

4.10.1.2 Steep Creeks

Norrish and Deroche creeks and surrounding small debris-flow channels flow down northern slopes bordering Areas C and F. Construction of the dike at Norrish Creek upstream of the railway increased sediment transport to lower reaches of the fan and rail bridge (NHC, August 1999).

4.10.1.3 Landslides

Thurber (September 21, 2004) found no evidence of very large landslides in the electoral area. They identified rock fall as possible in the mountain range to the north and suggested debris slides will have limited runout as material loses energy on the flat valley floor.

4.10.1.4 Seismic

Area G may experience ground shaking and associated effects from a coastal earthquake. The Fraser River floodplain is mapped as moderate to high liquefaction hazard (GSC, 1998).

4.10.1.5 Snow Avalanche

Areas in Dewdney and Deroche downslope of avalanche terrain could be exposed to avalanche hazards, as well as recreational trails that cross steep slopes.

4.10.1.6 Wildfires

Blackwell (May 19, 2020) assessed fire threat behaviour along the slopes above the Fraser River Valley as "moderate to extreme".

4.10.2 Consequences

Table 4-14 summarizes elements at risk from steep creek and flood hazards based on existing mapping. Table 4-15 summarizes the potential consequences of geohazards in Area G.

			Steep Creek	Floodplain
Number of Mapped Hazards			11	1
Mapped Hazard Area (km²)			6.0	74.8
Community	Property	Total No. of Properties	169	791
		No. of Registered Businesses	8	27
Lifeline	Transportation	Length of Highway (km)	0.8	13.4
		Length of Railway (km)	5.1	13.9
		Length of Roads (km)	11.6	105.2

Number of floodplains represents the number of individual mapped water courses.

Table 4-14.

Elements within mapped steep creek and flood hazard areas in Electoral Area G.

Type	Element at Risk	Consequence
Community	People	» Loss of life is a potential consequence to persons hit by landslide and steep creek hazards, or trapped by wildfires. » Indirect consequences of disrupted access to transportation corridors include elevated risk to community members reliant on goods and services (e.g. food, water, medical services, school, banking, etc.). Damage to utilities can similarly elevate risk if water, power, and/or communications are cut off or de-energized during disasters. » Property located in hazard zones, including at the base of steep slopes and in areas of low elevation, is susceptible to damage by landslide and steep creek hazards. Standing water damage due to clearwater flooding is also possible in localized depressions. » Property damage and personal injury as a result of liquefaction of sediments during an earthquake are possible and may be catastrophic depending on earthquake magnitude.
	Critical Facilities	» Loss of access or damage to North Fraser Fire Hall #1 due to flooding in the Fraser River floodplain. » Damage or loss of access to Deroche Elementary and Dewdney Elementary due to flooding within the Fraser River floodplain.
	Environmental Values and Areas of Cultural Significance	» Disruption to and destruction of ecosystems and/or areas of cultural significance are potential consequences of flooded or washed-out land, forests burned by wildfire, landslides, and unseasonal occurrences of atmospheric events. » The Fraser River ecological reserve is in an area susceptible to flooding within the Fraser River floodplain. » Sumas Mountain Regional Park has a history of landslides summarized by Thurber (December 17, 2002) » Impacts to utilities (listed below) may have environmental consequences.
Lifeline	Transportation	» Damage to and/or closure of Highway 7 and the CPKC railway due to flooding within the Fraser River floodplain. Parts of both are built on the Norrish and Deroche creek alluvial fans, making them susceptible to steep creek hazards. » Damage to and/or closure of the CPKC railway due to steep mountain slopes near Nicomen slough, making it vulnerable to landslide and snow avalanche hazards.
	Utilities / Infrastructure	» Water intakes located in steep creeks with frequently occurring events may be damaged due to sediment infill and/or impact forces. Norrish Creek Dike is an orphan dike and could increase downstream impacts if it fails. » Linear infrastructure, including powerlines, water supply, and communications, is susceptible to damage from impact forces of landslides and steep creek events. » Infrastructure foundations within high liquefaction hazards zones are susceptible to damage during an earthquake.

Table 4-15.

Potential consequences of hazards in Electoral Area G.

4.11 Electoral Area H

Electoral Area H has a population of 2,459 people and 1,575 private dwellings as of 2021 (Statistics Canada, 2023). Cultus Lake, Lindell Beach, and Columbia Valley are within the area. Most land use is residential and recreational.

