



# Geohazard Risk Assessment North Slope of Cowichan Lake

Strategic Climate Risk Assessment for the Cowichan Valley Regional District  
Final Report (Revision 1)



*12 June 2020*



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## Revision History

<b>Revision Number</b>	<b>1</b>
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<b>Summary of changes</b>	
<p>An error was identified in the original report. Specifically, the translation of hazard likelihood into hazard likelihood scores was incorrect. The following changes have been made to this revised report:</p> <ul style="list-style-type: none"> <li>• All figures showing mapped consequences have been re-issued with a new hazard scores.</li> <li>• All likelihood scoring tables have been adjusted to reflect new scoring.</li> <li>• All risk matrices have been adjusted to reflect new hazard scores.</li> <li>• Risk scores have been adjusted downwards in tables and in text.</li> </ul> <p>Notwithstanding the reduction in hazard and risk scores, the original report conclusions and recommendations remain valid.</p>	

Cover Photo: Warning sign on Youbou Road, April 2018. Ebbwater Consulting Inc. image.

### Disclaimer

This document has been prepared by Ebbwater Consulting Inc. and its subconsultant for the exclusive use and benefit of the Cowichan Valley Regional District. It has been developed in accordance with generally accepted engineering practices and with full understanding of applicable natural hazard guidelines in the Province of British Columbia.

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## Acknowledgements

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The authors wish to acknowledge the support of CVRD staff Kate Miller and Jeff Moore. Further, many other CVRD staff, stakeholders, and members of the public informed the process and provided their time to attend workshops and provide input. This is much appreciated.

The report was written by Tamsin Lyle, P.Eng., Heather Murdock, P.Eng., and Dickon Wells C.Eng. of Ebbwater Consulting Inc. with support of other Ebbwater staff. Palmer Environmental Consulting Ltd. played an integral role in the project; they conducted the geohazard analysis that informed the rest of the work. Copy-editing services were provided by Interwoven Editing.

## Executive Summary

The Cowichan Valley Regional District (CVRD) is known for its stunning landscape of mountains, lakes, wetlands, and coastline. It spans an area of approximately 3,500 km<sup>2</sup> from the west coast of Vancouver Island to the east coast and includes several of the gulf islands. This landscape makes the CVRD a desirable place to live and visit; the region is home to 84,000 people (Statistics Canada, 2016) and welcomes many more as visitors every year. However, these natural features are also linked to a number of natural hazards. This includes slope hazards for the watersheds along the north slope of Cowichan Lake in the area of Youbou and the Town of Lake Cowichan (Figure 1). These watersheds have previously been identified at a planning level as being potentially hazard prone and it is expected that the occurrence of hazard events in this area will worsen with climate change and increasing precipitation. Consequently, the CVRD sought funding to further explore these and other hazards within the region.

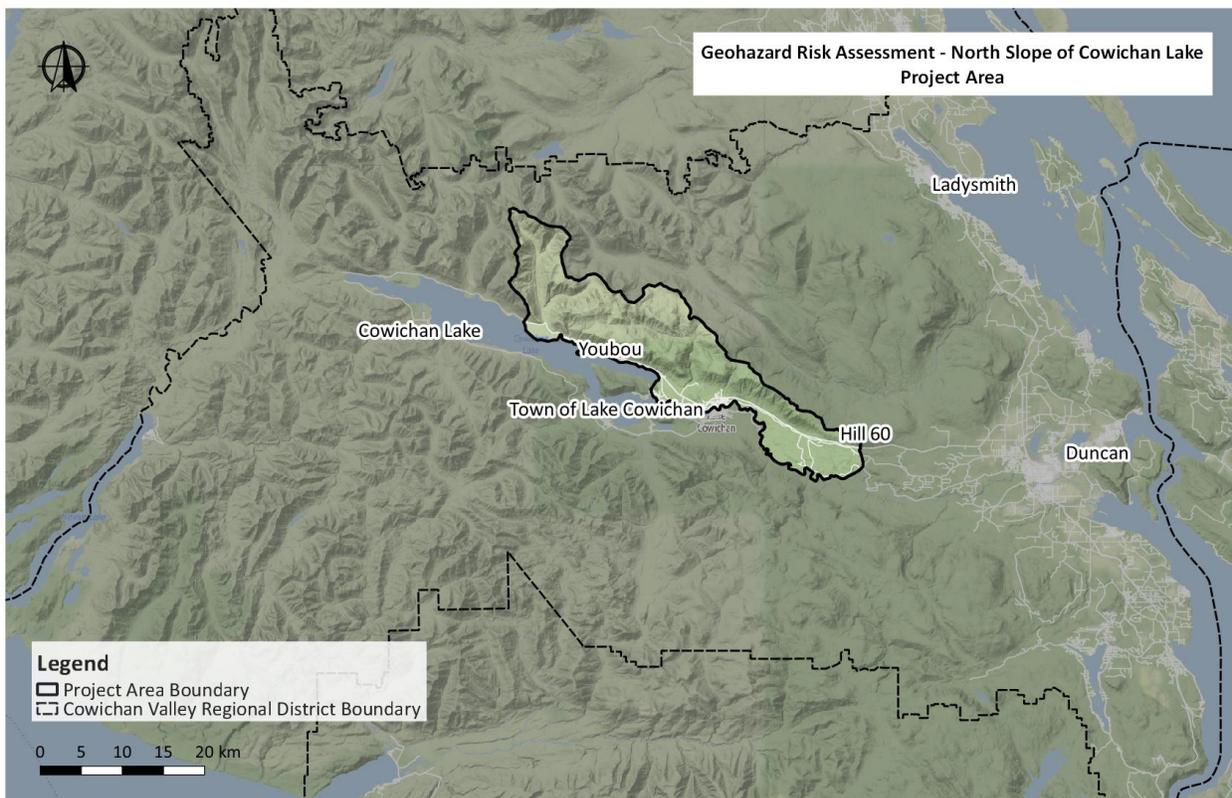
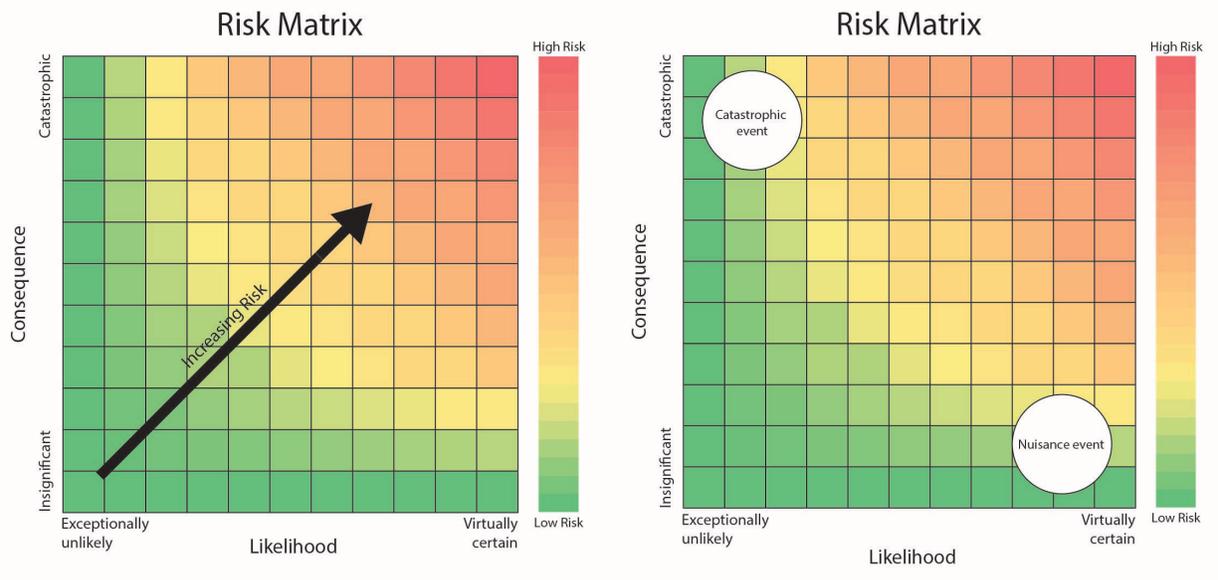


Figure 1: CVRD boundary and project area along the north slope of Cowichan Lake.

The CVRD was a successful Stream 1 applicant to the National Disaster Mitigation Program (NDMP) to study geohazard risk on the windward-facing slope of Lake Cowichan to the end of Hill 60. The **objective of this project is to understand present-day and future risk from geohazards, specifically debris flows, in the project area**, which can then inform risk reduction, and resiliency planning policy. The CVRD engaged Ebbwater Consulting Inc. (Ebbwater) and Palmer Environmental Consulting Group Inc. (Palmer) to support them in this endeavour.

## Risk Assessment Primer

The primary objective of this work is to provide an understanding of present-day and future risk associated with geohazards within the project area. Risk is a function of both the likelihood and consequence of a hazard occurring (see Figure 2).



**Figure 2: Risk as a function of likelihood and consequence – nuisance and catastrophic risk.**

A risk assessment can be used to compare both the impacts and the potential benefits of mitigation options for the whole spectrum of nuisance to catastrophic events. This provides the best possible tool to make informed investment and planning decisions.

Risk assessment (including impacts and consequences) is considered best practice but is still in its infancy in Canada. There are currently no regulated guidance documents on how impacts from natural hazards should be estimated. There are, however, international documents on methods and practice that can be used to inform methods. In particular, the following frameworks and documents were considered for this project:

1. Sendai Framework for Disaster Risk Reduction (UNISDR, 2015)
2. The Global Facility for Disaster Risk Reduction Riskier Future Framework (GFDRR, 2016)
3. International Standards Organization (ISO) Standard 31000 – Risk Management

Other resources from around the world, particularly from the Australian Institute for Disaster Resilience (AIDR), were also used. The AIDR provides particular insight into the use of stakeholder knowledge and expert elicitation to support the estimation of intangible and indirect impacts (Australian Institute for Disaster Resilience, 2015).

Finally, methods were derived from recent consultant experience completing natural hazard risk assessments for other communities (also under the NDMP). Over time, these have evolved based on

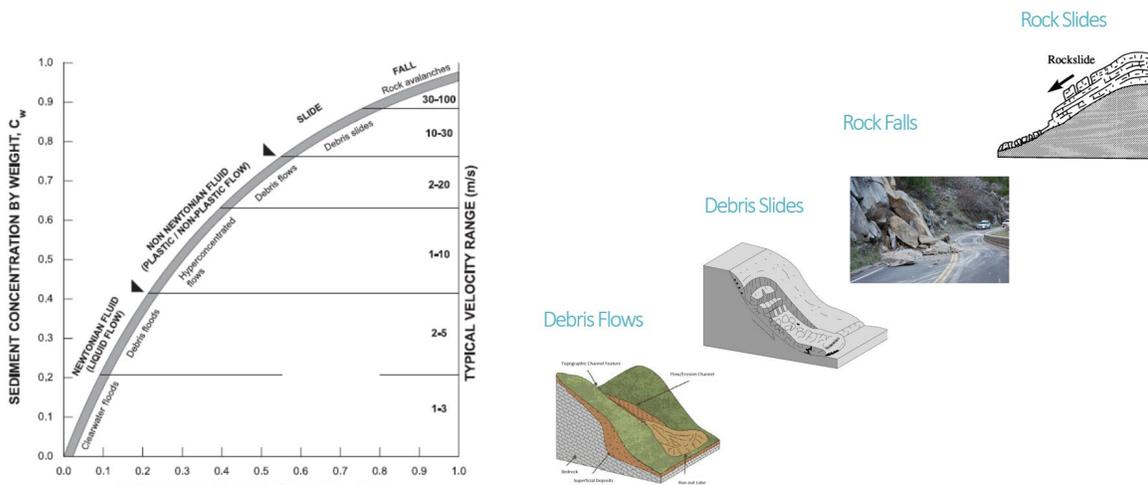
experience and data availability. The methods applied to this project all consider forthcoming guidance on natural hazard risk assessment being developed by various agencies in Canada.

The following provides a summary of the methods, analysis, and results of the risk assessment for the project area. This is presented with consideration of the component pieces of risk: hazard and hazard likelihood, impacts and consequence, and then risk.

### Geohazards in the Project Area

An assessment of the locations of hazard and the associated likelihood are key components of a risk assessment and mitigation planning. Geohazard is best estimated through the development of detailed topographical modelling combined with field assessments and ground-truthing. As part of this project for the CVRD, terrain mapping, a hazard inventory, a quantitative hazard model, and hydrogeomorphic classification of watersheds in the project area were developed.

Within the project area, geohazards were assessed with a focus on debris flows. Debris flows as a hazard type exist within a spectrum of geohazards from fall (e.g., rock avalanches) to liquid flow (e.g., clearwater floods) that is characterized by several parameters, as shown in Figure 3.



Graphic from Jakob and Jordan (2001)

Graphics from Smith (2004)

**Figure 3: Watershed morphometrics graph.**

The landslide hazard mapping was developed using an inventory of historic failures in the project area and hazard modelling based on terrain attributes (Figure 4). The analysis shows that there is significant hazard across the project area, with more hazard towards the west. Limited hazard was mapped below Highway 18 in the eastern reaches of the project area. The figure below represents higher encounter probabilities (i.e., areas that are more likely to experience a geohazard event) as darker shades of brown. There are three major areas with high probability hazards, the upper watershed of Cottonwood

Creek, the lower slopes between Cottonwood Creek and Meade Creek, and finally, the upper slopes between Hill 60 and the Town of Lake Cowichan.

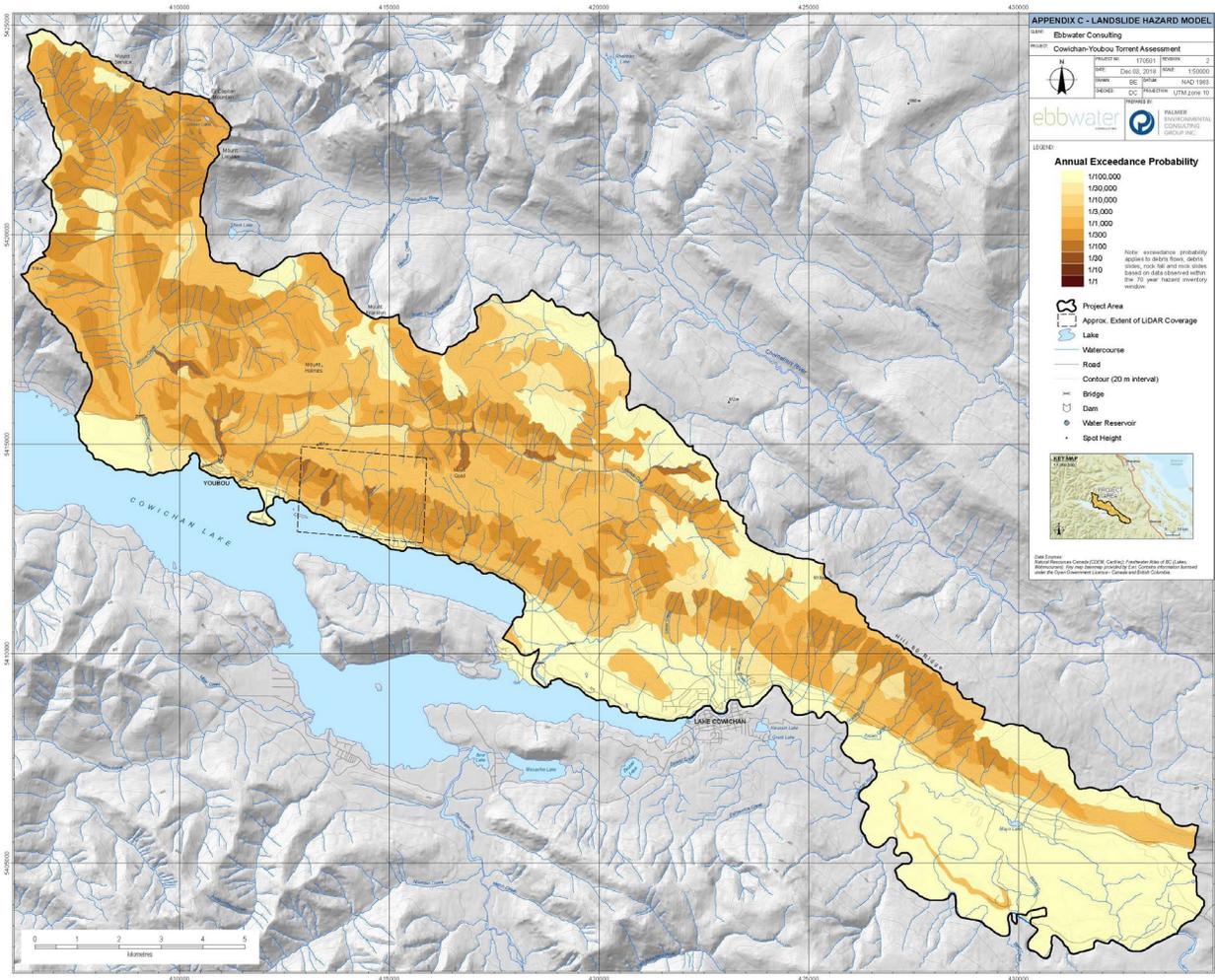


Figure 4: Landslide hazard model results (Palmer Consulting Environmental Group Inc., 2018).

The hazard profile is not static; climate change and landscape change will affect hazard likelihood. General trends in climate and land use suggest that the overall likelihood of debris flow and other geohazard events will rise, potentially quite significantly (by a factor of 10 for logging, and over a critical threshold for climate).

### Impact Analysis in the Project Area

A key component of any risk assessment is an understanding of what is in the way of the hazard (the exposure), as well as an understanding of how each of the exposed assets will react and recover (the impacts). **What is measured matters**, and therefore it is important to measure as many potential impacts as possible, and not simply rely on easily calculated indicators. The approach taken for this project is mindful of the need to explore some of the more difficult intangible and indirect impacts that

result from natural hazard exposure. A mix of quantitative and qualitative measures are presented below, each of which can provide different insights. These are broadly grouped into six indicator groups:

- People (mortality and/or missing)
- Affected people
- Economic impacts
- Disruption (critical infrastructure)
- Environmental impacts
- Cultural impacts

The impact analysis is presented as a mix of qualitative and quantitative outputs and a mix of tabular and mapping outputs. Figure 5 provides an overview of the major impacts.

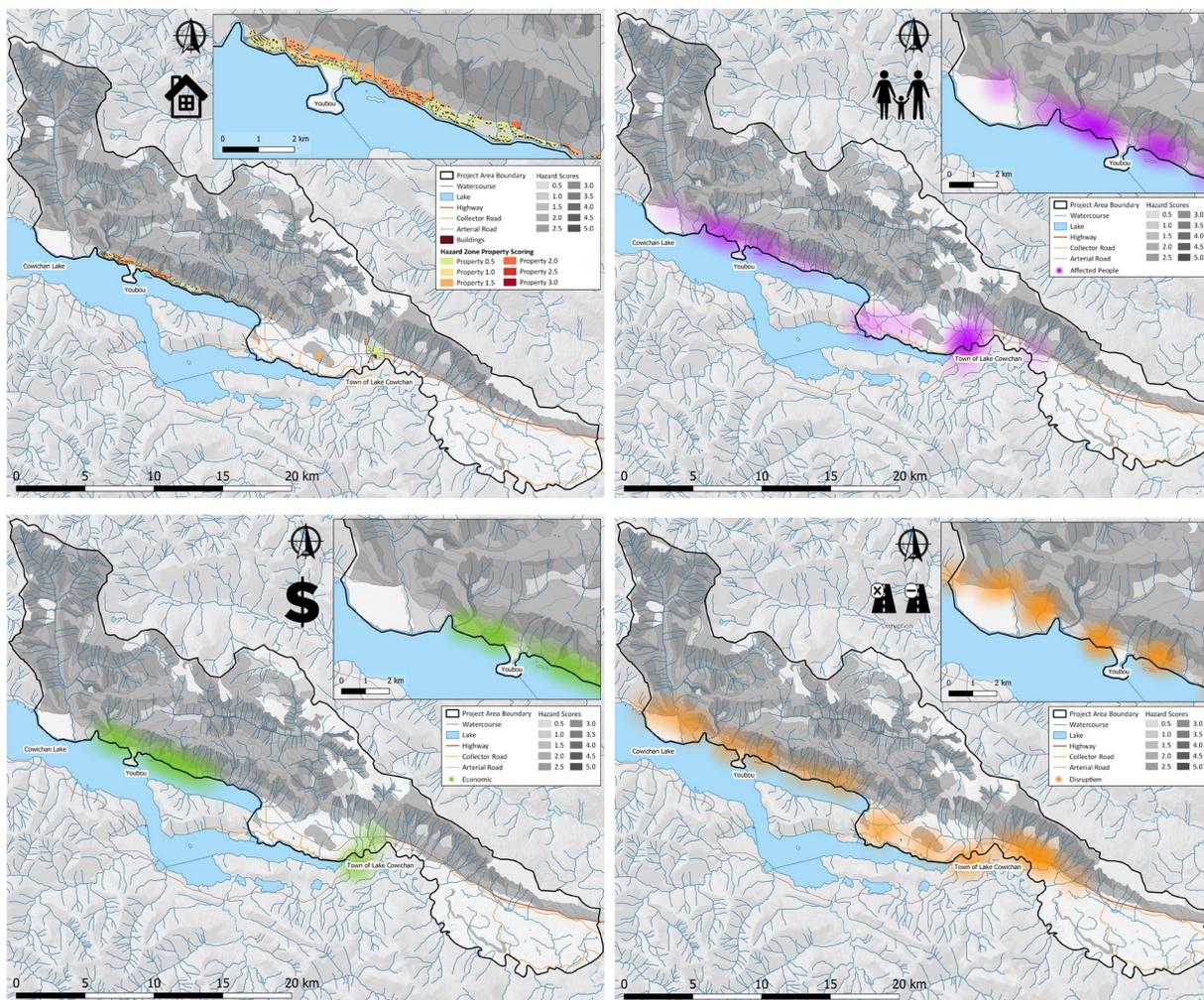


Figure 5: Impacts to people, affected people, economy, and disruption (mix of qualitative and quantitative measures, represented from left to right).