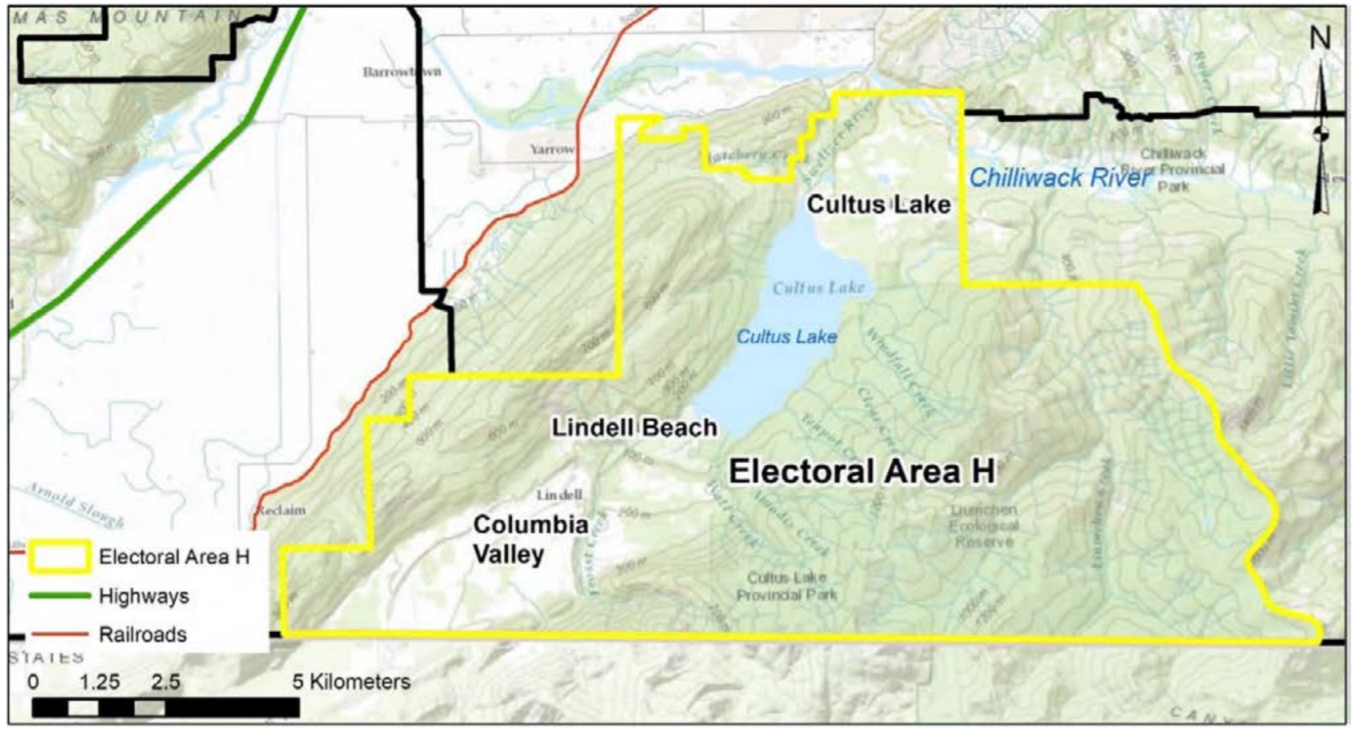


Figure 4-8.

Electoral Area H site overview.

4.11.1 Description of Hazards

4.11.1.1 Clear-Water Floods

Flooding of the Chilliwack River, located north of the Area H, is a hazard to infrastructure in the floodplain, including the Vedder Bridge which provides access to the north side of the river and critical facilities in Chilliwack. While there is no provincial floodplain mapping for Cultus Lake, lakeside property can be susceptible to lake flooding (Government of BC, 2022).

NHC (July 25, 2011) identified four hazard zones on the Frosst Creek alluvial fan where most Lindell Beach properties are located. Installation of dikes along the south side of the creek was completed to manage erosion and avulsion. NHC recommended a suitable setback distance from the toe of the dike be maintained when permitting new construction (NHC, July 25, 2011).

4.11.1.2 Steep Creeks

Lindell Beach and Leisure Valley are on the Frosst and Watt creek alluvial fans. Numerous debris floods on both creeks have deposited sediment and debris (NHC, March 2006). Construction of two debris basins and improvements to 1,000 m of existing dikes have been implemented at Frosst Creek (NHC, July 25, 2011). NHC recommends a suitable setback distance be maintained for potential future emergency works (NHC, July 25, 2011).

4.11.1.3 Landslides

Landslides in the Frosst Creek watershed are common and a source of sediment and debris for debris flows and debris floods (NHC, September 2001). In March 2017, a shallow debris slide in the Frosst Creek watershed followed significant precipitation but did not impact property (Golder, April 10, 2017). Rock slides, mountain slope deformation, and rock avalanches are mapped in the valley slopes bordering Cultus Lake (Brideau, et al., 2023).

4.11.1.4 Seismic

Area H may experience ground shaking and associated effects from a coastal earthquake or Boulder Creek fault zone in northern Washington. The Columbia Valley north and south of Cultus Lake is mapped as moderate to high liquefaction hazard transitioning to low liquefaction hazard away from the lake. (GSC, 1998).

4.11.1.5 Snow Avalanche

Several recreational hiking trails are located on the slopes of Vedder Mountain, which may intersect avalanche terrain during winter months.

4.11.1.6 Wildfires

Blackwell (June 30, 2020b) assessed fire threat behaviour in the Columbia River Valley as "moderate to extreme". Recreational activity may increase the risk of human-caused fires.

4.11.2 Consequences

Table 4-16 summarizes elements at risk from steep creek and flood hazards. The summary may underestimate flood risk, as existing floodplain mapping does not include Cultus Lake. Table 4-17 summarizes the potential consequences of geohazards in Area H.

			Steep Creek	Floodplain
Number of Mapped Hazards			2	2
Mapped Hazard Area (km²)			1.6	1.7
Community	Property	Total No. of Properties	784	21
		No. of Registered Businesses	6	1
Lifeline	Transportation	Length of Highway (km)	0	0
		Length of Railway (km)	0	0
		Length of Roads (km)	16.3	3.3

Number of floodplains represents the number of individual mapped water courses.

Table 4-16.

Elements within mapped steep creek and flood hazard areas in Electoral Area H.

Type	Element at Risk	Consequence
Community	People	» Loss of life is a potential consequence to persons hit by landslide and steep creek hazards, or trapped by wildfires. » Indirect consequences of disrupted access to transportation corridors include elevated risk to community members reliant on goods and services (e.g. food, water, medical services, school, banking, etc.). Damage to utilities can similarly elevate risk if water, power, and/or communications are cut off or de-energized during disasters. » Private property located in hazard zones, including at the base of steep slopes and in areas of low elevation, is susceptible to damage by landslide and steep creek hazards. Standing water damage due to clearwater flooding is also possible in localized depressions.
	Critical Facilities	» Cultus Lake Fire Department and Cultus Lake Community School are located on the north side of Cultus Lake off Columbia Valley Road outside of mapped floodplain extents.
	Environmental Values and Areas of Cultural Significance	» Disruption to and destruction of ecosystems and/or areas of cultural significance are potential consequences of flooded or washed-out land, forests burned by wildfire, and unseasonal occurrences of atmospheric events. Areas of critical habitat are especially susceptible to the impacts of geohazards. » Impacts to utilities (listed below) may have environmental consequences.
Lifeline	Transportation	» Damage to and/or closure of Vedder Bridge due to erosion of steep channel banks during riverine flooding. Damage to roads on the southwest side of Cultus Lake due to landslide and debris-flow/debris-flood impact forces and debris deposition. This could incur repair, mitigation, and rerouting costs depending on the duration of closure. » There is limited egress via Columbia Valley into the City of Chilliwack.
	Utilities / Infrastructure	» Water intakes located in steep creeks with frequently occurring events may be damaged due to sediment infill and/or impact forces. » Linear infrastructure, including powerlines, water supply, and communications, is susceptible to damage from impact forces of landslides and steep creek events. » Infrastructure foundations within high liquefaction hazards zones are susceptible to damage during an earthquake.

Table 4-17.

Potential consequences of hazards in Electoral Area H.

5.0 Additional Considerations

Current hazard conditions in the FVRD are subject to change due to many factors. The dynamic nature of hazards in a changing climate means there are likely areas at risk from hazards that have not yet been identified. The dynamic nature of geohazards can also lead to cascading hazards, for example the occurrence of wildfires increasing the potential for steep creek and landslide hazards in the immediate years following a storm, or high river flows leading to bank erosion at the toe of a landslide triggering acceleration or reactivation of the landslide. These interrelationships are discussed qualitatively in this report and should be assessed in more detail during detailed or site-specific assessments. Anthropogenic activities can also affect geohazard occurrence and should be assessed during land use planning.

Non-natural hazards can be directly or indirectly caused by geohazards. The consequences of these complex hazards can also be inflated by geohazards; for example, a rural community with limited access to medical services can be put further at risk during a flood that cuts off transportation to critical resources.