The maps and analysis for each of these impact categories paint a picture of where there are potential effects of geohazard and provide some context for thinking around what kinds of measures might be appropriate to address these issues. Some specific commentary based on the results:

- There are significant impacts to people, the economy, disruption, and culture. There are lesser impacts to the environment. Assessment of impacts to culture and the environment were done at a higher level than the other indicators and are considered preliminary. Further data on cultural and environmental exposure, such as access to harvesting sites or the impact of geohazard on sites of environmental importance, could result in greater impacts.
- Impacts to people are dispersed; many community members would be impacted by debris flow, regardless of where they live in the project area, since disruption to infrastructure would affect people across the project area.
- Direct impacts are concentrated at the toe of the slopes, while indirect impacts are clustered within population centres around Youbou and the Town of Lake Cowichan.

### Risk Assessment in the Project Area

The overall form of a risk assessment includes the combination of a hazard's likelihood with the consequences of that hazard. Risk scoring was completed for each impact category using the outputs of either a quantitative or qualitative assessment. Quantitative assessment was completed where possible with the best available data for most impact categories, however a mostly qualitative method was applied for cultural impacts. The results of the assessment are presented in Figure 6 and Table 1.

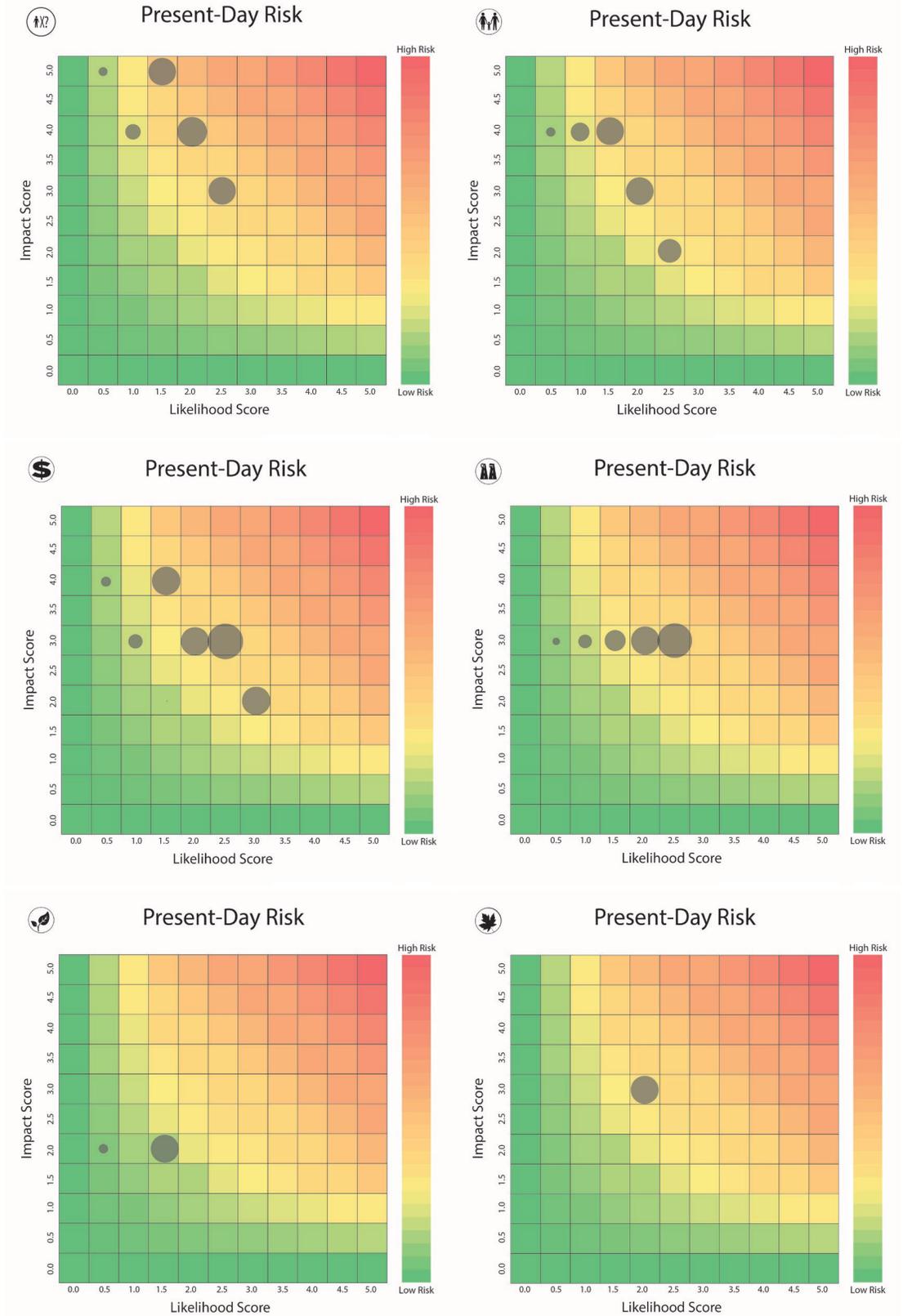


Figure 6: Risk to people, affected people, economy, disruption, environment, and culture (mix of qualitative and quantitative measures, represented from left to right).

Table 1: Risk summary for project area.

Impact Category	Absolute Impact or Qualitative Metric Used	Comments	Risk Score (Based on Mode)
<b>People (Mortality and/or Missing)</b>	2 residential buildings in moderate hazard areas	Some creeks have moderate hazard ratings for debris flow; there are roads and homes nearby. This figure is likely to be higher in the summer when the population increases significantly.	<b>6 – MEDIUM</b>
<b>Affected People</b>	950 people directly affected	A relatively high number of people will have homes or businesses impacted by moderate hazard ratings, especially when considering the scale of the CVRD and Vancouver Island.	<b>6 – MEDIUM</b>
<b>Economic Consequences</b>	\$400 M total exposed property	Scores vary with the level of property value in the affected area. This is significant when considered at the scale of Vancouver Island GDP.	<b>7.5 – MEDIUM</b>
<b>Disruption</b>	12 locations of overlap between hazard areas and road	Several disruption points were identified and weighted based on the importance of the asset.	<b>7.5 – MEDIUM</b>
<b>Environment</b>	2 potential sources of contamination	The environmental impact is relatively low (as compared to other impacts) with only 2 potential sources of contamination in hazard zones. This score does not cover all possible environmental impacts so may be higher in reality.	<b>3.0 – LOW</b>
<b>Cultural</b>	Qualitative — based on harvesting access	Some harvesting of fish and plants occurs in the project area. Access is important for First Nations and impacts are expected to be moderate.	<b>6.0 – MEDIUM</b>

The analysis shows that there is considerable risk in the project area. Of primary concern is the risk to life. Other indicators also show significant levels of risk (including the affected people, the economy, disruption, and culture). Risk to the environment, although lower than other indicators, has a high level of uncertainty and therefore may still warrant further assessment.

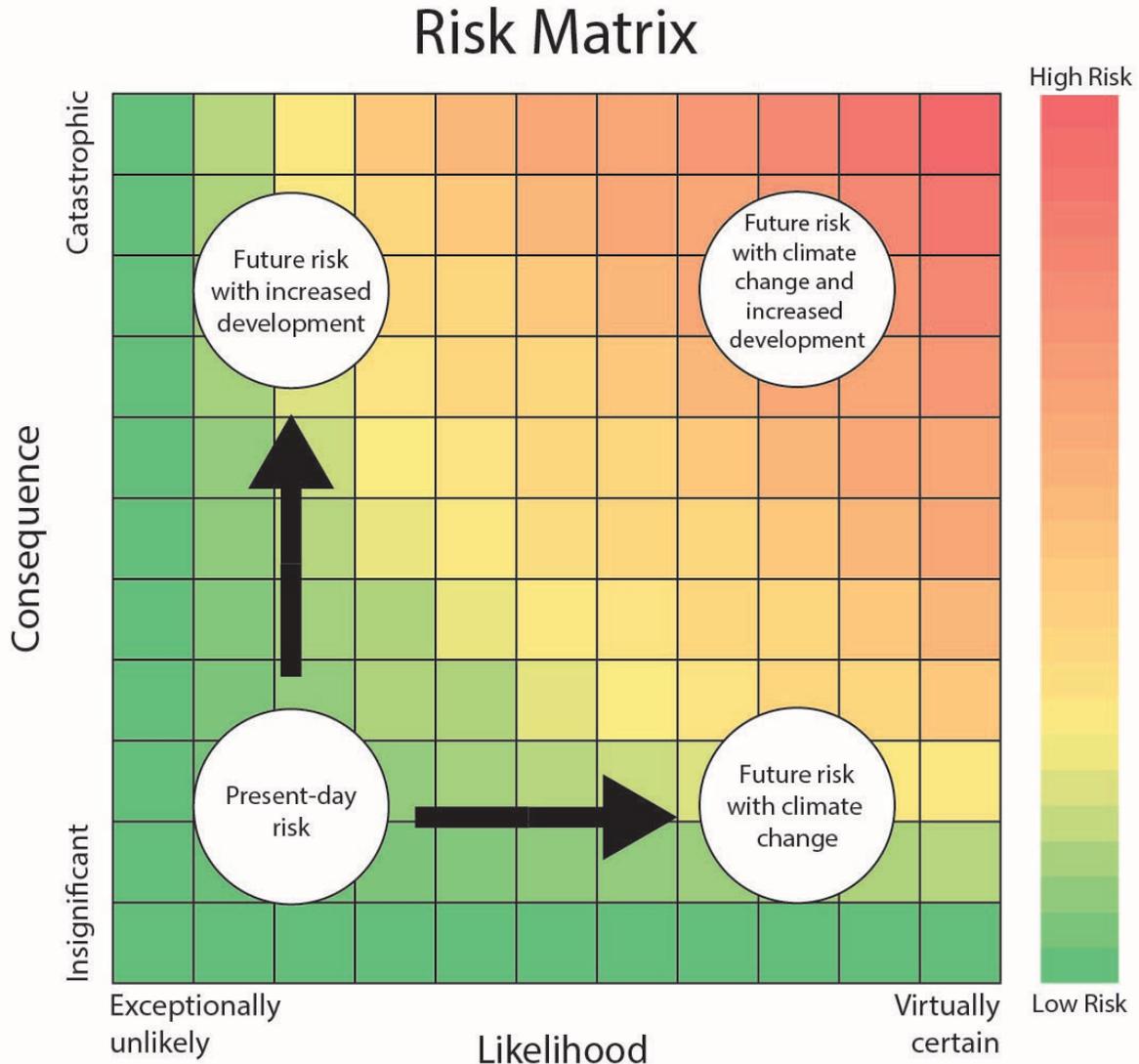


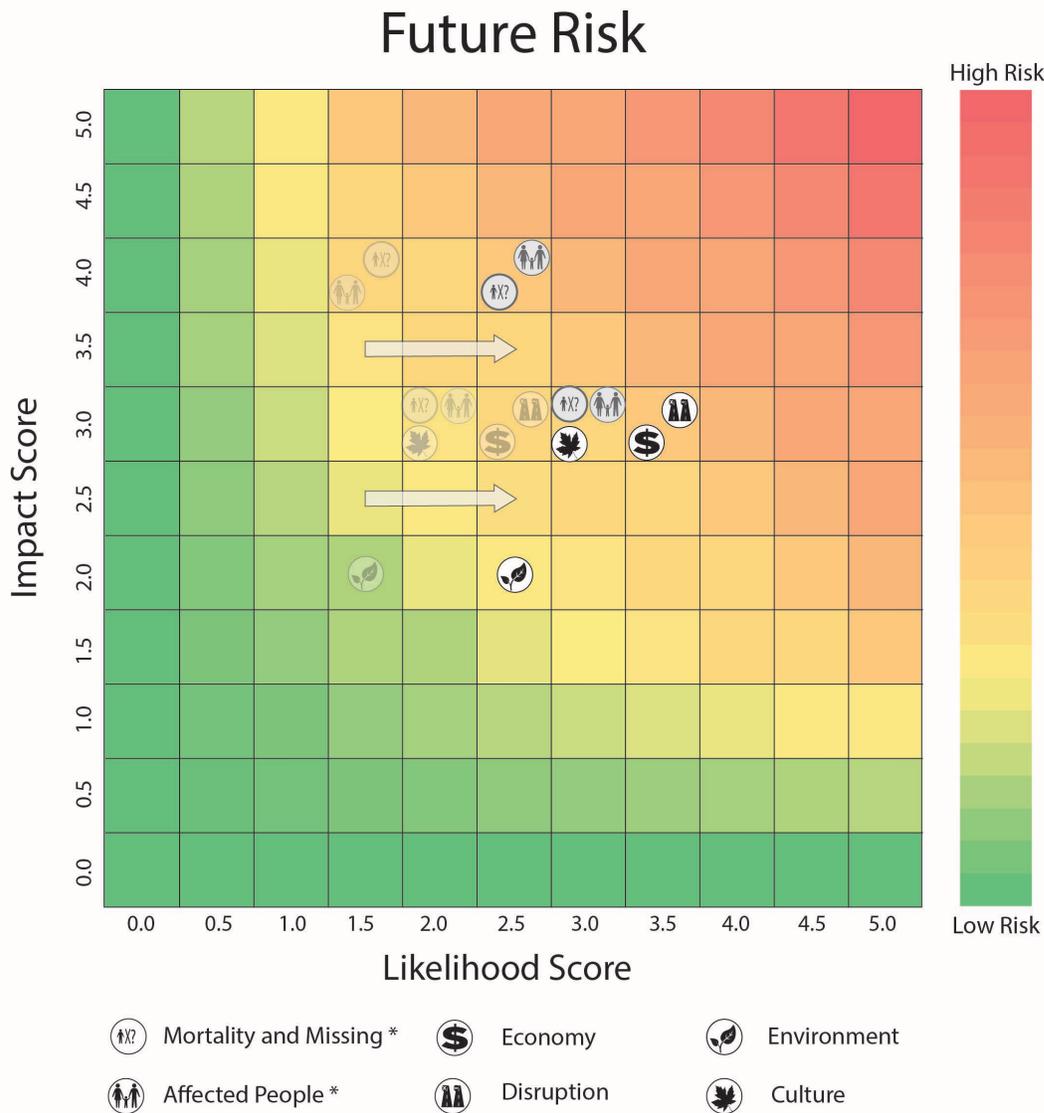
Figure 7: Risk as a dynamic concept

Risk is dynamic and will change with time (see Figure 7). There is no exact science to describe the future, however in this instance consideration was made of the potential increased likelihood of geohazard events in the region, which will affect overall risk. An assumption was made to increase all likelihood scores by 1 point (i.e., given the logarithmic nature of the scoring system, a 10-fold increase). This was based on two parallel and reinforcing assumptions:

1. Research described in Section 4.4 suggests that the region will soon reach a tipping point in its 24-hour extreme rainfall conditions that will be higher than the currently estimated threshold for triggering geohazards. This is because of climate change.

- Further, additional information cited in Section 4.4 suggests that potential anthropogenic changes to the landscape can affect the likelihood of triggering debris flows by as much as a 10-fold increase.

Given these potential changes, it is proposed that a 10-fold increase (i.e., a 1-point increase) in likelihood is not unexpected in the future. This results in an increase risk as shown in Figure 8.



**Figure 8: Present-day and future risk (present-day risk is represented by lighter icons, and future risk by darker icons).**

In summary, the results of the risk assessment show that many current risk scores are MEDIUM; this is a result of moderate hazard scores combined with moderate exposure scores. Some specific trends on the results of the risk scoring include:

- The risk scores for people and affected people are MEDIUM. Risk is clustered in a few locations.

- Risk to disruption and economy is MEDIUM. However, the risk is more dispersed.
- Risk to culture is MEDIUM and to environment is LOW and is relatively dispersed for both indicators. It should be noted that due to the limited nature of these assessments the actual risk level may be higher than reported.

It should be noted that in many cases risk scores are considered minimum scores due to the limitations of the assessment. Whilst all efforts have been made to provide the maximum level of resolution in the hazard model, spatial variability still exists. Further assessment, such as runout modelling (hazard refinement) and vulnerability/susceptibility modelling (impact refinement), is therefore recommended to further refine these scores.

Overall, the scores for this project area are on the high side relative to other recently completed natural hazard risk assessments in BC. The primary concerns are people, affected people, and impacts to infrastructure.

## Engagement and Community Resilience

Building on the CVRD's ongoing efforts to manage risk and build resilience, this project intentionally engaged a broad set of stakeholders at two points in the process, in order to build awareness and understanding of impacts and risk, and to begin to consider establishing risk tolerances to shape policy. Due to the nature of geohazard as a "wicked problem", engaging stakeholders in this type of a process is an essential first step towards understanding and building resilience for the community. Joint understanding, ownership, action, and ongoing learning are essential for a community to become truly resilient. Leaping to solutions without first understanding the complexity of the problem can yield poor results.

Engagement efforts yielded significant information that supported this risk assessment. By furthering stakeholder understanding of the issues and providing some initial values, these efforts will also support the goals and development of future disaster risk reduction strategies. These are all further outlined in the main report.

## Recommendations

The results of the geohazard risk assessment for the north slope of Cowichan Lake highlight that there are significant risks. Acknowledging and understanding these risks is a first and important step in reducing and managing these risks in the future. Reducing risks to the geohazards in the project area will not be a quick or easy task, but will require a long-term strategic approach to the problem. There are however some actions that can be taken immediately to support disaster risk reduction in the project area.

A series of recommendations are made in the main report and are summarized here. These include specific recommendations arising from the technical analyses presented in this report and recommendations to support a broader strategic approach to disaster risk reduction.

## High Priority Action

High priority actions were identified through the technical and policy analysis. Of utmost importance is the need to address the **risk to life**. First, the CVRD should consider disclosing the level of hazard and risk to those that are most affected (i.e., homeowners in the highest hazard zones). Then with support of the broader disaster risk reduction strategy and the development of risk thresholds, the CVRD can consider means to reduce the risk. The most effective means to reduce the risk will be to retreat from the highest hazard areas; this will require a strong will on the part of CVRD leadership. In the interim, the CVRD can support homeowners to reduce their risk through simple actions—for example, by moving sleeping quarters to the safest part of the house and by understanding when risk is highest temporally (e.g., after wet periods followed by intense rainfall).

## Quick Wins and No-Regrets Actions

Many geohazard mitigation planning strategies take time and/or money to implement. There are however some no-regrets actions that can be taken by the CVRD immediately. This will serve to reduce risk and also ensure that momentum built throughout this process is not lost.

- **Continue to promote education and preparedness.** The CVRD should continue to provide updates to stakeholders and residents on their efforts to act on geohazard mitigation planning. This will likely be focused first on stakeholders as the process of developing risk tolerances moves forward. There are advantages to engaging the public early and seeking input to ground any future policy within the local community.
- **Develop and nurture connections with partners.** Working with local partners, such as forestry companies and land developers, will help make the implementation of future policies smoother. Both of these groups have an effect on geohazard risk—forestry activities can increase the severity of the hazard and developers may add additional exposure to areas.
- **Avoid any increase in geohazard risk.** The CVRD should consider a policy statement that they will avoid increasing geohazard risk, specifically by zoning or providing development guidance for areas that are in the currently recognized hazard area. This also may be applied to the use of land—for forestry or other types of development—upslope from vulnerable areas.

## Conclusions

The CVRD faces significant geohazard risk in the project area, and seeks to reduce this risk to the community. This project, along with work previously conducted by the CVRD, lays the groundwork for a geohazard mitigation plan. This is in addition to many specific gains in understanding geohazard risk in the community, and the development of deliverables that will support future work.

The CVRD is taking a proactive approach to understanding natural hazard risk in a changing climate. This approach is in line with the priorities of the Sendai Framework for Disaster Risk Reduction, which the Government of BC has adopted. In addition, the CVRD plans to implement geohazard management best practice by following in the footsteps of other Canadian and international jurisdictions to implement risk tolerance-based policy. With this assessment, the CVRD is now well placed to move these plans and

policy development forward in an integrated fashion, including modernized land use planning policies, climate adaptation, appropriate disaster risk and response planning, and supportive infrastructure strategies.

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## LIST OF ACRONYMS

AEP	Annual Exceedance Probability
AHRA	All-Hazards Risk Assessment
AIDR	Australian Institute for Disaster Resilience
ALARP	As Low as Reasonably Possible
BC	British Columbia
CEPF	Community Emergency Preparedness Fund
CVRD	Cowichan Valley Regional District
DMAF	Disaster Mitigation and Adaptation Fund
DNV	District of North Vancouver
DPA	Development Permit Area
DRR	Disaster Risk Reduction
EGBC	Engineers and Geoscientists British Columbia
EMBC	Emergency Management British Columbia
FCL	Flood Construction Level
FHALUMG	Flood Hazard Area Land Use Management Guidelines
GDP	Gross Domestic Product
GIS	Geospatial Information System
INFC	Infrastructure Canada
ISO	International Standards Organization
LaRiMit	Landslide Risk Mitigation Toolbox
NDMP	National Disaster Mitigation Program
NRCan	Natural Resources Canada
OCP	Official Community Plan
PSC	Public Safety Canada
RAIT	Risk Assessment Information Template
RIBA	Royal Institute of British Architects
ROI	Return on Investment
SDM	Structured Decision Making
SLRPA	Sea Level Rise Planning Area
UBCM	Union of BC Municipalities
UN	United Nations
UNISDR	United Nations Office for International Strategy for Disaster Risk Reduction

## 1 Introduction

The Cowichan Valley Regional District (CVRD) is known for its stunning landscape of mountains, lakes, wetlands, and coastline. It spans an area of approximately 3,500 km<sup>2</sup> from the west coast of Vancouver Island to the east coast and includes several of the gulf islands. This landscape makes the CVRD a desirable place to live and visit; the region is home to 84,000 people (Statistics Canada, 2016) and welcomes many more as visitors every year. However, these natural features are also linked to a number of natural hazards. This includes slope hazards for the watersheds along the north slope of Cowichan Lake in the area of Youbou and the Town of Lake Cowichan (Figure 1). These watersheds have previously been identified at a planning level as being potentially hazard prone and it is expected that the occurrence of hazard events in this area will worsen with climate change and increasing precipitation. Consequently, the CVRD sought funding to further explore these and other hazards within the region.

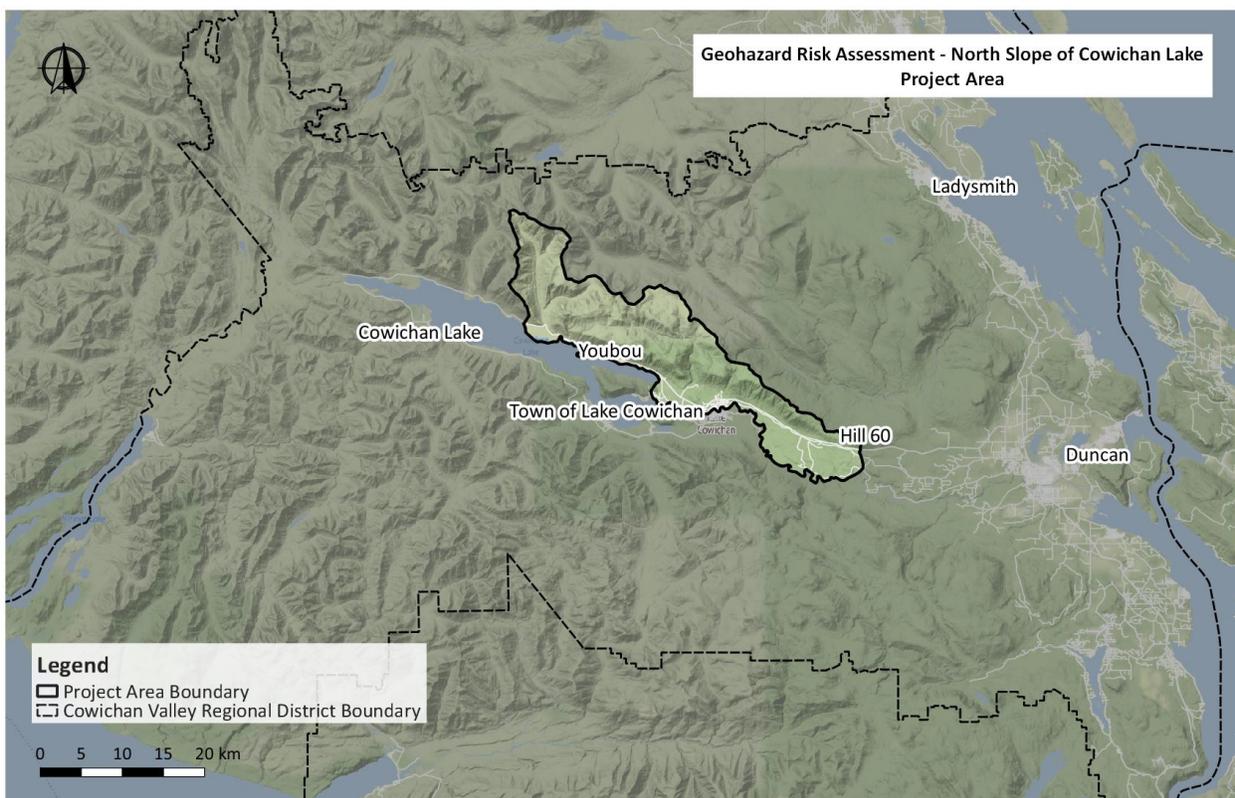


Figure 1: CVRD boundary and project area along the north slope of Cowichan Lake.

Best practice dictates that natural hazard mitigation<sup>1</sup> be achieved through a thoughtful, risk-based planning process based on community values and considering a range of hazard levels, including the effect of climate change. The CVRD is working on exploring different approaches to risk assessment, risk reduction, and resilience planning through pilot studies for different hazards throughout the region. These case studies will serve to inform process (for risk and resiliency assessments), as well as policy and strategic direction at the CVRD. These will also serve to inform the CVRD's Climate Adaptation Strategy, which has a focus on the identification of natural hazard risks and the protection of core community services through natural disaster risk reduction strategies.

The CVRD was a successful Stream 1 applicant to the National Disaster Mitigation Program (NDMP) to study geohazard risk on the windward-facing slope of Cowichan Lake to the end of Hill 60. The **objective of this project is to understand present-day and future risk from geohazards, specifically debris flows, in the project area**, which can then inform risk reduction, and resiliency planning policy. The CVRD has engaged Ebbwater Consulting Inc. (Ebbwater) and Palmer Environmental Consulting Group Inc. (Palmer) to support them in this endeavour.

The outcome of this pilot project looking at geohazard risk for the project area is twofold: to provide an assessment of current and future risk severity affecting the project area, and to inform more refined risk policy development throughout the region. It will also support the CVRD to avoid creating future risks, and to develop mitigation and management plans to reduce and manage the existing risk where possible.

### 1.1 Project Geographic Scope

The area of interest was defined by the CVRD at the outset of the project as being the north slope of Cowichan Lake and the north-facing slopes immediately to the east of the lake. This area was selected as an example of steep windward-facing slopes projected to receive increasing precipitation levels over time. As can be seen from the map in Figure 1, this area is adjacent to the communities of Youbou and the Town of Lake Cowichan. The watersheds in the project area extend from the mountain ridgeline north of Cowichan Lake and drain into either Cowichan Lake or the Cowichan River. For this assessment, only areas within the project area extents shown below were considered for geohazard exposure, impacts, and risk.

### 1.2 Project Objectives

Over the course of the project, a series of objectives were evolved based on the needs of the CVRD and of the granting agency, along with what could be accomplished through this project:

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<sup>1</sup> This report was written primarily with a disaster risk reduction lens and has adopted standard terminology from this field. Mitigation, in this case, relates to strategies or measures that are used to directly reduce natural hazard impacts or risk. Whereas, mitigation is often used in climate adaptation literature to refer to local or global efforts to reduce greenhouse gas emissions.

1. **Better understand geohazard and risk in project area.** Understanding the scope of the problem is key to good decision-making. This objective includes an explicit effort to understand the level of hazard and the existing exposure (i.e., key assets at risk) in the project area. Understanding the nature of the risk can enable resilience by providing tools to avoid the creation of new risk and the reduction and management of existing risk.
2. **Inform active and future planning.** The CVRD wishes to use the outcomes of this work to inform current and future planning efforts, including strategic climate adaptation and mitigation strategies, Official Community Plans, zoning bylaws, and Development Permit Areas, with the objective of reducing risk over time to tolerable levels.
3. **Lay a foundation for future funding.** Funding programs for disaster mitigation in Canada—both for foundational research and planning studies, and for implementation of geohazard reduction measures—require that basic risk assessments are completed. This project seeks to develop materials to support future funding applications, including risk assessments, project scopes, and costings.
4. **Prepare a foundation for mitigation planning.** Understanding geohazard risk is merely the first step in developing and implementing a geohazard mitigation plan. This project seeks to develop base information to support future mitigation work including the development of a long-list of options to reduce risk.
5. **Lay a foundation for stakeholder engagement and risk tolerance development.** This project seeks to develop a common understanding of geohazard risk and endeavours to lay the foundation to develop agreed-upon tolerances to those risks.

### 1.3 Project Limitations

Given the available information, timing, and resources, there are limitations to the work completed in this phase. Many of these limitations can be addressed in the future:

1. **Geographic scope.** The CVRD is home to slopes of different configurations, gradients, and with diverse geology. The defined project area is meant to be an example area to support policy development for geohazard risk. Geohazards (see below) may be found elsewhere in the region.
2. **Hazard scope.** This project focused primarily on debris flow with some consideration of debris flood, and clearwater flood in steep creek catchments within the project area. Other hazard types and hazards outside the project area were not included.
3. **Data and resources.** The hazard data for this project was produced by Palmer through a desktop study and field investigations. The exposure and vulnerability used for risk assessment was sourced from the CVRD or accessed through open data sources. As described later in this report, there are limitations to the data and the methods currently available to support natural hazard impact and risk assessment in the CVRD, and across the country.
4. **Stakeholder input.** Throughout this project, we sought to understand geohazard vulnerabilities as completely and richly as possible—this was mostly achieved through direct engagement with stakeholders at two workshops. The information collected through these sources is limited to the knowledge and input from those who participated; there are potentially some geohazard

vulnerabilities and impacts that were not identified because a given stakeholder was not able to participate. Of note is the limited participation of local First Nations.

5. **Actions and next steps.** The primary objective of this work was to develop a better understanding of the problem and lay the groundwork for a robust and transparent plan. It purposely did not seek to provide engineering designs at this stage; pre-determining a solution before fully understanding the problem will often lead to failure. Further, the technical information required to develop and assess some geohazard mitigation options (especially structural works) was not available at this time. The recommendations are therefore focused on no-regrets geohazard mitigation options, and a discussion of deliberative next steps that will enable the community to select appropriate geohazard mitigation options to reduce risk and increase resilience over time.

## 1.4 Report Structure

This report starts by providing the context of the problem, including the hazard and geographic scope (Section 2) and provides some overall context for natural hazard risk and risk assessment (Section 3). Next is a description of the known technical aspects of geohazard (Section 4), as well as the exposure and vulnerability to geohazard (Section 5) as part of better understanding risk in the community. The results of a geohazard risk assessment are provided (Section 6), and lessons learned from engagement with local stakeholders are provided in Section 7. Finally, information on mitigation options are outlined (Section 8) along with a discussion of current best practice with regards to natural hazard risk management (Section 9). This is followed by recommendations for going forward (Section 10) and conclusions (Section 11).

More detailed risk assessment outputs suitable for input into funding program templates are found in Appendix A, which provides tables of generic risk information that should be suitable for a renewed National Disaster Mitigation Program (NDMP), as well as for the Disaster Mitigation Adaptation Fund (DMAF), and Appendix B, which provides a completed Risk Assessment Information Template (RAIT) for the current NDMP program. The report also includes a summary of the stakeholder workshops in Appendix C, a description of the hazard modelling approach in Appendix D, the mitigation measures report with a long-list of options is provided in Appendix E, and a full list of data used in the project in Appendix F. Finally, Appendix G includes reproductions of the maps provided in this report at a scale suitable for hard copy printing. Finally, Appendix H provides a table summarizing the many recommendations made throughout this report.

## 2 Project Background

The CVRD is taking a proactive risk-based approach to managing natural hazards within the context of a changing climate. As a component of the CVRD's Climate Adaptation program, locations for a series of case studies have been identified to develop a better understanding of how hazards are changing along with the changing climate. The goal of this program is to assess adaptive or mitigative actions to reduce risk to the region's communities. The north slope of Cowichan Lake was identified as being an area of potential slope failure hazard or debris flow<sup>2</sup> at a planning level prior to this project, as specified in the Request for Proposal (RFP)—based on simple GIS and limited background studies. Ultimately the goal is to build a series of case studies to inform a number of master planning documents related to land use, infrastructure, and service provisions, as well as educating and supporting communities to build capacity for resilience to natural hazards.

Geohazard events in the project area have the potential to cause significant damage and disruption for the residents of the region. Communities with residential, commercial, and industrial buildings, as well as supporting infrastructure (i.e., roads, bridges, and culverts) could all be potentially affected.

It is expected that geohazard severity will increase in the coming years with climate change (Jakob and Lambert, 2009), and it is important to understand what the impacts of these future geohazards will be. It is also important to understand what kind of strong policy and governance tools will be needed to address the risk.

### 2.1 Project Area

The north slope of Cowichan Lake consists of steep slopes, several small creek catchments, and two larger watersheds (Figure 2). The watersheds in the project area drain either directly into Cowichan Lake or the Cowichan River. The full project area is approximately 36,000 ha and runs northwest to southeast. The Cowichan Valley Highway (Hwy 18) crosses the project area along the north side of Cowichan Lake and Cowichan River. The south side of the project area is bounded by Cowichan Lake in the west, and Cowichan River in the east. The north side of the project area is bounded by a drainage divide separating the Cowichan River watershed from the Nanaimo River and Chemainus River watersheds to the north. The slope faces southwest towards the Pacific Ocean and captures much of the moisture moving in from coastal storms.

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<sup>2</sup> The project RFP refers to debris torrent. This term was adopted in the "Pacific Northwest region to describe coarse-grained rapid channelized flows rich in organic debris." This is a type of "channelized debris flow" (Slaymaker, 1988). For the purposes of this report, the more internationally standard terms for geohazards have been adopted.

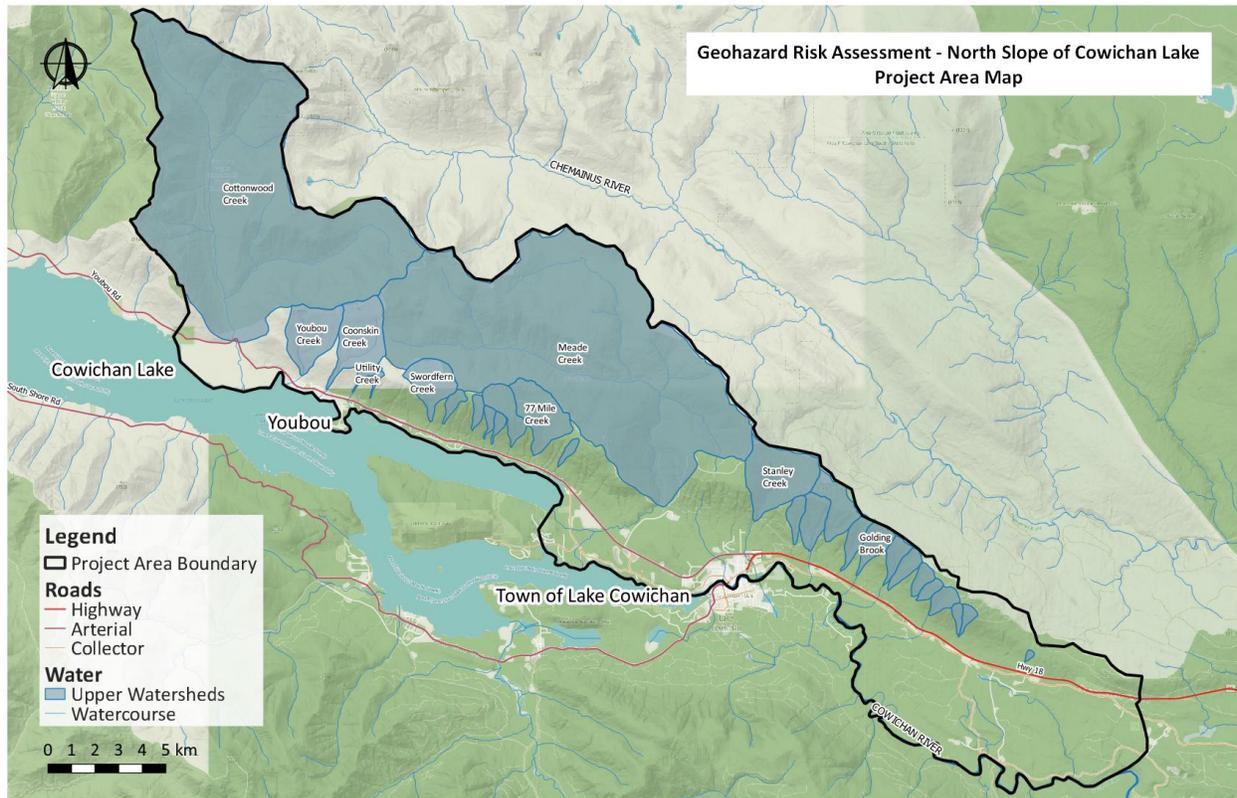


Figure 2: Project area map.

## 2.2 Geohazards in Project Area

The north slope of Cowichan Lake is prone to a number of natural hazards. The broad focus of this work is on geohazards along the spectrum of clearwater floods, debris flows, through to debris slides. These types of hazards have been observed on the geological record and could be expected in the future. These hazards are also affected indirectly and directly by other increasing pressures, including changing precipitation patterns (Jakob and Lambert, 2009), and changing fire (Cannon and Gartner, 2005) and drought mechanics. Details on the types, extent, and likelihood of these hazards today and in the future are provided in Section 4.

## 2.3 Climate Change in Region

Global temperatures are warming, which has direct and important implications for the CVRD. Average annual temperatures in the region are expected to increase by almost 3°C by mid-century (Cowichan Valley Regional District, 2017). This shift in temperature regime also affects other climate and weather variables. Locally, the region can expect:

- Longer dry spells in summer.
- More precipitation in fall, winter, and spring.
- A decrease in snowpack.
- More intense extreme events (Cowichan Valley Regional District, 2017).

The implication of each of the above with regards to geohazard severity and likelihood is discussed in Section 4.

## 2.4 Regulatory Context

Since the introduction of the *Local Government Act [2004]* the CVRD, as a local government within BC, has a responsibility to manage its lands for natural hazards, including the identification of hazardous areas (e.g., flood mapping). There is limited provincial and federal guidance on natural hazard management (e.g., structural and foundation design for earthquakes (Porter and Dercole, 2011)), but no specific direction. This is a challenge for local governments across the province.

While the focus of this project is geohazard, some watersheds in the project area have been classified (based on Melton ratios<sup>3</sup>; see Section 4 for more information) as being primarily prone to clearwater floods, so it worth mentioning the relevant flood policy. This section outlines the regulatory requirements for the CVRD, as well as available guidelines, and examples of policy development from other Canadian and international jurisdictions.

### 2.4.1 Provincial Legislation and Policy

#### 2.4.1.1 Provincial Policy on Disaster Risk Reduction

A recent development in BC, mostly stemming from the criticisms and recommendations in the 2018 report on the findings of the 2017 BC Flood and Wildfire season (Abbott and Chapman, 2018), is the commitment to adopt the Sendai Framework for Disaster Risk Reduction. The Government of Canada endorsed Sendai in 2015, and in late 2018, the Government of British Columbia announced that it would also adopt Sendai, stating, “Canada is already a signatory to the framework and the Province will now also adopt the framework to align and improve our approach to all phases of emergency” (EMBC, 2018).

The Sendai Framework is the new global blueprint for building disaster resiliency; it is supported by the United Nations. The goal of the framework is to prevent new and reduce existing disaster risk. This is promoted through four priorities for action:

1. Understanding disaster risk.
2. Strengthening disaster risk governance.
3. Investing in disaster risk reduction for resilience.
4. Enhancing disaster preparedness.

Sendai provides a framework to support all levels of government, including local governments, to increase their resilience to both chronic and acute shocks.

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<sup>3</sup> A metric based on watershed area and relief used to differentiate watersheds prone to clearwater flooding from those subject to debris flows and floods.

### 2.4.1.2 Provincial Regulations for Natural Hazards

Under the *Local Government Act [2004]*, local governments are responsible for understanding and managing natural hazard risk through land use planning and regulations. Some policy documents and guidelines are available to support planning for the predominant natural hazard in the province: flood. However, no specific direction on geohazards either within the *Act* or in supporting materials (none were identified) are available. The primary policy tools allowable under the *Act* are outlined below along with related natural hazard guidelines.

#### 2.4.1.2.1 Flood Hazard Area Land Use Management Guidelines

Under the *Act*, local governments are *required to consider* the provincial [Flood Hazard Area Land Use Management Guidelines \(FHALUMG\)](#). Initially released in 2004, these are intended to support the development of land use management plans and decision-making regarding subdivision approvals in flood hazard areas (BC Ministry of Water Land and Air Protection, 2004). The guidelines were [amended in 2018](#) to require that sea level rise projections are incorporated into building setbacks and flood construction levels (BC Ministry of Forests Lands and Natural Resource Operations, 2017). This is achieved through the definition of sea level rise planning areas (SLRPAs), and the use of Flood Construction Levels (FCLs). The 2018 amendment also includes new reference to the use of a long-term flood protection strategy (as prepared by a *qualified professional* defined by Engineers and Geoscientists British Columbia) as a means to relax FCL or setback requirements.

#### 2.4.1.2.2 Development Permit Areas

Development Permit Areas (DPAs) are a planning tool used by BC municipalities. They were originally promulgated in the 2004 *Local Government Act* (Section 919.1). As part of the *Act*, local governments were given the authority to designate DPAs within their Official Community Plans (OCP) for various diverse purposes including:

- The protection of the natural environment, its ecosystems, and biological diversity.
- **The protection of development from hazardous conditions.**
- The protection of farming.
- The revitalization of an area in which a commercial use is permitted.
- The establishment of objectives for the form and character of intensive residential development.
- The establishment of objectives for the form and character of commercial, industrial, or multi-family residential development.

Further to this, the *Act* was amended in 2008 to include three additional DPA purposes for climate action:

- The establishment of objectives to promote energy conservation.
- The establishment of objectives to promote water conservation.
- The establishment of objectives to promote the reduction of greenhouse gas emissions (BC Ministry of Community Sport and Cultural Development, no date).

DPA must include contributions or objectives that justify the designation and must also provide guidelines for developers and homeowners to meet the requirements of the DPA. DPAs for natural hazards have been most notably used by the District of North Vancouver (DNV) with a recommendation to council in 2009 outlining “Natural Hazards Risk Tolerance Criteria” and the adoption of the “As Low as Reasonably Practicable (ALARP)” principle (Dercole, 2009).

In 2011, the DNV introduced a bylaw (7900) designating DPAs within the DNV Official Community Plan (OCP). For the DNV, this process was prompted by a death due to a natural hazard event in the community that created a shift in thinking at political and staff levels. Development permits are required within the DNV for areas of wildfire, slope, and creek hazards. Creek hazards include those arising from debris flow, debris geohazard, and clearwater riverine geohazards. The success of this approach is not yet known, as DPAs are relatively new, and further they are a long-term strategy aimed at mitigating risk as land is redeveloped. However, anecdotally, they are an effective tool to manage building-scale responses to geohazard risk.

#### 2.4.1.2.3 Additional Regulatory Options

Local governments in BC have several options to regulate land use within hazard zones in addition to OCPS and related DPAs. With regard to geohazard in particular:

1. **Zoning bylaws** can also be used to regulate an individual parcel of land. Section 903 of the *Local Government Act 2004* can regulate parcel configuration, the density of the land use, siting and standards of buildings and structures. Zoning bylaws are no longer promoted as a tool for geohazard management—the provincial government cites the use of DPAs instead (BC Ministry of Water Land and Air Protection, 2004).
2. **Local building bylaws** can be used by local governments to potentially affect disaster risk. However, many components of the building bylaw that are relevant to risk mitigation are controlled within the BC Building Code.