The location of recreational areas and major infrastructure projects can impact the number and location of people within hazard areas who may not be represented in maps showing only permanent communities. This may include campsites, recreational parks, construction, and logging camps, run-of-the-river facilities, linear infrastructure construction and maintenance operations, and other works. In some cases, the number of people occupying an area can be substantially more than indicated in census data. In the event of an emergency, people may need to be evacuated from these areas. BGC has not reviewed recreational sites, or ongoing or planned projects such as these as part of the present scope, and acknowledges that emergency response planning should consider these locations.

5.1 Additional Geohazards

Geohazards not considered in this report should be considered in risk assessments used to inform emergency and land use planning. These include:

» **Atmospheric hazards:** Extreme rainfall and snowfall have a direct impact on flooding, steep creek hazards, landslides, and avalanches. Monitoring for site-specific precipitation thresholds for hazard initiation can be useful in preparing for emergency response.

» **Volcanic hazards:** The Cascade Volcanic Arc is a chain of volcanoes that extends from southwest B.C. to northern California (USGS, n.d.). The most recent catastrophic eruption was at Mount St. Helens in Washington in 1980, followed by a lava flow in 2004. Hazards associated with volcanic eruptions and flows include lahars, which are volcanic mudflows that pose similar risk to people and infrastructure as landslides and debris flows. Ash fall is another hazard that can severely impact the health and safety of people and the environment depending on the concentration of ash in the atmosphere.

» **Tsunamis:** A tsunami is a series of long-period waves usually caused by an earthquake and, less commonly, by volcanic eruptions and large coastal landslides (Climate Ready BC, n.d.). Because it is protected by Vancouver Island, the FVRD and the greater Lower Mainland area are at low risk of being hit by a tsunami but increasing sea level elevations will likely change the extents of tsunami hazard zones. Direct impacts of tsunamis include flooding, destruction of infrastructure, and loss of life.

6.0 Recommendations for Future Work

In support of ongoing hazard and risk management in the FVRD, BGC recommends that, if and when funding opportunities arise to undertake additional projects beyond the scope of this report, FVRD focus future work in the following areas:

1. **Hazard Identification and Assessment**
   a. Extend floodplain mapping in regions not previously mapped.
   b. Review and update wildfire hazard rating to include climate change, if required.
   c. Review and update hazard delineations, including steep creek mapping, as updated topographic information (i.e. lidar) is available. BGC recommends prioritizing efforts in areas of highest potential consequence, future proposed development, or where land use changes are requested.
   d. As future lidar is available, consider completing regional lidar change detection to identify areas of changed conditions that may indicate hazard occurrence, and to support regional and site-specific hazard assessments.
   e. Complete detailed hazard assessments and, as appropriate, risk assessments, to support future land use planning, and, where required, engineering design. Based on the hazard information reviewed and compiled as part of this scope, BGC suggests that areas to prioritize for more detailed assessment could include:
      i. Flooding, debris-flow, and debris-flood hazards to new developments, i.e. in Electoral Area C (Siddle, Squakum, and Holachten creeks).
      ii. Avalanche hazard mapping in recreational areas at hazardous slopes.
      iii. Updated assessment of flood and steep creek mitigation conditions at Norrish and Deroche creeks in Area G.

   The Union of British Columbia Municipalities (UBCM) Community Emergency Preparedness Fund (CEPF) may be an avenue to support future assessments, and the UBCM CEPF, the Investing in Canada Infrastructure Program (ICIP), and the Disaster Mitigation and Adaptation Fund (DMAF) may be avenues to support future risk reduction that include both policy and structural options.

2. **Hazard Inventory**
   a. Develop and maintain an inventory of hazard events within the FVRD. BGC recommends that FVRD collect, at a minimum, the 1) hazard location, 2) hazard date, 3) hazard type, and 4) estimated size (volume or peak discharge, as most appropriate to the hazard type). Where possible, BGC suggests FVRD collect information on the estimated consequences (e.g. number of properties affected, economic damages, number of people evacuated, or other metrics most applicable to the FVRD to support future emergency response decision making).

3. **Hazard and Risk Communication**
   a. Continue to make hazard information available on the FVRD WebMap, along with improved functionality by having hazard delineations visible at all zoom levels.
   b. Engage with First Nations communities within the FVRD to incorporate traditional and local knowledge into hazard and risk assessments and to understand locations of cultural significance that may influence evaluations of consequences as part of the risk assessment process.

7.0 Closure

We trust the above satisfies your requirements. Should you have any questions or comments, please do not hesitate to contact us.

Yours sincerely,

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