#### 2.4.2 Professional Guidance Documents

In BC, there is a general trend to rely on qualified professionals, as opposed to rigid regulatory standards, in the natural resources field—this includes natural hazard management. In order to provide guidance to clients and professionals, the Engineers and Geoscientists of British Columbia (EGBC), have developed a series of professional practice guideline documents. Of limited relevance to this project is the *Legislated Landslide Assessments for Proposed Residential Developments in British Columbia* (EGBC, 2010). These guidelines provide some ideas and concepts related to landslide hazard and risk assessment, but are very focused on increased understanding and mitigation of risks for individual homes (as opposed to this project, which is at a regional scale), and are focused on only a few quantifiable indicators of risk. Further, these guidelines are now dated, and do not reference current international best practice for natural hazard risk assessment and reduction (i.e., the Sendai Framework).

### 2.4.3 Cowichan Valley Regional District Policy

The primary currently enacted policy in the project area is the 2005 Official Community Plan (OCP) No. 2650 for Electoral Area I – Youbou/Meade Creek. This includes specific direction on development in geohazard areas to require a professional engineering report that describes the potential risks. This OCP does not currently include mapping to support the policy.

**Policy 2.5:** In areas where hazard lands have not been formally mapped by senior governments the following criteria will be established as a means of determining hazard slope lands:

- (a) All lands with gradients exceeding 25%;
- (b) All lands within 30 metres of undeveloped slopes with gradients exceeding 50%; or
- (c) All lands within 30 metres of developed slopes with gradients exceeding 25%.

Where the Regional Board considers that construction would be on hazard lands or lands that are subject to or are likely to be subject to flooding, mud flows, debris flows, debris torrent, erosion, landslide, rockfalls, subsidence or avalanche, the Regional Board may require the owner of land to provide a report certified by a licensed, professional engineer with experience in geotechnical engineering indicating that the development will not result in the detriment of the environment, possible property damage or the loss of life on the site or in the surrounding area.

The OCP also notes that the CVRD “encourages the Province and private forest companies to manage natural resource lands in a manner which minimizes adverse impacts on the community water supply, surface watercourses, groundwater sources, **hazard lands**, critical wildlife habitat, old growth forests and other sensitive ecosystems”. It should be noted that while most of the community impacts lists (water supply, wildlife, etc.) are also listed in the provincial *Private Managed Forest Land Act* [2003], the *Act* does not include hazard lands.

There are numerous additional references to land use within hazard lands throughout the OCP, including within Development Permit Areas (DPA), specifically for Youbou. Additional details on requirements for development in this area as they pertain to hazards specifically include “a report by a qualified engineer with experience in natural hazard assessment, management and mitigation, which will identify areas that ought to remain free of development, areas that may be used for development provided that specified engineering measures are employed, and areas that may be developed without constraint”.

The CVRD is in the process of updating and consolidating their OCPs and supporting materials. The information above reflects the regulatory regime at the time of reporting and may change as new policies are developed and promulgated.

In summary, the CVRD currently has policies to support natural hazard risk management. The challenge that is presented by the current policies is the potential for inconsistency by relying on individual (and

potentially different) professional opinions. The professional reliance model can also create a resource challenge for CVRD staff who require time and expertise to review and approve professional reports. Streamlining this process by providing base information (such as the work within this report) and a consistent approach to risk reduction (by setting target thresholds, for example) would likely improve natural hazard risk, consistency, and staff resources.

In addition to the OCP, the CVRD is currently exploring its approach to the management of natural hazards through various projects, including this one. Most relevant is another project (The Natural Hazards Disaster and Risk Reduction Strategy), which has the objective to “review policy, baseline analysis, gap analysis, and hazard vulnerability assessment of CVRD policies”. The initial phase of that project should be completed in Spring 2019.

## 2.5 Funding Context

The regulatory context above shows that geohazard management is primarily a local government responsibility. However, geohazard mitigation, especially structural geohazard mitigation projects, are generally far more expensive than local government budgets can stretch. In recent years, the provincial and federal governments have developed some new granting programs to support geohazard mitigation planning, as well as to implement geohazard management solutions; these are summarized in Table 1.

**Table 1: Summary of available funding programs for geohazard risk reduction.**

Program	Owner	Comments
<a href="#"><u>National Disaster Mitigation Program (NDMP)</u></a>	Public Safety Canada (PSC)/Emergency Management British Columbia (EMBC)	This is a 5-year program (currently in its last cycle) designed to support hazard mitigation through the funding of foundational research and planning (hazard risk assessments, hazard mapping, hazard mitigation plans). This project was funded through the NDMP.
<a href="#"><u>Community Emergency Preparedness Fund (CEPF)</u></a>	Union of BC Municipalities (with funding from EMBC)	This is a 2-year program (currently in its last cycle) that, in part, mirrors the NDMP. There are also additional funding streams for structural mitigation works and for emergency management/response and emergency social services.
<a href="#"><u>Disaster Mitigation and Adaptation Fund (DMAF)</u></a>	Infrastructure Canada (INFC)	This is a 10-year program that has just had its first intake. This was envisioned as a complementary program to the NDMP, where foundational work, including proposed mitigation options, is realized through DMAF funding. This program supports all-hazards (as opposed to the flood-focused NDMP and CEPF) and has a basement funding allocation of \$20M. Further, this program has a strong focus on green infrastructure and low-carbon resilience (as opposed to structural mitigation).

Variations on the following criteria/requirements are common to all the current programs for both planning and structural mitigation:

- A hazard risk (either historic or based on a risk assessment) needs to be established.
- Any proposed project must show a reduction in risk.
- The proponent must show a commitment to preparedness, planning, and mitigation.
- Any proposed project should contribute to or be based on a comprehensive, cooperative, and regional mitigation plan.
- Any project must consider climate change (both mitigation of greenhouse gases and adaptation to climate futures).
- Any proposed project must demonstrate good value for money.

These criteria, along with the overall mandates for these programs, show a clear directional shift in senior government funding for mitigation of geohazard and other natural hazards. Namely, that senior government is shifting away from reactionary funding and from a focus on structural measures towards investing in long-term resiliency based on comprehensive risk-based plans. In order for the CVRD to leverage these funds in the future, they need to invest in the development of comprehensive geohazard management planning (see Section 9 for a description of what this is). This current project lays the foundation for this type of work and should put the CVRD in good stead for senior level government funding in the future.

## 2.6 Summary

The CVRD is challenged by numerous natural hazards, including extensive geohazards along the north slope of Cowichan Lake, and the hazard profile is will increase with the changing climate.

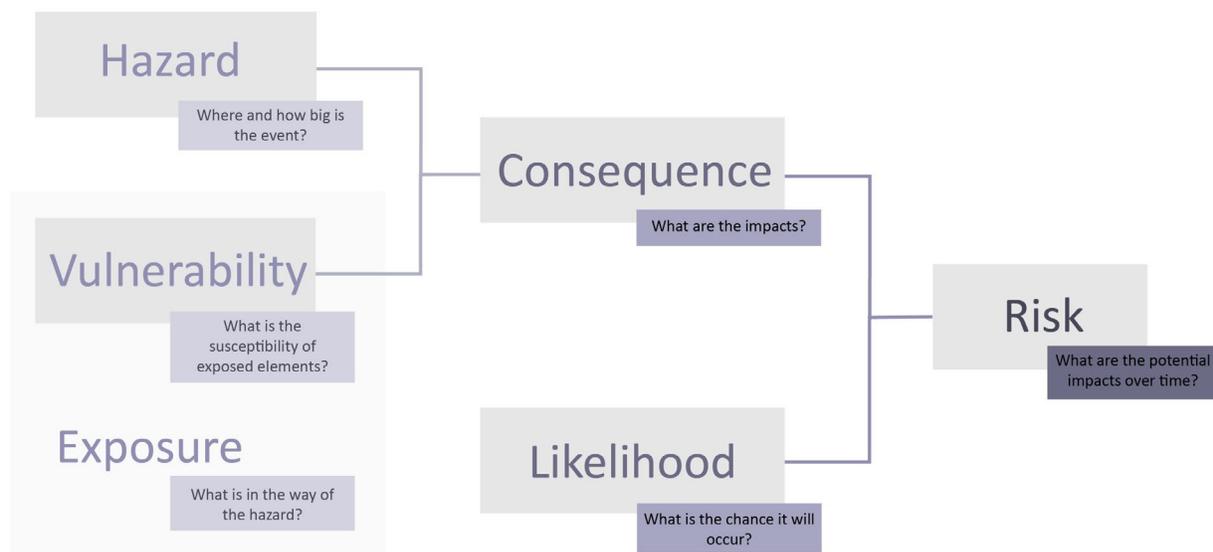
The approach to the management of natural hazards, like debris flow, is shifting in Canada in an attempt to move away from reactive measures to more proactive risk-based planning. There are senior government funds and policy directives on the approaches to risk mitigation for natural hazards; however, the nuts and bolts of the process are not clearly defined. This provides an opportunity for a community like the CVRD to benefit and draw from international best practice for risk management and mitigation, without the constraints of strict regulations.

### 3 Risk Assessment Primer

The primary objective of this work is to provide an understanding of present-day and future risk associated with geohazards within the project area. This section outlines the concepts of natural hazard risk, especially as it pertains to geohazards, and informs the next three sections, where the specific hazard, impacts, and risks are discussed.

#### 3.1 What is Natural Hazard Risk?

A solid grounding in the understanding of the term *risk* is key to understanding the components of a risk assessment. *Risk* is a function of both the *likelihood* of an event occurring, and the *consequences* if that event occurs. *Consequence* is defined as a function of the *hazard* (where and how big is the event?), and *vulnerability* (what's in the way and how susceptible is it?). *Vulnerability* can be further described as a function of *exposure* (what's in the way?), *resilience* (how will the system resist and recover?), and *mitigation* (what measures are in place to reduce damage?).



**Figure 3: Risk as a function of consequence and likelihood (simplified).**

Figure 4 shows how risk is a function of both likelihood and consequence, and that risk increases radially across the diagram. A virtually certain but insignificant event can have the same risk as a catastrophic but rare event. This becomes particularly important as we look across long time-horizons. For example, a nuisance hazard that occurs annually over several decades and accumulates losses, may in fact be more impactful than a catastrophic hazard that occurs just once. A risk assessment can be used to compare both the impacts and the potential benefits of mitigation options for the whole spectrum of nuisance to catastrophic events. This provides the best possible tool to make informed investment and planning decisions.

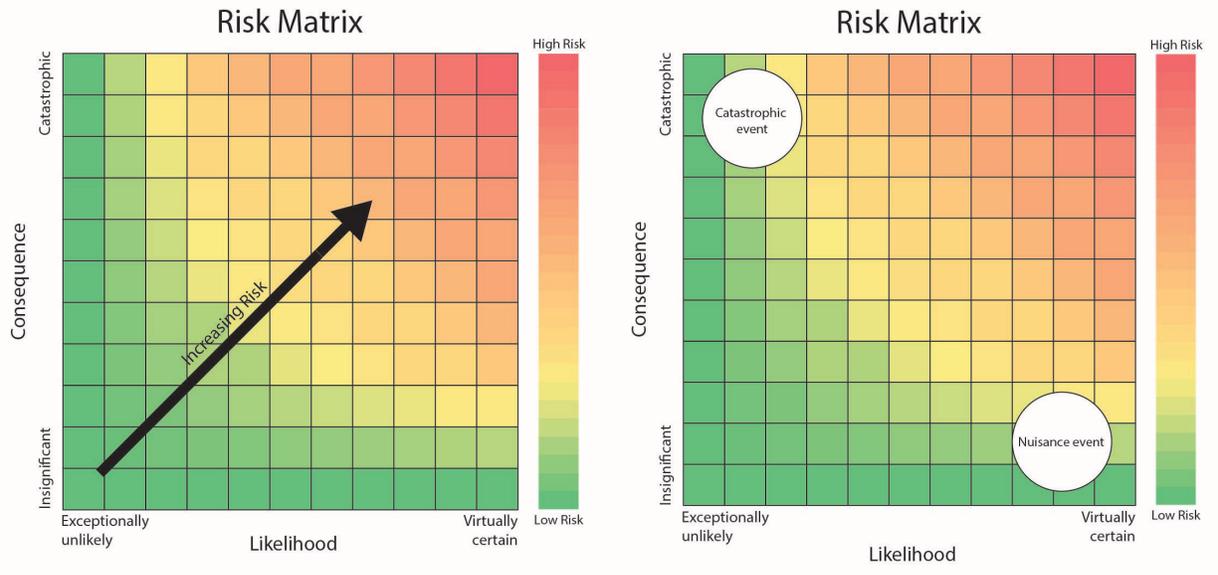


Figure 4: Risk as a function of likelihood and consequence – nuisance and catastrophic risk.

### 3.1.1 Geohazard Risk

Geohazards, like debris flows, are generally considered to be low likelihood, high consequence events; this is similar to earthquakes or tsunamis, but in contrast to coastal or riverine flooding. In Figure 4, geohazards, like debris flows, fall near the bubble for a large magnitude earthquake. However, when considering scale, debris flows are much more intensive (i.e., smaller scale) than something like a large-magnitude earthquake, which is considered an extensive risk. A further important characterization of natural hazards is the speed at which they are triggered and propagate. Geohazards are generally considered to be sudden (as opposed to slow-onset), which has considerable implications to warning times and response capacity. Understanding the scale and the type or the particular risk is key to planning for mitigation, management, and response to these hazards.

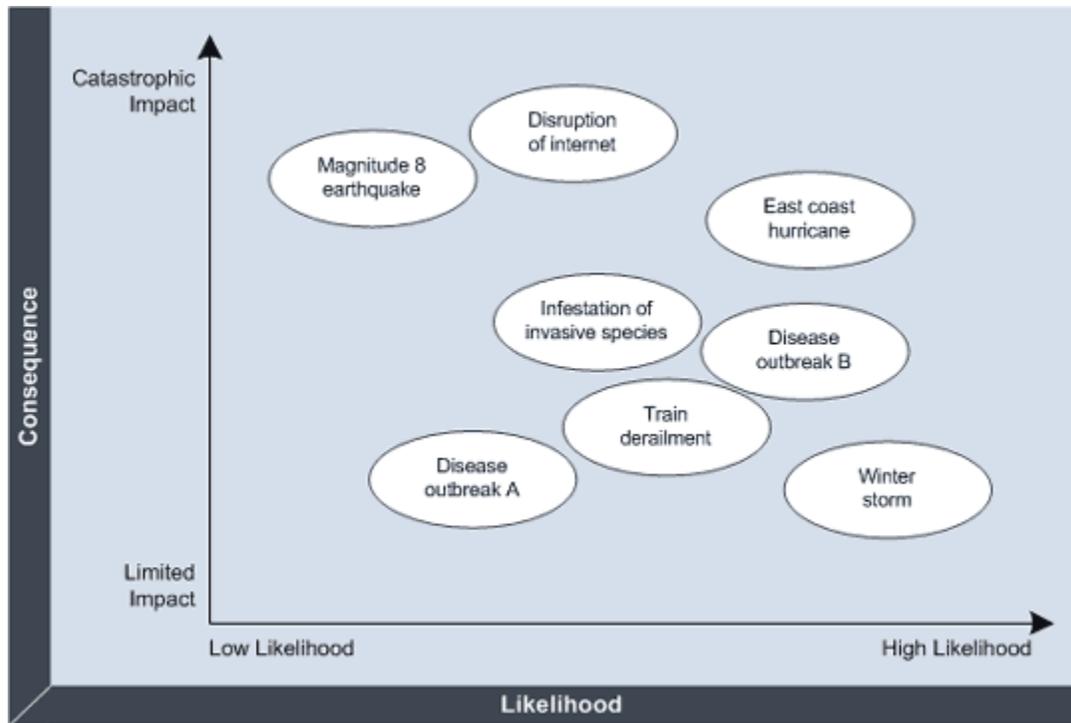


Figure 5: Consequence and likelihood of various natural and anthropogenic hazards (Public Safety Canada, 2013).

### 3.1.2 Risk as a Dynamic Concept

Risk is not static. The variables that form risk (i.e., hazard likelihood and severity, exposure, and vulnerability) are all prone to change over time. These changes are a result of both global-scale issues, such as climate change, which can impact local hazard profiles, and local issues, such as land-use decisions, which may affect exposure and vulnerability. Figure 6 demonstrates schematically how risk can increase with time. For example, for many natural hazards it is expected that climate change will increase the likelihood of occurrence (it may also increase the severity and therefore the consequences), which shifts risk from the left to the right of the diagram resulting in increased risk. Alternatively, risk can be changed by increasing the consequences of the hazard occurring, for example by allowing increased development in hazard areas. In this case, the risk shifts from the bottom to the top of the graphic, resulting in increased risk. It should also be noted that these issues can be compounded, and increased likelihood combined with increased consequences will result with dramatically increased risk (as illustrated by the bubble in the top right of the graphic).

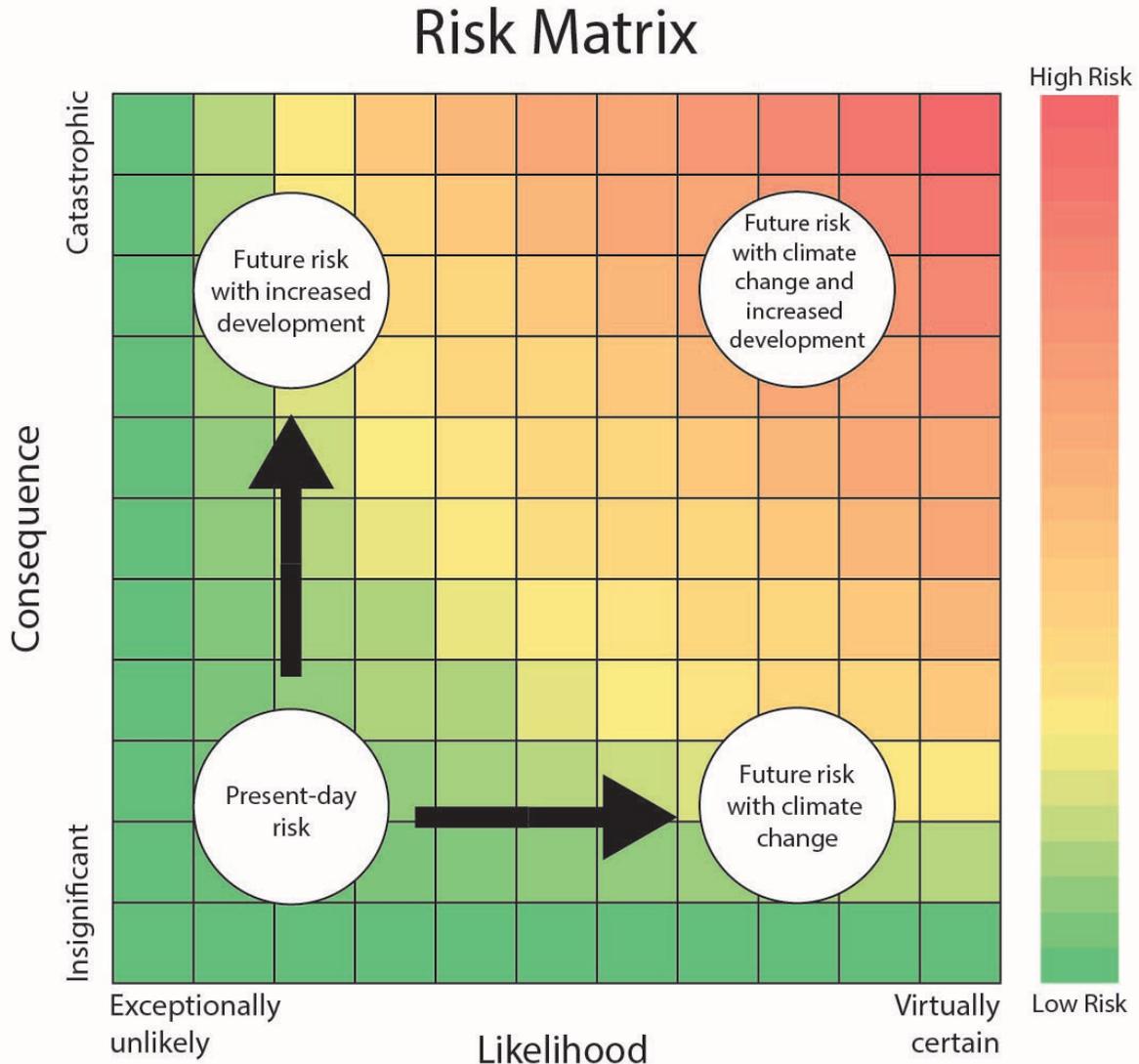


Figure 6: Dynamic risk with climate change and increased development.

Given that risk is dynamic, it is important to consider both present-day and future risk, especially when seeking means to maintain or reduce risk over time. These ideas, in the context of geohazard risk in the CVRD, are explored in more detail later in the report.

### 3.1.3 Hazard Likelihood Concepts

The likelihood (or probability) of hazard occurrence is a key component of understanding the hazard. The frequency of a particular event is tied to its severity. Minor hazard events occur more frequently, and severe ones occur less frequently.

In this report, hazard likelihood is expressed as an Annual Exceedance Probability (AEP). AEP refers to the probability of a geohazard event occurring in any year and it is represented as a percentage. For

example, an extreme geohazard that has a calculated probability of 0.2% of occurring in this or any given year is described as the 0.2% AEP geohazard<sup>4</sup>.

Another way to think about hazard likelihood is through the use of asset encounter probabilities, where it is possible to calculate the likelihood of encountering an event of a given size over a defined time period—for example, the length of an average mortgage (25 years) or the average lifespan of a human (75 years). Table 3 shows that for a 1% AEP event there is a 22% chance that an event of this size or greater will occur over a 25-year period. Understanding the likelihood of an event as well as the encounter probability of an event can support decisions related to geohazard management. For this project, we have considered multiple likelihood scenarios, and have reported them all using the AEP terminology.

**Table 2: Encounter probabilities for various likelihoods.**

Annual Exceedance Probability (AEP)	Indicative Return Period	Encounter Probability of Occurrence in 25 years	Encounter Probability of Occurrence in 50 years	Encounter Probability of Occurrence in 75 years	Encounter Probability of Occurrence in 100 years
<b>100%</b>	Annual	100%	100%	100%	100%
<b>30%</b>	Once every three years	100%	100%	100%	100%
<b>10%</b>	Once every 10 years	93%	99%	100%	100%
<b>3%</b>	Once every 33 years	53%	78%	90%	95%
<b>1%</b>	Once every 100 years	22%	39%	53%	63%
<b>0.1%</b>	Once every 1000 years	2%	5%	7%	10%

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<sup>4</sup> It is emerging best practice to represent hazard likelihoods with an AEP. In the past, hazard likelihood was commonly represented as an X-year return period. However, this tends to cause confusion regarding the frequency of an event with the lay public. For example, it is commonly believed that if a 100-year event has occurred, it will not re-occur for another 99 years, which is incorrect.

### 3.2 What is a Risk Assessment?

Given that *risk* is the combination of the *likelihood* of an event and its negative consequences, a *risk assessment* is essentially a methodology to determine the nature and extent of *risk*. This is done by analyzing potential *hazards* and evaluating existing conditions of *vulnerability* that together could potentially harm exposed people, property, services, livelihoods, and the environment on which they depend. A *risk assessment* can be qualitative or quantitative. For example, the national all-hazards risk assessment (AHRA) is a qualitative tool that will help identify, analyze, and prioritize a full range of potential threats (Public Safety Canada, 2012). This type of tool can be relatively quickly and cheaply developed at a national scale and is invaluable for prioritization exercises. However, to make decisions to reduce risk locally, in particular through the use of land-use policy, requires a more robust methodology—ideally a fine-scale quantitative risk assessment (see Figure 5). A quantitative risk assessment is one that uses measurable, objective *hazard*, *vulnerability*, and *likelihood* to calculate *risk* and loss. The quantification of *risk*, although at times cumbersome, provides invaluable information for risk reduction through the provision of robust, transparent data for planning and decision-making.

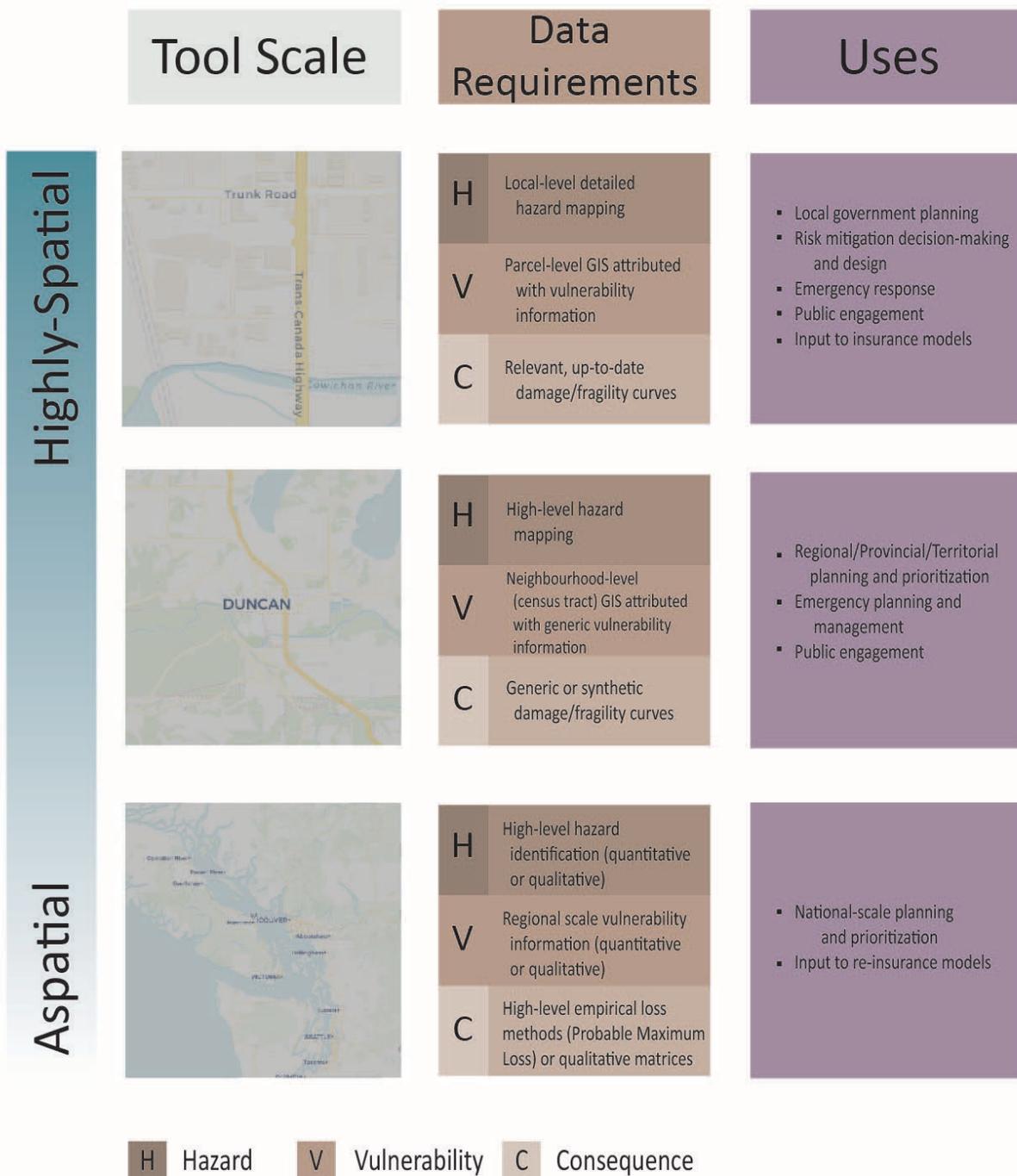


Figure 7: Scales of risk assessment.

### 3.2.1 Indicators for Risk Assessment

The CVRD has several objectives for this risk assessment. First, there is an interest in developing a better understanding of the risk generally throughout the area, as well as specifically in the project area due, to geohazards, and understanding how this is likely to change with climate change. In addition, the results

of this project will be used to support future funding applications. Both objectives have been considered in the development of the indicators used for this project.

Risk assessment is shaped by the types of exposed elements that are considered, however it is important to think about what can be measured. Given that the impacts of geohazards are often widespread and diverse, best practice suggests that a broad spectrum of impacts should be considered. One approach is to base impacts on the recently released UN document on indicators for disaster risk reduction (United Nations, 2016), which itself is based on the Sendai Framework indicators (UNISDR, 2015). These base indicators are currently being used by federal agencies in Canada to support various disaster risk and risk reduction programs. These are as follows:

1. **People** – An indicator used to represent the number of directly impacted people (fatalities and/or missing). This indicator is often quantified.
2. **Affected People** – An indicator used to represent the number of people indirectly impacted by a geohazard. These are people who have had their homes, schools, businesses, and/or other services lost or disrupted. This indicator is often quantified.
3. **Direct Economic Impacts** – An indicator used to represent direct (e.g., as a result of encountering a debris flow) losses that result from a geohazard. This primarily includes damage and reconstruction costs to public and private structures. This also generally includes the cost of response. This indicator is often quantified and monetized.
4. **Disruption** – This is an indicator that describes the potentially more widely spread impacts that can result from a geohazard (e.g., when a road is cut off, or when a substation is damaged). This indicator can be quantitative or qualitative.
5. **Environment** – This indicator is used to describe environmental impacts resulting from geohazard and is often considered to include both environmentally sensitive areas that are directly exposed (e.g., are within a debris flow area) and the effects of contaminants that are released into the geohazard area when industrial or other hazardous sites are affected. This indicator tends to be reported qualitatively, although new methods are being developed to monetize both the ecological value of the affected site and the cost of clean-up.
6. **Culture** – This indicator is used to describe impacts to cultural sites and includes both Indigenous and non-Indigenous areas and items. This indicator tends to be reported qualitatively.

The above is not a complete list of impacts, but provides a good starting point for review and discussion. For example, it does not fully cover indirect impacts (e.g., long-term health) or intangible impacts (e.g., human stress). However, given that most indirect and intangible impacts are difficult to quantify and to monetize, the above provides a good foundation for a risk assessment. The categories outlined above also fully meet the needs of the existing RAIT form.

### 3.2.2 General Impact Types

Beyond the gross indicators for risk mentioned above, there are many ways to categorize and consider impacts. As described below, not all of these impact types are easy to estimate, but that does not mean

they should not be considered. At a minimum, it is important to recognize what types of impacts have been considered in a risk assessment and to be explicit about those that have not.

**3.2.2.1 Direct and Indirect Impacts (or Consequences)**

Impacts can also be grouped into direct and indirect impacts. **Direct** impacts describe all harm that relates to the immediate physical contact of water and debris to people, infrastructure, and the environment. Examples include damage to buildings, impacts on building contents and other assets, damage to the environment, and loss of human life. **Indirect** impacts are those caused by the disruption of the physical and economic links in the region, as well as the costs associated with the emergency response to a hazard. For example, business losses because of interruption of normal activities, or costs associated with traffic disruption when roads are impassable.

**3.2.2.2 Impacts (or Consequences) by Tangibility**

The effect of a geohazard event on the environment, human or community health, or loss of life are difficult to quantify, and are therefore considered to be **intangible** impacts. On the other hand, the **tangible** dollar losses from a damaged building or ruined infrastructure are more easily calculated. This does not mean that tangible losses are more important than the intangibles, just that they are easier to quantify and assess. The inclusion of intangible impacts is desirable for the development of a robust risk assessment (Messner *et al.*, 2006). Table 2 provides examples of direct/indirect and tangible/intangible impact typologies.

Table 3: Examples of hazard impact typologies.

Hazard Impact	Tangible	Intangible
Direct	<ul style="list-style-type: none"> <li>• Building damage</li> <li>• Infrastructure damage</li> </ul>	<ul style="list-style-type: none"> <li>• Loss of life</li> <li>• Health effects</li> <li>• Loss of habitat and environment</li> </ul>
Indirect	<ul style="list-style-type: none"> <li>• Loss of business</li> <li>• Traffic disruption</li> <li>• Emergency response costs</li> </ul>	<ul style="list-style-type: none"> <li>• Inconvenience of event recovery</li> <li>• Increased vulnerability of survivors</li> </ul>

**3.2.3 Scenario Risk and Probabilistic Risk**

Risk as a function of likelihood and consequence can be defined in different ways. Two approaches with different outcomes that serve different purposes are outlined below.

### 3.2.3.1 Scenario-Based Risk

If a single event likelihood (e.g., an extreme event) is used to calculate damages and losses, this is called a risk *scenario*. This is the most common type of assessment completed in Canada, as it is relatively straightforward and requires only one hazard event be calculated and mapped. Scenarios are commonly used for emergency response planning, where large probable maximum events are used for exercises on the assumption that a plan for a catastrophic event will also be valid for smaller events. Scenarios have also traditionally been used to support hazard mitigation decisions because this simple standards-based approach is relatively straightforward to calculate.

### 3.2.3.2 Probabilistic-Based Risk

A probabilistic assessment is one that considers a range of hazard events and damage outcomes. The area under a curve (with likelihood and consequence as the axes) is integrated to give a full picture of risk. This approach is rarely used at present, but is quickly being considered best practice, as it provides an understanding of the impacts of frequent small events, as well as infrequent large events. Probabilistic assessments can be resource intense; however, updates in technology and methods are slowly reducing the relative effort to conduct them.

### 3.2.3.3 Scenario Versus Probabilistic Approaches

Scenario approaches are the most commonly used—primarily because of the relative effort. However, probabilistic approaches are becoming more common and are generally considered best practice. This is especially true with climate change, as some smaller and medium events become more common. Decisions can be affected by the approach taken (Lyle, 2016), and it is therefore important to choose an appropriate approach given the available resources, data, and time. For this project, where a relatively fine-scale and detailed hazard assessment was conducted, probabilistic approaches were used.

## 3.3 Limitations to Risk Assessment Methods

Although widely accepted as best practice for natural hazards management, risk-based planning and the requisite risk assessments are a relatively new concept in Canada. Traditionally, natural hazards have been managed based on specific hazard standards (e.g., a 0.5% AEP flood event or a factor-of-safety on engineered designs in geohazard areas). As we transition from a factor-of-safety approach for geohazards to more holistic quantitative risk assessment methods, there is a need to develop new methods to understand the interactions between the hazards and the assets at risk. For the most part, methods for this type of detailed assessment are in their infancy.

Further, the impacts of geohazards are widespread, and affect people, infrastructure, the economy, culture, and the environment. Damage estimation, however, has traditionally been the domain of engineers, and, as such, has focused on economic valuation of infrastructure and building losses, leaving a large gap in knowledge regarding intangible impacts (Messner and Meyer, 2006). This gap has increasingly been acknowledged, but there is still very limited validated research available, and tools to look at intangible impacts are largely undeveloped. It is known that when damages are monetized, buildings become priorities for hazard mitigation, whereas when damage is expressed as the number of

people affected by an event (through stress or inconvenience), road damage and associated disruption become a mitigation priority (Veldhuis, 2011). The metrics chosen for assessing damage can deeply affect subsequent planning decisions. In effect, the non-inclusion of intangible impacts can affect priorities. The methods used in this project (further described in Section 5) aim to be as holistic and robust as possible given the limitations of the project and data.

### 3.4 Summary

Risk assessment for natural hazards is a challenging and evolving field. The level of effort it takes to conduct a risk assessment is very dependent on the use of the information, but also on the available data and resources. Detailed quantitative methods for all-hazard risk in particular are in their infancy in Canada (Ebbwater Consulting, 2016). Landslide hazard assessment guidelines for BC are available from EGBC, however their implementation is often high level, quantitative and only takes into account direct and tangible impacts.

It should be noted that much of this work is leading-edge and therefore requires significant innovation. We anticipate that these methods will be refined and improved over time by risk management professionals. The risk assessment provided in Section 6 meets and exceeds current best practice and is suitable for input into risk assessment templates required by various funding agencies. The results also provide foundational information that can be used to support future mitigation planning.

In summary, a true risk assessment, one that looks at consequences over time, is an invaluable instrument for decision makers, policy makers, and planners. It can be used to understand and mitigate present and future damages, to create risk management strategies that are both cost effective and community supported, and to help plan for long-term financial investments in risk mitigation.

## 4 Geohazards in the Project Area

An assessment of the locations of hazard and the associated likelihood are key components of a risk assessment and mitigation planning. Geohazard is best estimated through the development of detailed topographical modelling combined with field assessments and ground-truthing. As part of this project for the CVRD, terrain mapping, hazard inventory, quantitative hazard model, and hydrogeomorphic classification of watersheds in the project area have been developed by Palmer. This hazard information was then used by Ebbwater to complete an assessment of exposure and vulnerability as presented in Section 5 and then complete a risk assessment as presented in Section 6.

This section describes some general types of geohazards, including those present within the project area. Additional detail regarding the hazard study can be found in the hazard report produced by Palmer, available in Appendix D.

### 4.1 Types of Geohazards in the Project Area

Within the project area, geohazards were assessed with a focus on debris flows. Debris flows as a hazard type exist within a spectrum of geohazards from fall (e.g., rock avalanches) to liquid flow (e.g., clearwater floods) that is characterized by several parameters as shown in Figure 8.

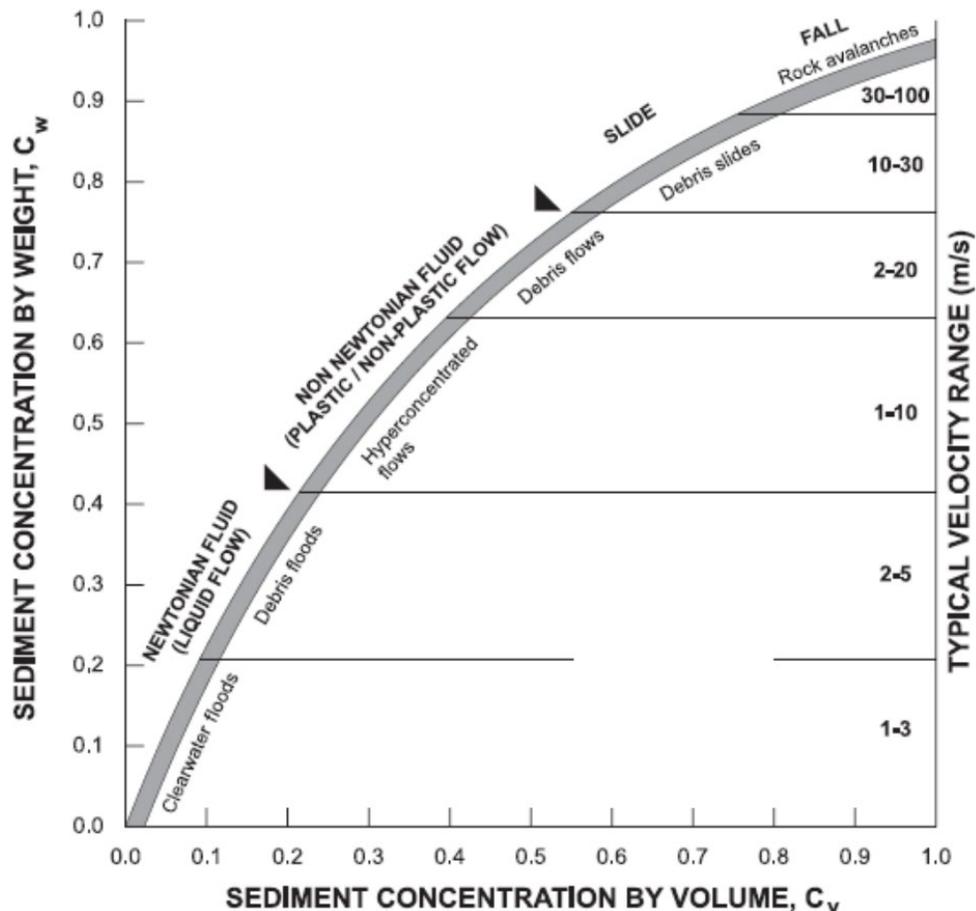


Figure 8: Watershed morphometrics graph (Jakob and Jordan, 2001).

There are three parameters that characterize these hazards along the spectrum, including velocity, sediment concentration by weight, and sediment concentration by volume. It is, however, very difficult to measure these characteristics directly and so typically other parameters, including the slope and watershed size, are used for classification. To define watershed morphometrics<sup>5</sup> the parameters used are watershed size, watercourse length, and watercourse slope. Many studies have been done using these methods in BC, and it has been found that for 90% of the cases, the Melton ratio correctly predicted debris flow (Wilford *et al.*, 2004).

In addition, while there are individual definitions and classification criteria for debris flow, debris flood, and clearwater floods, these events exist on a continuum, and exact differentiation of these processes can only be achieved through direct sampling. Even with direct sampling, some of the relevant thresholds can be difficult to detect. It should be kept in mind, therefore, that classification indicates the dominant process in a given watershed, not the only possible process (Jakob, 2016).

While debris flows are the focus of this project, several geohazard or landslide types were identified in the project area as part of the landslide inventory of historic aerial images. These hazards include debris flow, debris slides, rock falls, and rock slides, and are briefly described below.

#### 4.1.1 Debris Flows

Debris flows are rapid mass movements of saturated surficial material and organic debris, which can be a mixture of rock, sand, and/or soil. The high water content of debris flows allows them to flow downhill as slurry, often resembling wet concrete. This category includes debris torrents, also known as “channelized debris flows”. Channelized debris flows commonly grow larger through entrainment of in-channel material.

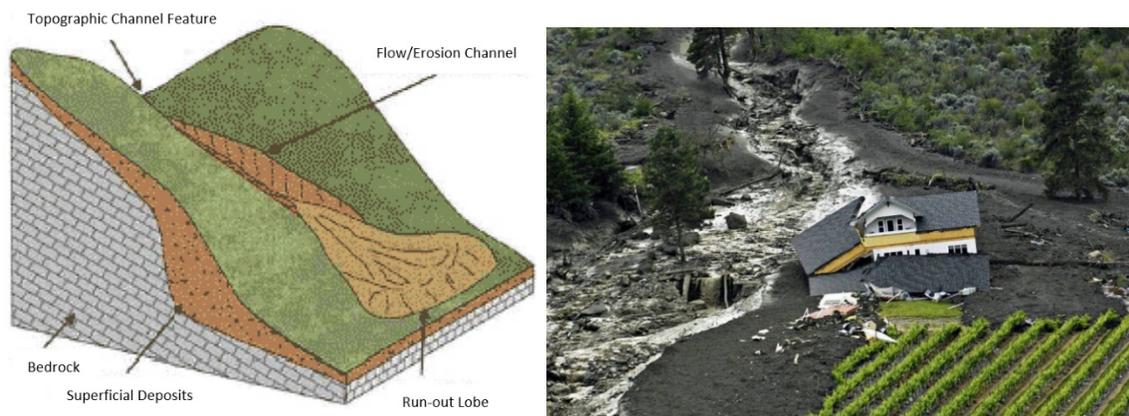


Figure 9: Channelized debris flows (Smith, 2004).

<sup>5</sup> Morphometrics describes measures of the shape or form of the watershed.

Debris flows can initiate from other movement styles, such as rock slides—as those masses disintegrate and release internal water or entrain other material, they can form debris flows. This is the most common hazard in the project area.

#### 4.1.2 Debris Slides

Debris slides are rapid sliding masses of surficial material. These typically have a shorter runout length than debris flows and move as a solid rather than a liquid or a slurry. Debris slides are common where slopes have been steepened or undercut by road building.

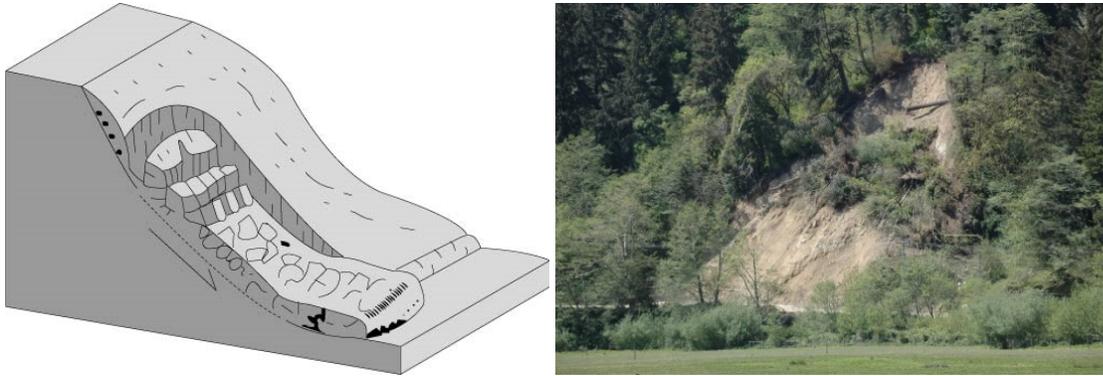


Figure 10: Debris slides (Smith, 2004).

#### 4.1.3 Rock Falls

Rock falls occur when detached masses of bedrock move by falling, bouncing, or rolling. Rock falls typically have small volumes, but may occur with a high frequency. These occur on steep bedrock slopes and cliffs.



Figure 11: Rock falls (Smith, 2004).

Rock falls occur on steep slopes and can be caused by a number of factors, such as the structure of the rock mass, weathering, ground and surface water, freeze-thaw dynamics, root wedging, and external stress.

#### 4.1.4 Rock Slides

Rock slides are large disintegrating masses of bedrock moving downslope by sliding. Rock slide volumes can vary greatly. The largest landslides in Canada are rock slides (e.g., Frank Slide near Hope, BC, pictured).

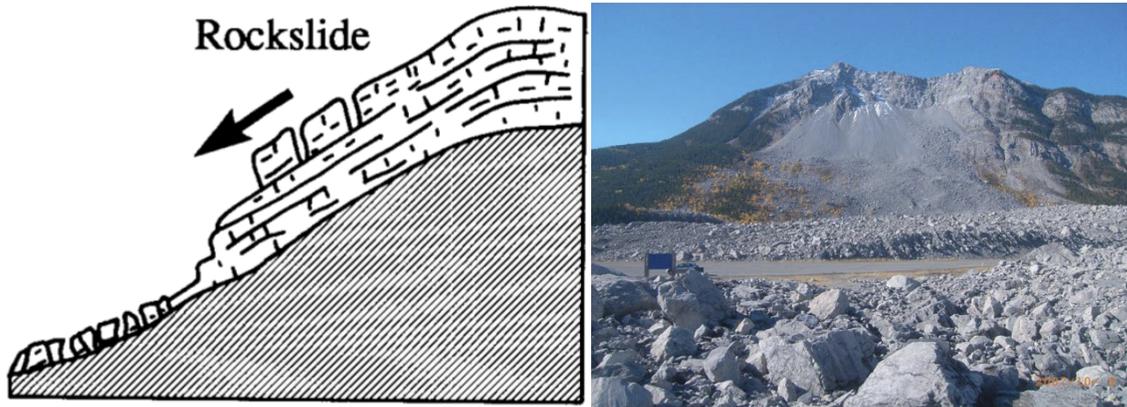


Figure 12: Rock slides (Smith, 2004).

Rock slides can be caused by factors such as seismic activity, external stress, as well as ground and surface water.

## 4.2 Triggering Mechanisms for Geohazards

Geomorphic characteristics (as described above) are one indicator of the existence of geohazards in a given area. However, other processes, such as climate, are extremely important in determining if and when a geohazard will be triggered. The dominant weather processes that affect the likelihood of an event are the antecedent conditions (i.e., how saturated is the ground?) and the occurrence of short, intense rainfall (Jakob and Lambert, 2009). R. Guthrie (2009) notes that a critical threshold for landslides on Vancouver Island is 80–100 mm in a 24-hour period.

In addition to hydroclimatic triggers, additional weather- and climate-related processes can affect the likelihood of occurrence. Specifically, wildfire is well known to increase the likelihood of debris flows (Cannon and Gartner, 2005) due to these factors:

- The removal of the tree canopy will affect hydrologic processes, increasing surface runoff.
- Fire can change the soil structure such that it becomes hydrophobic (i.e., the ground will not absorb water), which will also increase surface runoff.

Drought, especially when followed by extreme precipitation, will also increase the likelihood of landslides (Handwerker *et al.*, 2019). The science associated with this link is in its infancy, but it should be noted in an era of climate change when more extremes and more extreme fluctuations (i.e., from drought to flood) are expected.

Finally, anthropogenic activities can also affect the likelihood of occurrence. In particular, landscape modification through logging is well known to increase the frequency of geohazards (Guthrie, 2002).

Road-building associated with logging has the greatest impact on frequency; this is a result of the enhanced concentration of surface water and the over-steepening of cut and fill slopes when roads are built (Guthrie, 2005). Logging also affects area hydrology by changing the tree canopy (reducing interception and infiltration, and increasing surface runoff).

### 4.3 Summary of Methods and Results for Hazard Assessment

A hazard assessment for the project area was completed by Palmer using a combination of methods, including desktop mapping and validation through field investigation. This section outlines the key features of the hazard assessment. More details on the assessment method applied can be found in Section 3 of Palmer’s hazard report in Appendix D.

#### 4.3.1 Desktop Mapping

To assess hazard in the project area, desktop mapping was completed by Palmer using several methods, including quantitative hazard mapping, where a probability of encountering a hazard is assigned to each part of the project area. In addition, watersheds were classed by dominant hazard type.

##### 4.3.1.1 Watershed Morphometrics

As described above (Section 4.1), there is a spectrum of potential geohazards that might occur in the project area. Watershed morphometrics are used to understand the dominant expected hazard type.

Watersheds that produced fans large enough to be mapped at the scale of the aerial photos (1:15,000) were delineated and classed by dominant hydrogeomorphic process. The classification is based on the key characteristics of watershed size, slope, and watercourse length. These are used for the calculation of Melton ratios and relief ratios<sup>6</sup>. Additional detail is provided in Appendix D. Dominant processes in these watersheds (i.e., clearwater flood, debris floods, or debris flows) are shown in Figure 13.

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<sup>6</sup> Relief ratios are a measure of the watershed characteristics and describe the grade of a stream channel.

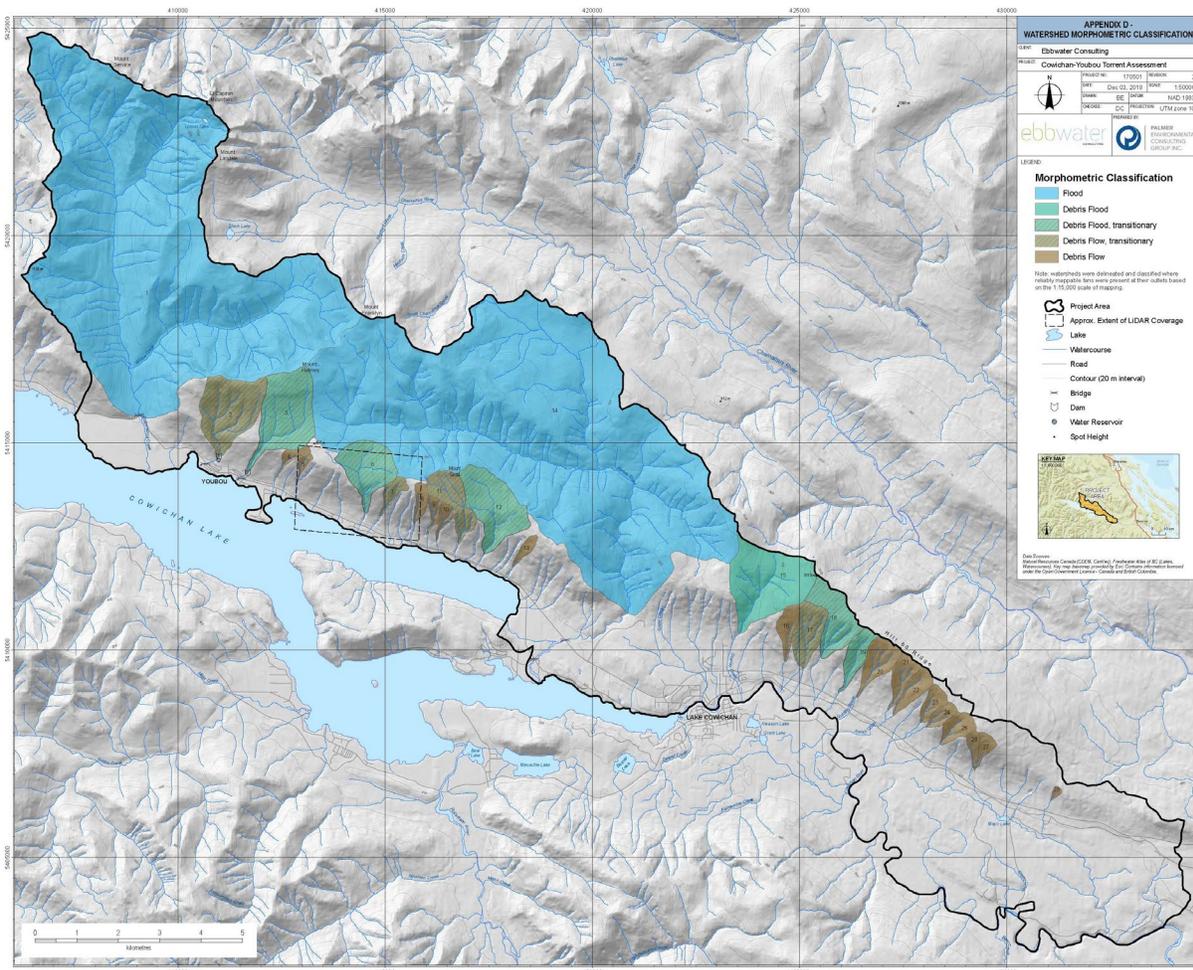


Figure 13: Watershed dominant morphometric classification (Palmer Consulting Environmental Group Inc., 2018).

The dominant hazard type in the area is clearwater flooding (shown in blue). A few sub-watersheds were found to have debris flood potential (green) and some smaller sub-watersheds in the eastern end of the project area are found to be dominated by debris flow potential (brown). There are numerous transitional areas as well.

#### 4.3.1.2 Geohazard Mapping

The landslide hazard mapping was developed using an inventory of historic failures in the project area and hazard modelling based on terrain attributes. The output of the landslide hazard mapping exercise was spatial polygons with probabilities of a hazard being encountered for each portion of the project area. These are presented in Figure 14, and are also provided in Appendix D.

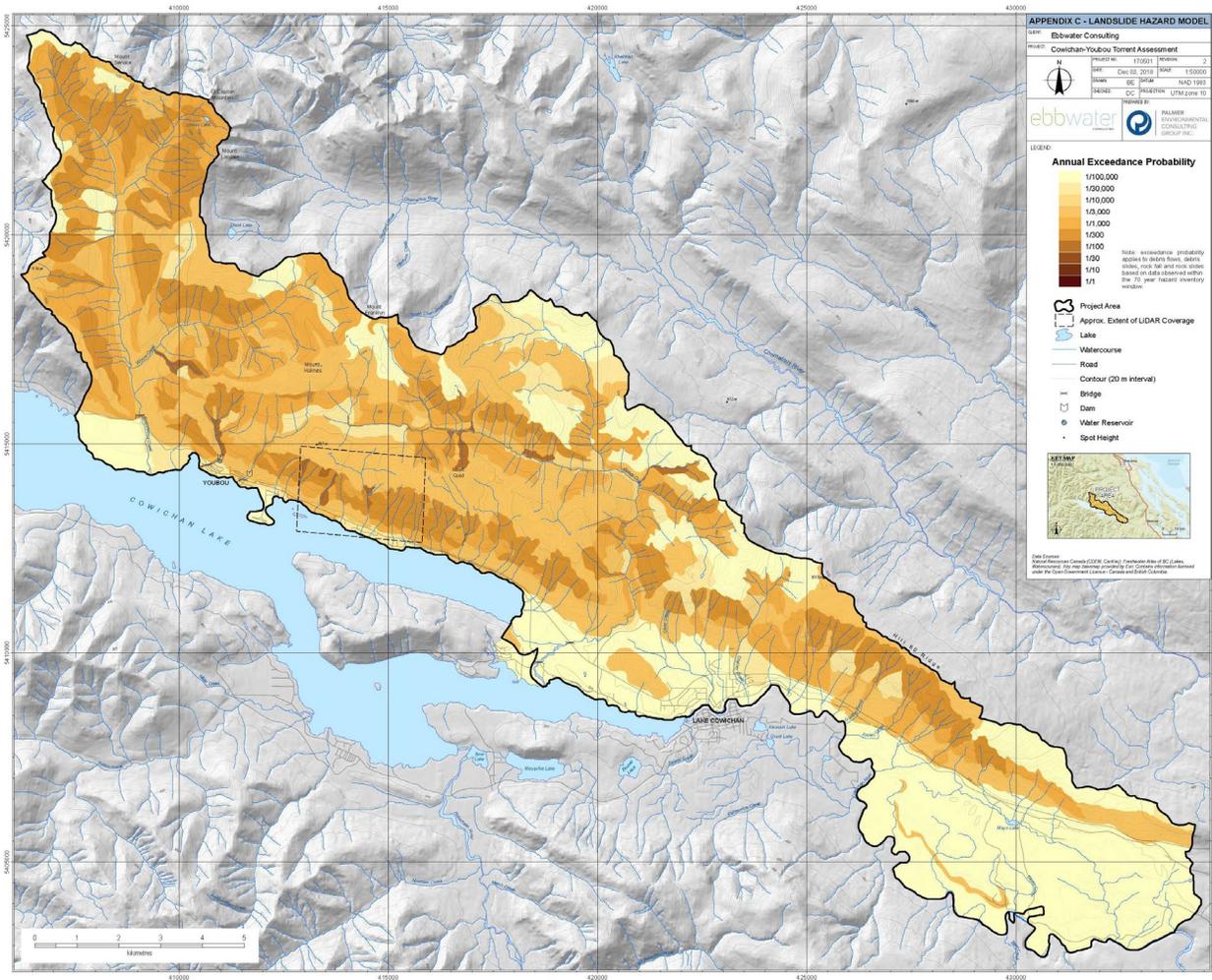


Figure 14: Landslide hazard model results (Palmer Consulting Environmental Group Inc., 2018).

The analysis shows that there is significant hazard across the project area, with more hazard towards the west. Limited hazard was mapped below Highway 18 in the eastern reaches of the project area. The figure above represents higher encounter probabilities (i.e., areas that are more likely to experience a geohazard event) as darker shades of brown. There are three major areas with moderate probability hazards: the upper watershed of Cottonwood Creek, the lower slopes between Cottonwood Creek and Meade Creek, and the upper slopes between Hill 60 and the Town of Lake Cowichan. There are notable areas where the probability of a geohazard occurring is low. These include the fan at the base of Cottonwood Creek, the Youbou peninsula, the Town of Lake Cowichan and the slopes below Highway 18 on the eastern edge of the project area. It should be noted that the mapping shows the best representation of the likelihood of a geohazard—in this case, defined as rock slide through debris flows. The morphometrics (see below) suggest that Cottonwood Creek is in fact more prone to clearwater floods than debris flows, and therefore the fan may be subject to hazard from flooding or induced avulsions and erosions. A geomorphic study to better understand the probability of a clearwater flood

creating an avulsion hazard (through a better understanding of the fan morphology—e.g., the entrenchment of the channel at the apex of the fan) should be considered.

Whilst all efforts have been made to provide the maximum level of resolution in the hazard model, spatial variability still exists. Further, the modelling completed considers the hazard likelihood for the initiation of a geohazard event. This will runout downhill, and therefore additional assessment, such as runout modelling, is suggested to gain a more accurate understanding of the interaction between different geohazards, hazard probabilities, and the hazard extents.

#### 4.3.2 Field Investigation

Field investigations were carried out in the summer of 2018 by Palmer, TimberWest<sup>7</sup>, and CVRD staff to validate the outputs of the desktop exercise. There are some signs of previous slope failures that can be observed and confirmed in the field that cannot be detected from the data used for the desktop exercise. The information collected during these field exercises was used to inform and confirm the desktop mapping. Additional details are provided in Appendix D.

#### 4.3.3 Conclusions

In summary, the hazard assessment produced a quantitative assessment of slope hazard and watershed classification. It was found that the project area is located in a glacially modified landscape containing steep slopes with active catchments that are prone to debris flows and other hydrogeomorphic events. Much of the higher hazard scores are in proximity to smaller (active) creeks. Many of the larger fans in the project area, such as the Cottonwood Creek fan, are paraglacial<sup>8</sup> and their surfaces appear to be isolated from more recent activity.

In all, 28 watersheds were classified based on their dominant process and it was found that 15 of these were affected by debris flows and another 9 were transitional between debris flow and debris flood. Of the watersheds whose dominant process is debris flow, one that is of concern with moderate probability is Youbou Creek. The cluster of creeks numbered 7 to 11 also have dominant debris flow processes and moderate hazard likelihood for much of the catchment, including runout areas, which cross Youbou Road in one location. Figure 15, which shows the portion of Figure 14 around Youbou, shows higher probability hazard in darker shades of brown. This image clearly highlights the intersection of moderate hazard areas with exposed elements (i.e., roads, development). This is further explored in the next section.

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<sup>7</sup> TimberWest, a forestry company, have tenure of lands within the project area. They participated in field work as a stakeholder of the project.

<sup>8</sup> Paraglacial describes the period after deglaciation, when unstable conditions can occur.

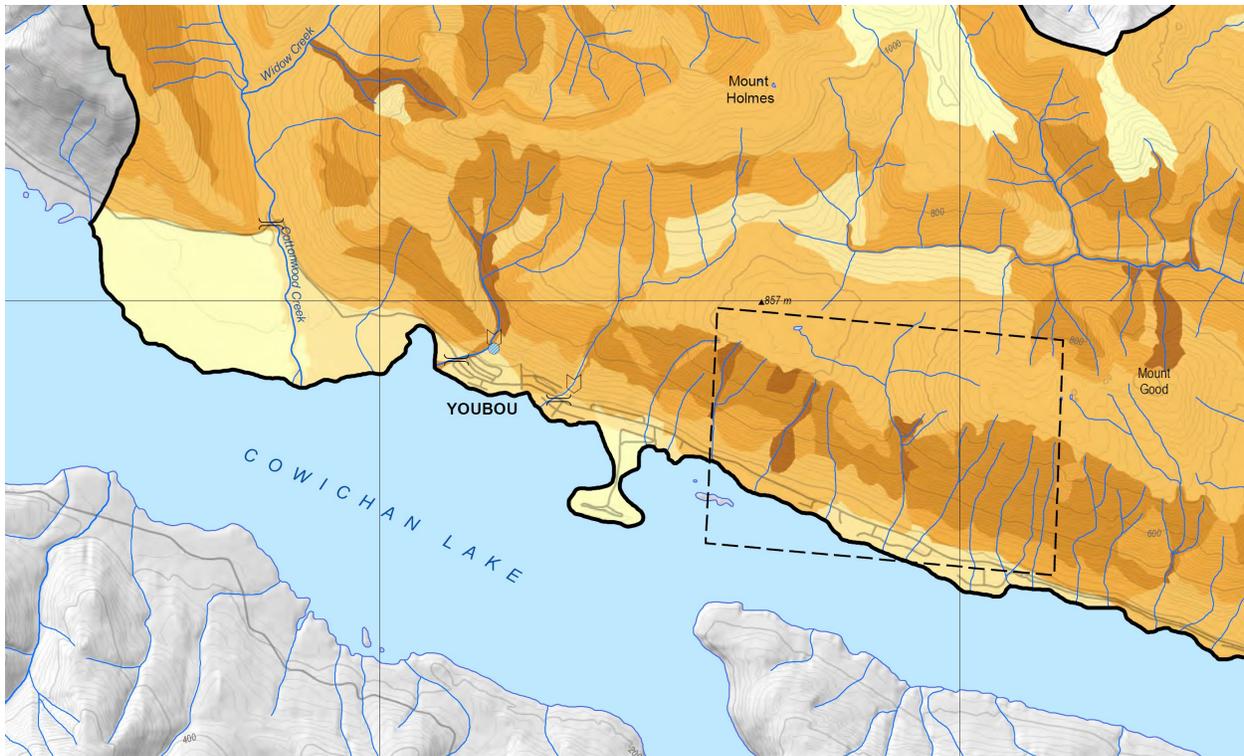


Figure 15: Hazard exceedance probability in Youbou Creek and unnamed creeks 7 to 11.

#### 4.4 Future Hazard Likelihood and Severity

Sections 4.1 and 4.2 describe some of the key conditions that affect the likelihood and severity of geohazard events. These include the morphometrics of the landscape, which would be considered generally stable for the timescales of concern (100s of years, as opposed to millennia), along with other hydroclimatic and anthropogenic factors. The primary drivers that are prone to change are:

- Land cover, which affects hydrologic processes.
- Land disturbance, which can affect localized morphology.
- Climate and weather:
  - Long-term temperature and precipitation (e.g., drought, saturated soils, snowpack)
  - Short-term precipitation (e.g., intense rainfall)
- Wildfire disturbance.

Some general discussion on trends and available science related to changing likelihood and severity is presented below. Analysis and discussion of how this affects hazard and risk scoring is presented later in the report (Section 6.4).

##### 4.4.1 Land Use

The forested lands in the upper reaches of the creek catchments of the project area are owned by TimberWest and Hancock Forest Management and have been logged in the past. There is potential for additional logging in the future. The link between logging and increased landslide frequency is well

documented by Guthrie (2002) and can increase landslide frequency by up to 10 times when compared to undisturbed land.

#### 4.4.2 Climate Change

According to regional climate projections, the intensity of storms and rainfall is expected to increase this century. Specially, the Cowichan Valley is projected to receive a 5% increase in annual precipitation by 2050 (Cowichan Valley Regional District, 2017). Much of this increase is predicted to come in the form of extreme precipitation events rather than be spread out over the year. The intensity of extreme events is predicted to increase dramatically, with a 30% increase in rainfall on 95<sup>th</sup> percentile wettest days. This means higher flows in creeks and soils that are more saturated and therefore more prone to debris flow.

Of interest is the 24-hour maximum rainfall, as this has been tied to debris flow likelihood by Guthrie (2009), who noted a critical threshold for Vancouver Island watersheds of 80 to 100 mm (see also Section 4.2). CVRD average climate projections (Cowichan Valley Regional District, 2017) for single-day maximums in the water supply watersheds (i.e., the project area) go from 79 mm in the present-day (i.e., below the threshold), to 93 mm in the 2050s and 103 mm in the 2080s (i.e., within and above the threshold). It should be noted that these numbers represent general trends, and that actual rainfall events are variable; some events greater than 79 mm/24-hour period are expected in the present-day and will certainly be seen in the future. This is a critical finding, as the likelihood of occurrence will undoubtedly increase in the future, and this may be a significant increase.

The projection that debris flow occurrence is likely to increase is confirmed by additional studies in the province. For example, it has been observed previously that high intensity rainfall events and prolonged periods of high precipitation result in a higher frequency of debris flows (Jakob and Lambert, 2009). For example, these authors found that climate change could influence a 28% increase in debris flow frequency in Howe Sound by 2100 and it is reasonable to expect a similar increase in the project area, based on topographic and climatological similarities. However, with more frequent events, the project area may see more “flushing” of sediment and so the individual debris flow events may decrease in magnitude with climate change as well.

In addition to changes in precipitation, the project area is expected to experience changes in seasonal temperature variability based on downscaled climate models and to generally become warmer. In the region, it is expected that the number of summer days above 25°C will double from an average of 16 days per year to 39 (CVRD, 2017). Drier summers in particular can mean more wildfires, which have been shown to decrease water retention upstream as soils become hydrophobic following a fire; this will lead to even higher intensities of runoff during intense precipitation events.

#### 4.4.3 Summary

In summary, general trends in climate and land use suggest that the overall likelihood of debris flow and other geohazard events will rise, potentially quite significantly (by a factor of 10 for logging, and over a critical threshold for climate). There may be a slight decrease in long-term severity of events as material is wasted off the surface, and the watershed is limited by available materials. However, this decrease in severity will occur over a long period of time (on a geologic scale).

## 5 Exposure and Impacts in the Project Area

A key component of any risk assessment is an understanding of what is in the way of the hazard (the exposure), as well as an understanding of how each of the exposed assets will react and recover (the impacts).

Earlier in this report (Section 3) the importance of capturing a range of impacts is described. Simply, **what is measured matters**, and therefore it is important to measure as many potential impacts as possible, and not simply rely on easily calculated indicators. The approach taken for this project is mindful of the need to explore some of the more difficult intangible and indirect impacts that result from natural hazard exposure. A mix of quantitative and qualitative measures are presented below, each of which can provide different insights. These are broadly grouped into six indicator groups, as described in Section 3:

- People (mortality and/or missing)
- Affected people
- Economic impacts
- Disruption (critical infrastructure)
- Environmental impacts
- Cultural impacts

### 5.1 Methods

As noted elsewhere in this report, risk assessment (including impacts and consequences) is considered best practice, but is still in its infancy in Canada. There are currently no regulated guidance documents on how impacts from natural hazards should be estimated. There are, however, international documents on methods and practice that can be used to inform methods. In particular, the following frameworks and documents were considered:

1. Sendai Framework for Disaster Risk Reduction (UNISDR, 2015)
2. The Global Facility for Disaster Risk Reduction Riskier Future Frameworks (GFDRR, 2016)
3. International Standards Organization (ISO) Standard 31000 – Risk Management

Other resources from around the world, particularly from the Australian Institute for Disaster Resilience (AIDR), were also used. The AIDR provides particular insight into the use of stakeholder knowledge and expert elicitation to support the estimation of intangible and indirect impacts (Australian Institute for Disaster Resilience, 2015).

Finally, methods were derived from recent consultant experience completing natural hazard risk assessments for other communities (also under the NDMP). Over time, these have evolved based on experience and data availability.

The methods applied to this project all consider forthcoming guidance on natural hazard risk assessment being developed by various agencies<sup>9</sup> in Canada. Specifically:

1. **Defence Research and Development Canada/Public Safety Canada**, who are developing a “Methodological Approach to Canada’s National Risk Profile”.
2. **Natural Resources Canada/Public Safety Canada**, who are developing flood risk assessment guidelines as part of the Federal Flood Mapping Framework initiative.
3. **National Research Council**, who are developing coastal flood risk assessment guidelines.
4. **Natural Resources Canada**, who are developing risk-based land use guidelines among other documents.

Each of the above are on different timelines, but all follow the basic frameworks for natural hazard risk assessment described in the international documents.

### 5.1.1 Methods for Qualitative Assessment

For the less tangible and indirect indicators, no hard datasets exist. Therefore, information on vulnerability to geohazard was gathered with the participation of local community stakeholders, as shown in Figure 16. Impacts were recorded in a workshop setting (more details on the workshops can be found in Appendix C) and this information was organized and mapped by the consulting team.



Figure 16: Gathering impact data at workshop 1.

Participants at the workshop were provided with some background materials on geohazard risk assessment and geohazard impact typologies (similar to the material presented in Sections 3 and 4). They were then asked to mark on maps the location and type of impact that they had experienced or felt they might experience. Direct and indirect impacts were marked in different colours, and the

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<sup>9</sup> Ebbwater is involved either as an author, advisor, or reviewer for each of the above guidelines. There may be other initiatives that are not yet public, and therefore not included in this list.

category of impact (i.e., people, economy, etc.) was inferred from the information provided, if not indicated by the stakeholder. This information was categorized and transferred to a digital GIS database and recorded as hotspot maps. Hotspot maps represent the density of impacts and can also be weighted to include other attributes if the data exists (e.g., the number of people within a dwelling could be used to improve hotspot mapping for affected people). These hotspot maps can be read by looking for areas with the most intense colour, which show areas with the greatest impacts and/or exposure.

This qualitative information can be very rich and can capture information that would otherwise be discounted. It shows spatially where impacts are, with larger areas of colour showing more impacts. However, it should be noted that there are limitations to this approach. Obviously, the diversity and number of stakeholders will affect the outcome (e.g., if there are only business owners present then economic indicators might be noted, but other indicators, such as environmental impacts, might be missed). For this project, a large and diverse stakeholder group attended the workshop, and the information presented below is considered relatively robust, although the assessment of cultural impacts could be improved. In addition, cultural impacts are particularly important from the First Nations who are stewards of the territory where the project is located. There was some participation from Cowichan Tribes in the second workshop, however only limited information was obtained.

#### 5.1.2 Methods for Quantitative Assessment

Quantitative assessments are generally considered more robust than qualitative ones, however they can only be conducted if appropriate data is available. For each of the indicators (see Section 3.3), a review of available data was conducted to establish whether a quantitative assessment could be conducted (a full list of available data is provided in Appendix E).

Where spatial data was available (e.g., building locations and/or footprints), this was overlaid with the hazard mapping to identify assets within the hazard area. For this project area, the topography is complex, and the watersheds are small. For the quantitative assessment, separate files were created for each hazard score and those were used to clip the exposure datasets. An example of this process is shown in Figure 17 with properties and building footprints shown for zones with different hazard scores.

Impacts have been reported according to the hazard likelihood score zone in which the assets are sited. This is to allow for an assessment of how many properties are exposed to different hazard likelihoods. Where assets overlap two different hazards zones they have been reported in the higher likelihood bracket. This is to provide a conservative estimate whilst avoiding double counting when estimating total impacts.

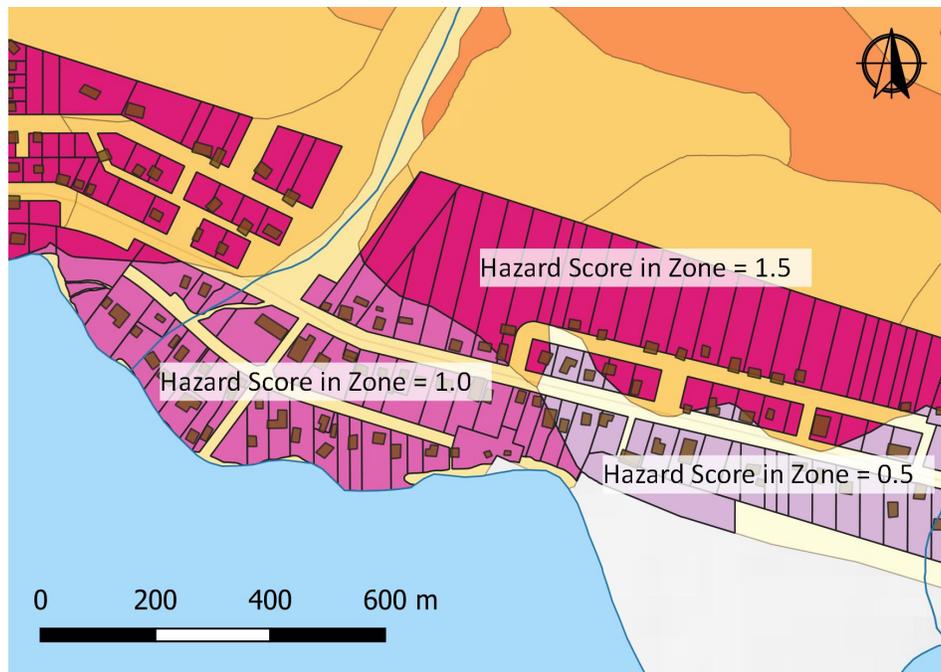


Figure 17: Quantitative exposure assessment process.

## 5.2 Results

The following summarizes the results of the exposure and impact analyses and includes some discussion for each of the six impact categories.

### 5.2.1 People (Mortality and/or Missing)

Debris flow events can happen quickly and can bring large volumes of sediment and soil with them, which pose a risk to life. There have been deaths in Canada due to debris flows and other geohazards (NRCan, 2017).

It is difficult to predict spatially where these events will intersect with people. This is simply because people move around and so population numbers in different locations will vary at times of the day, week, and year. For example, in the evening most people are home, so the exposure for residential buildings is higher. During the day, many people are at work or school, so the exposure for those areas would be higher. In the case of the project area, there are a significant number of vacation homes, so overall exposure of people would be higher on weekends and during the summer.

In the workshop, no particular areas of concern for risk to life were mentioned and so this was not assessed qualitatively. For the quantitative assessment, the number of residential buildings in the project area were calculated for each hazard zone as a proxy for exposed people. This proxy was chosen after consideration of available spatial and quantitative data. The proxy of residential buildings is intended to represent potential exposure to people, as most people spend a majority of their time in their homes. It is not a perfect representation of exposed people because of the many variables noted above, but it is considered robust enough to provide an indication of exposed population.

One thing of note in relation to mortality is that there is a temporal dimension as well as spatial dimension to the issue. Specifically, injury and/or mortality will only occur if the resident/visitor is present at the failure site when the failure occurs. This is in contrast to the affected people indicator (see below), which is a concern regardless of whether an individual was on site at the moment the failure occurs. And therefore, the methods used for these two indicators vary slightly, with the mortality indicator calculation being conducted using an extremely simplified approach that results in lower overall counts. There is considerable uncertainty in the estimation of mortality.

**Table 4: Summary of people (mortality and/or missing) impacts.**

Annual Exceedance Probability	Exposed Residential Buildings (proxy for people)
<0.001%	Not Calculated
0.001% to <0.0033%	280
0.0033% to <0.01%	44
0.01% to <0.033%	238
0.033% to <0.1%	14
0.1% to <0.33%	2
0.33% to <1%	0
1% to <3.3%	0
3.3% to <10%	0
10% to <30%	0
>30%	0

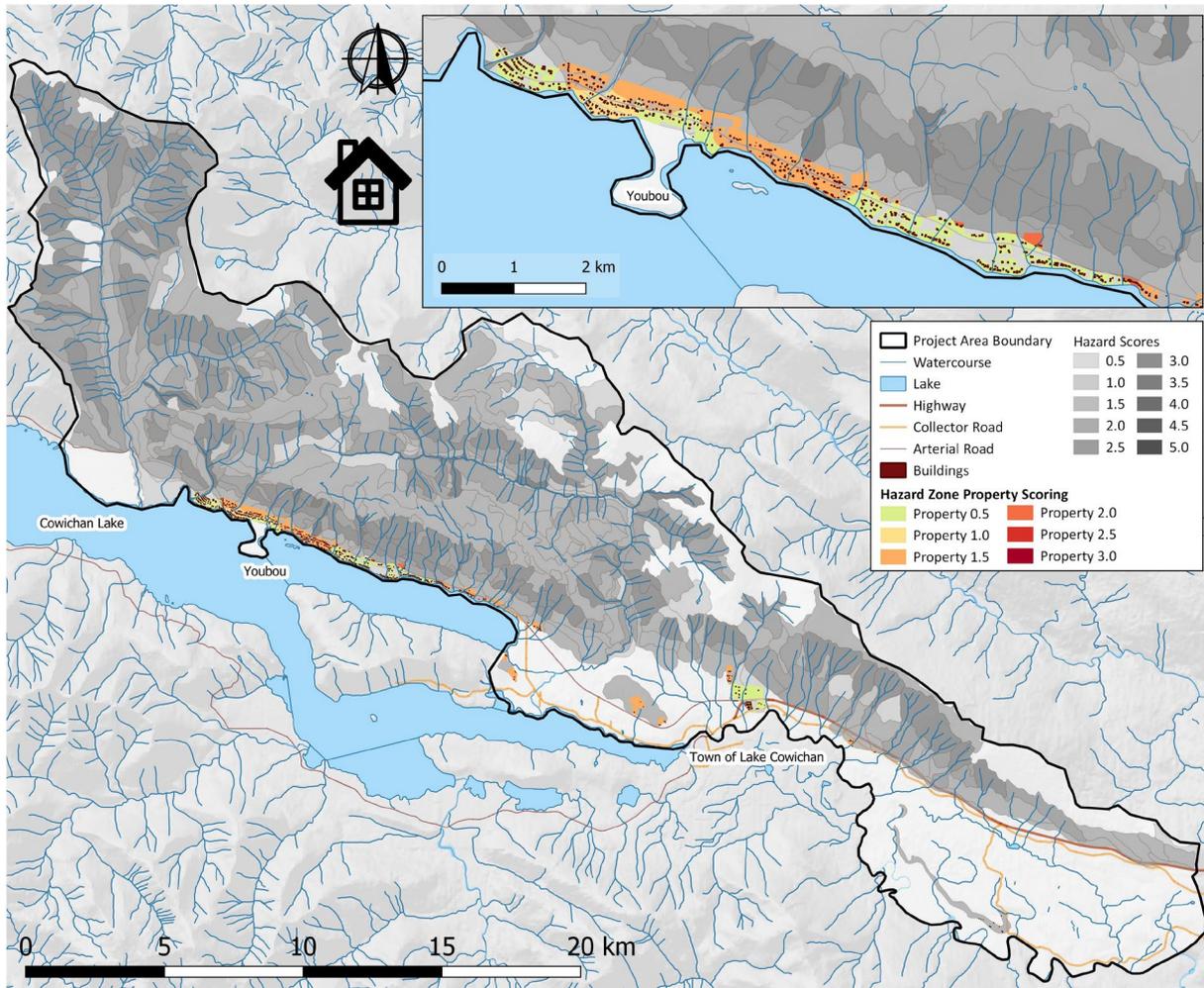


Figure 18: Exposed buildings in hazard zones within project area.

The number of buildings in moderate hazard areas (defined as an AEP of 0.1% or higher) is used as a proxy for the mortality and/or missing impact factor; there are 2. As can be seen in Figure 18, buildings (and therefore people) are concentrated at the toe of the slope. In particular, there are many buildings in close proximity to Youbou Creek at the northeastern end of the project area, where the hazard likelihood is moderate. In addition, there are many buildings along the lake and adjacent to Youbou Road that are exposed to hazard. This includes buildings above and below the road.

Thankfully, many of the areas with greater concentrations of residential buildings, such as the Youbou peninsula and areas of the Town of Lake Cowichan, have a minimal geohazard. However, it is possible that a fatality could occur in places without residential buildings and it could also occur in a low-likelihood area.

As mentioned previously, residential buildings are used as a proxy here since significant amounts of time are spent at home. Other studies have used methods such as agent-based modelling, where individual

behaviour and movement is considered, to do more detailed assessments. However, this type of modelling is very data intensive and not appropriate for this project. A further assumption that could be revisited with additional data is that the number of residential buildings is equivalent to the number of people present in the hazard area. This approach is simple and could underestimate the total exposed population; for example, on a summer weekend night, the population is likely to be considerably higher. Regardless, even with the lower estimate of exposed population, the impact, and subsequent risk, is significant and warrants attention.

The impact assessment for mortality and/or missing shows that there are many people that are exposed to geohazards within the project area. The strategic retreat of select buildings from the highest hazard areas would be an effective means of reducing exposure and risk.

### 5.2.2 Affected People

The number of people affected by geohazard is related to impacts felt by people related to lost shelter, employment, schooling, etc. This indicator is used to measure the broader impacts to society.

The locations of features in the community that would result in people being impacted were identified during workshop 1 and recorded spatially. They are represented with hotspots, as seen in Figure 19, as part of an initial qualitative assessment.

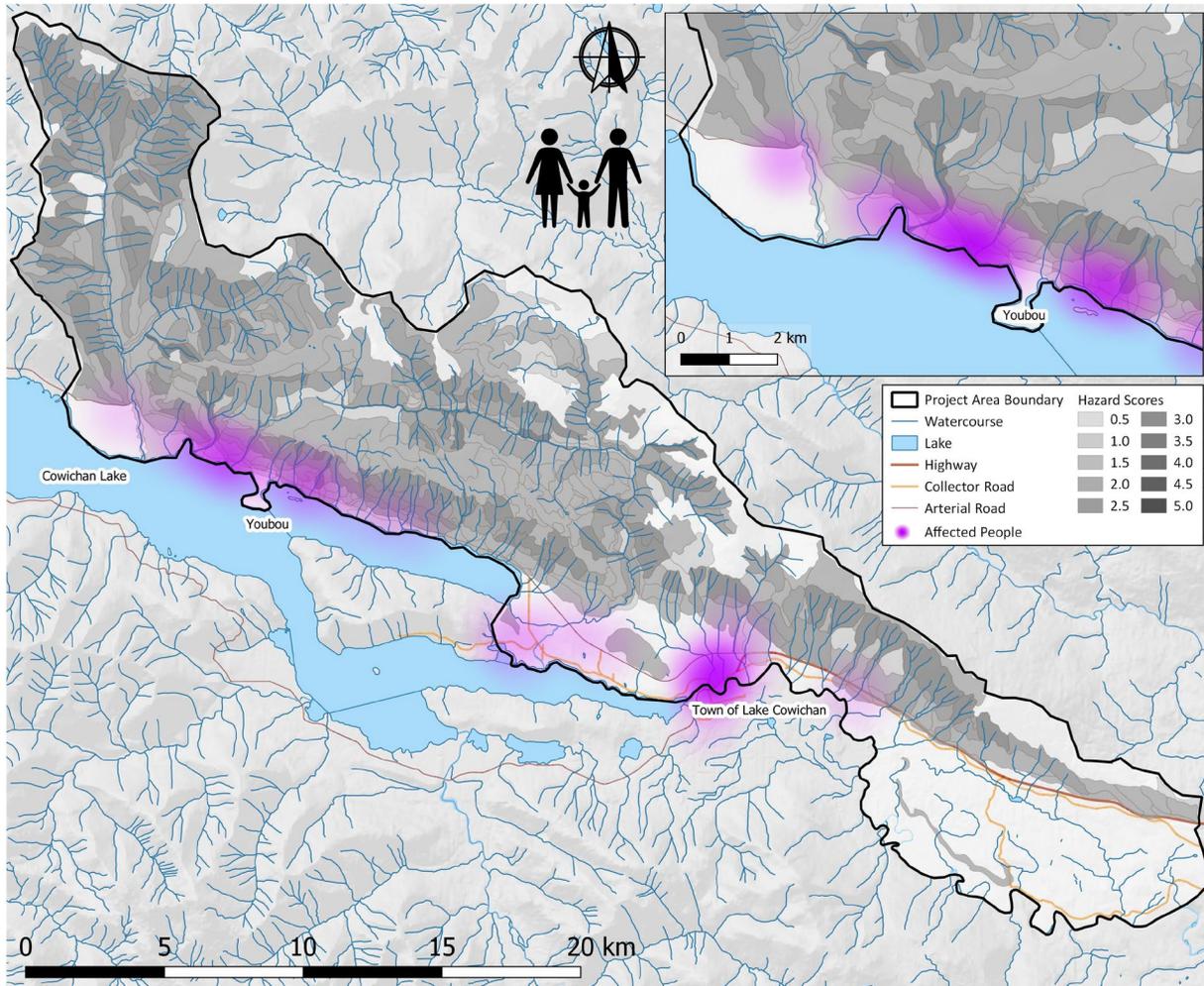


Figure 19: Hotspot map of affected people based on input from workshop 1.

The hotspot map shows that people are affected across the project area with concentrations in Youbou and the Town of Lake Cowichan. The hotspot areas (of Youbou and the Town of Lake Cowichan) are expected given the development densities, which include residences, as well as schools and commercial buildings. If these were impacted by a hazard, it would result in the disruption and/or loss of education, employment, and potentially social cohesiveness.

A quantitative estimate of affected people was also conducted, as suitable data was available. The number of people affected was mapped using the most recent (2016) Canadian census data, as shown in Figure 20. It is estimated that approximately 1,900 people in the project area could be directly affected by the assessed geohazard (see Table 5). This includes people living within the hazard area and people who could be cut off by a geohazard event occurring close to their property. The challenge with using census data is the size of the dissemination areas in this relatively sparsely populated area. The dissemination areas are large (see Figure 20), whereas the hazard areas are relatively small. In this instance, where it is known that the population is concentrated along the road at the lower edge of the

slope, most of the population was assigned to the project area using simple dasymetric approaches and judgment.

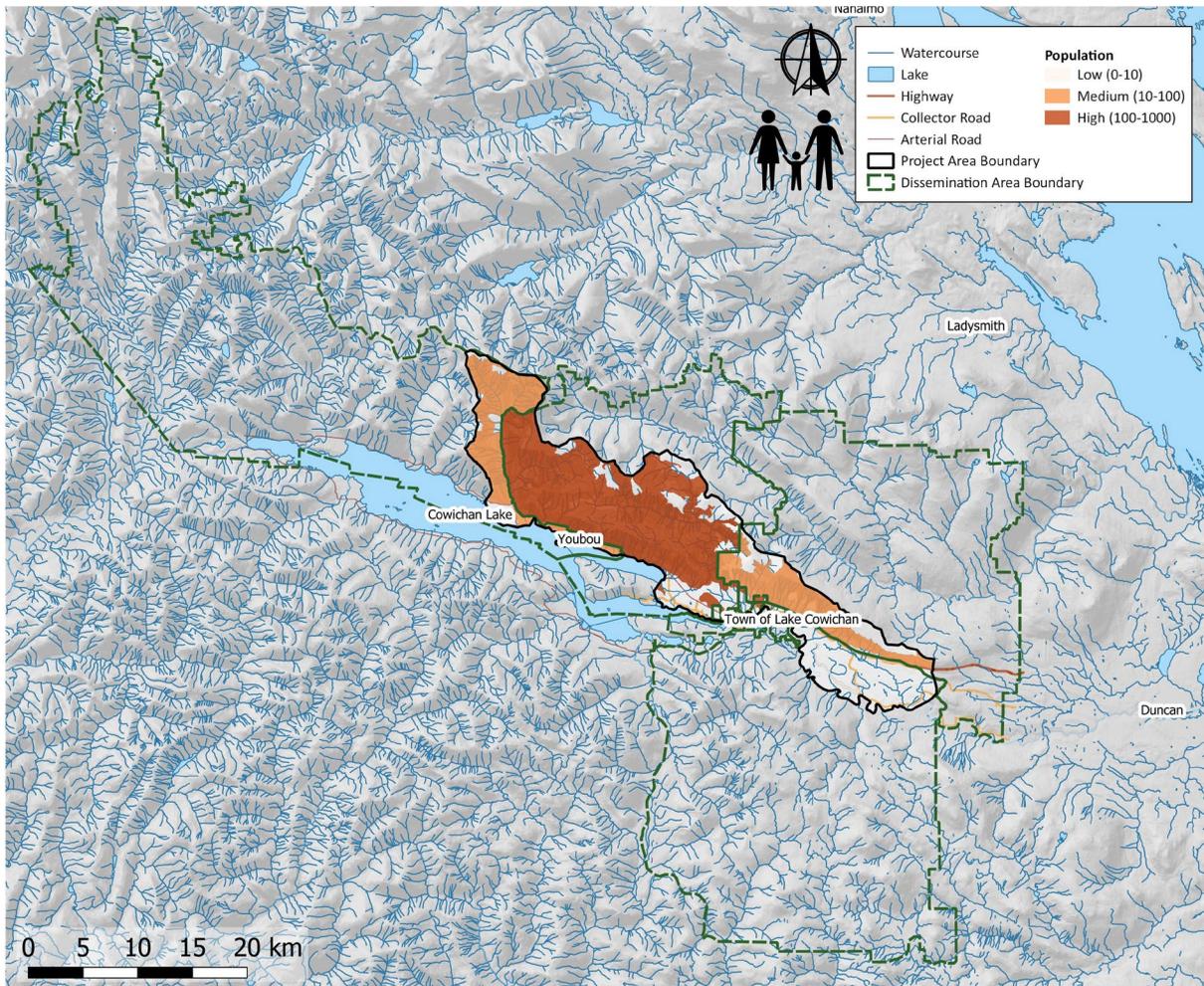


Figure 20: Population density in Lake Cowichan/Youbou by dissemination area within project area.

To validate the estimates of affected people and to explore alternate data sources, additional methods beyond the 2016 census were employed. Three different estimates were used in this assessment (see Table 5), using three data sources including census data, a recent and draft NRCAN disaster exposure database for BC, and an estimate based on the number of residential building footprints and estimates of occupants in each building (1.66 calculated from census information). Multiple sources of data were used to validate the number calculated.

**Table 5: Number of affected people by assessed geohazard**

Affected People		
Census Total	NRCan Exposure Database Estimate	Estimate Based on Residential Building Footprints in hazard areas
1,864 people	1,758 people	959 people

The census boundaries, on which the NRCan database is also based, are much larger than the area of interest. Whereas, the modified approach of using building footprints and average occupancy enables a more refined calculation especially as this relates to the spatial distribution of people across the region. And therefore, the third estimate (959 people) is used in all further calculations.

It should be noted that many properties in this area are vacation homes. Census numbers count population at the location of a primary residence only, therefore, if a geohazard event were to occur in the summer, the number of people affected would likely be higher. This would include people in vacation homes, property rentals, other accommodations, and campers. Further, the census numbers do not show the potentially significant seasonal increase in population from the Laketown Ranch, which can host up to 20,000 attendees for special events. The Ranch is located outside the hazard zones but could be affected if the ingress and egress roads to the site were blocked (this is further explored in the disruption indicator, Section 5.2.4).

For the purposes of the assessment, the number of people affected was based on the number of residential buildings within the hazard area, multiplied by 1.66 (as calculated in third column above). Residential buildings were used as this data provides the best available spatial resolution.

**Table 6: Summary of affected people impacts.**

Annual Exceedance Probability	Exposed Residential Buildings x 1.66 (proxy for affected people)
<0.001%	Not Calculated
0.001% to <0.0033%	280 x 1.66 = 465
0.0033% to <0.01%	44 x 1.66 = 73
0.01% to <0.033%	238 x 1.66 = 395
0.033% to <0.1%	14 X 1.66 = 23
0.1% to <0.33%	2 x 1.66 = 3
0.33% to <1%	0
1% to <3.3%	0
3.3% to <10%	0
10% to <30%	0
>30%	0

For a small community, the direct impacts to people is significant and represents almost 15% of the population centred around Cowichan Lake<sup>10</sup>.

This methodology limits the impacts to people with properties within the hazard area only. This is likely to underestimate the number of people affected e.g. it does not include people impacted through being cut off or otherwise disrupted by the geohazard.

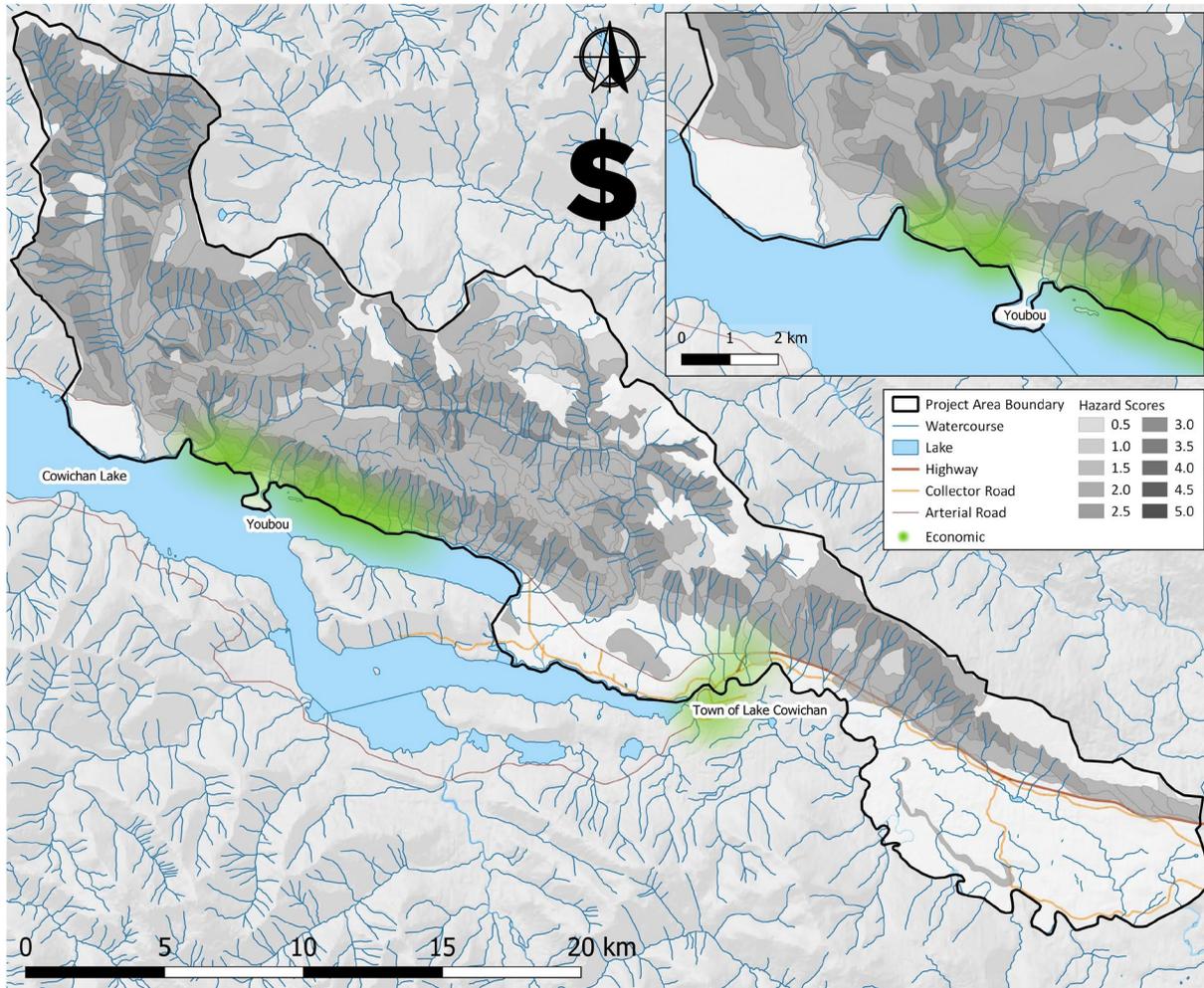
It should be noted that this would be if simultaneous debris flow events happened across the project area at one time. On the other hand, there will be more people who will be indirectly affected by a hazard event in addition to those directly affected, especially given the potential for disruption (see Section 5.2.4).

### 5.2.3 Economic Impacts

Economic impacts are important to measure because they represent the effect that geohazard can have on local livelihoods and the regional economy. Further, economic impacts are often used to support the business case for geohazard mitigation planning and infrastructure. Stakeholders in workshop 1 identified potential economic effects of debris flows in the project area, as shown in Figure 22.

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<sup>10</sup> Based on a total 2016 population of 6,802 from CVRD Electoral Areas I and F, Cowichan IR1, and Town of Lake Cowichan.



**Figure 21: Hotspot map of economic impacts based on input from workshop 1.**

The hotspot map for economic impacts shows that the impacts identified by stakeholders are concentrated in the Town of Lake Cowichan and around Youbou. This is to be expected since there is a concentration of population, infrastructure, and services in these two locations. This includes expected direct and indirect impacts, with the direct impact concentration around Youbou.

A quantitative assessment of economic impacts was conducted using property value information as a simple proxy. This provides an assessment of the total value of exposed property in the project area. Figure 22 presents the locations of properties that could be damaged by a geohazard and contribute to the overall potential economic impact of a debris flows.

Table 7: Summary of economic impacts.

Annual Exceedance Probability	Exposed Property Values \$Million	Exposed Building Values \$Million	Exposed Property & Building Values \$Million
<0.001%	Not calculated	Not calculated	Not calculated
0.001% to <0.0033%	77	73	150
0.0033% to <0.01%	13	8	21
0.01% to <0.033%	106	53	159
0.033% to <0.1%	19	8	26
0.1% to <0.33%	33	1	34
0.33% to <1%	15	0	15
1% to <3.3%	0	0	0
3.3% to <10%	0	0	0
10% to <30%	0	0	0
>30%	0	0	0
<b>Total</b>	<b>262</b>	<b>143</b>	<b>405</b>

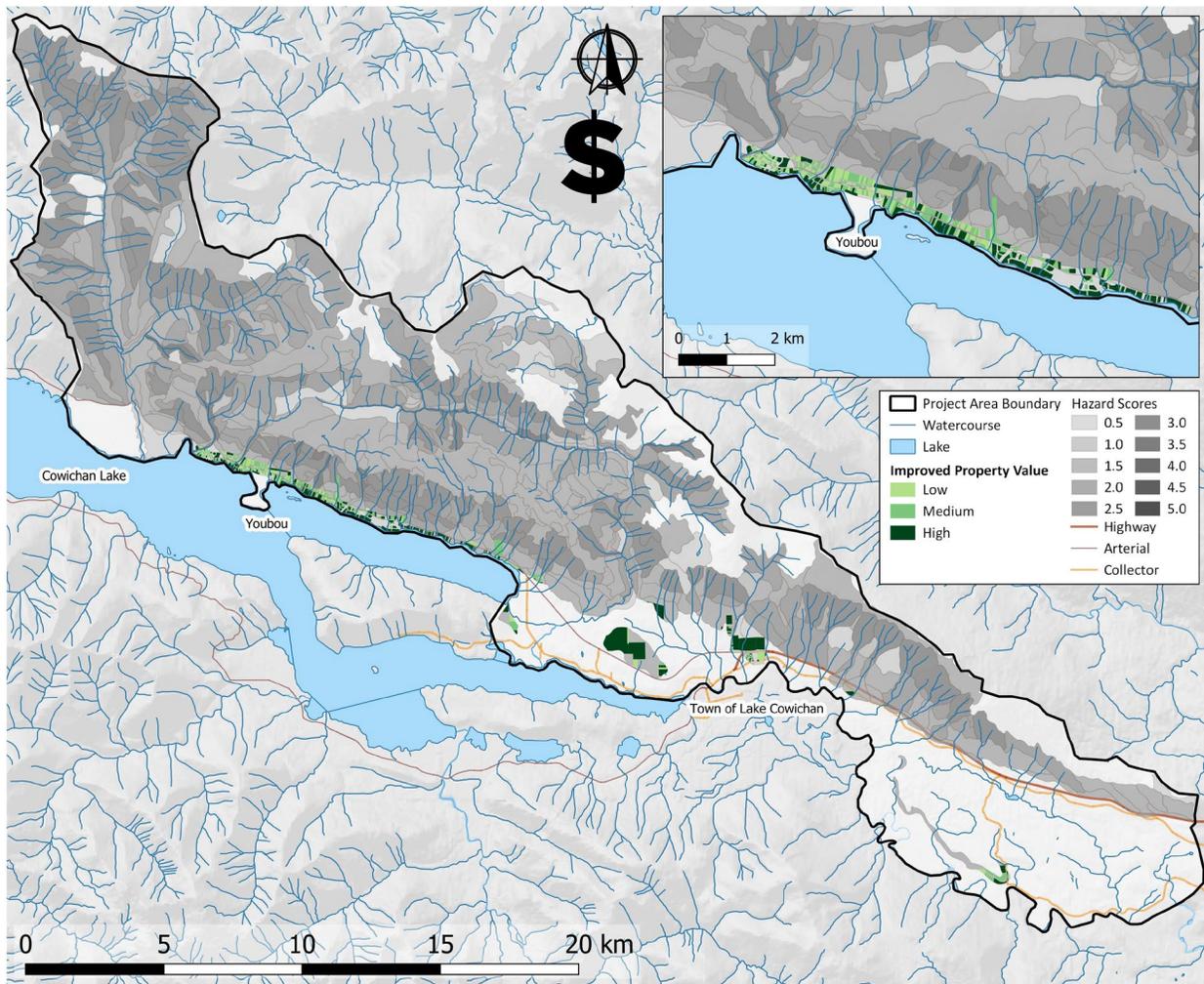


Figure 22: Economic impact of geohazard in project area using property values as a proxy.

The value of property in the project area was calculated using the available BC Assessment Authority Roll data provided by the CVRD (from 2018). This provides a quantitative estimate of economic impacts of geohazard. It should be noted that this is simply the total property value in the project area and not a calculation of expected damage. There are no functions to relate hazard severity to damage for this area, which is why property value exposure is used as a proxy for potential economic impact. Further, it should be noted that given the nature of debris flows and slides, which would likely make returning to the site after an event impossible, it was assumed that the total property value (land and buildings) would be a write-off. Whereas for other hazards, like flood, only building value is generally considered in impact and consequence assessments.

The total value of buildings in the project area exposed to an assessed geohazard is approximately \$143 million. When considering both building (improved) values and base land values, the total exposed value is over **\$400 Million**; this is 1 % of the Vancouver Island GDP<sup>11</sup>.

This assessment of economic impacts is significant and signals that there is a considerable amount of potential direct economic loss due to debris flows in the project area. In addition, the exposed properties are primarily in the area around Youbou, which presents some opportunities, such as measures targeted towards a smaller area.

As mentioned, there are no functions available for the project area that would relate hazard severity to damage. For this reason, a limitation of this assessment is that potential damage is not assessed at a building level. A more detailed assessment with building construction information could be conducted in a future phase of work.

#### 5.2.4 Disruption

Disruption due to geohazard refers to the amount of interruption to basic services (e.g., roads or power) attributed to the hazard. It is important to consider this because it represents the effect of a geohazard on infrastructure, services, and the people using those services. This is generally considered to be a significant proportion of the overall impact of natural hazards because the impacts are so dispersed in place and time. Input from stakeholders regarding disruption of these services was recorded in workshop 1 and is shown spatially in Figure 23.

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<sup>11</sup> Assuming a 2018 Vancouver Island GDP of \$39.5B (Economic Resources Vancouver Island, 2017)

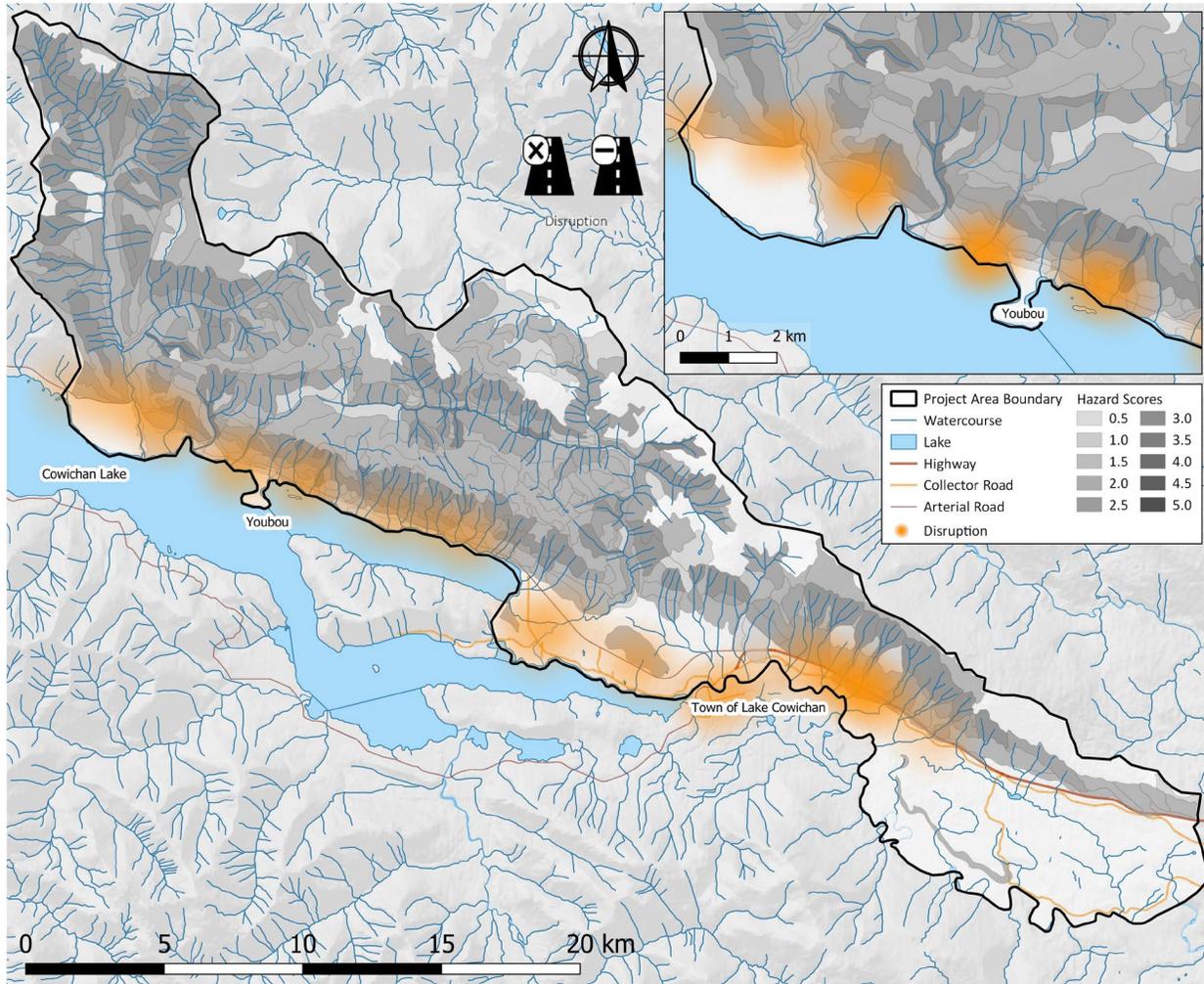


Figure 23: Hotspot map of disruption based on input from workshop 1.

The hotspot map shows that disruption is anticipated across the project area along Youbou Road and some parts of Highway 18. This is to be expected, as much of the infrastructure in this area is linear (roads, power, water, sewer) or is located along the road (water storage, wastewater facilities).

Disruption due to geohazard was also studied in terms of the length of major and minor roads within the geohazard extent, as shown in Figure 24. There are a number of both minor and major roads within the project area. In addition, potential disruption points (where incised channels cross linear roads) were also calculated, as shown in Table 11.

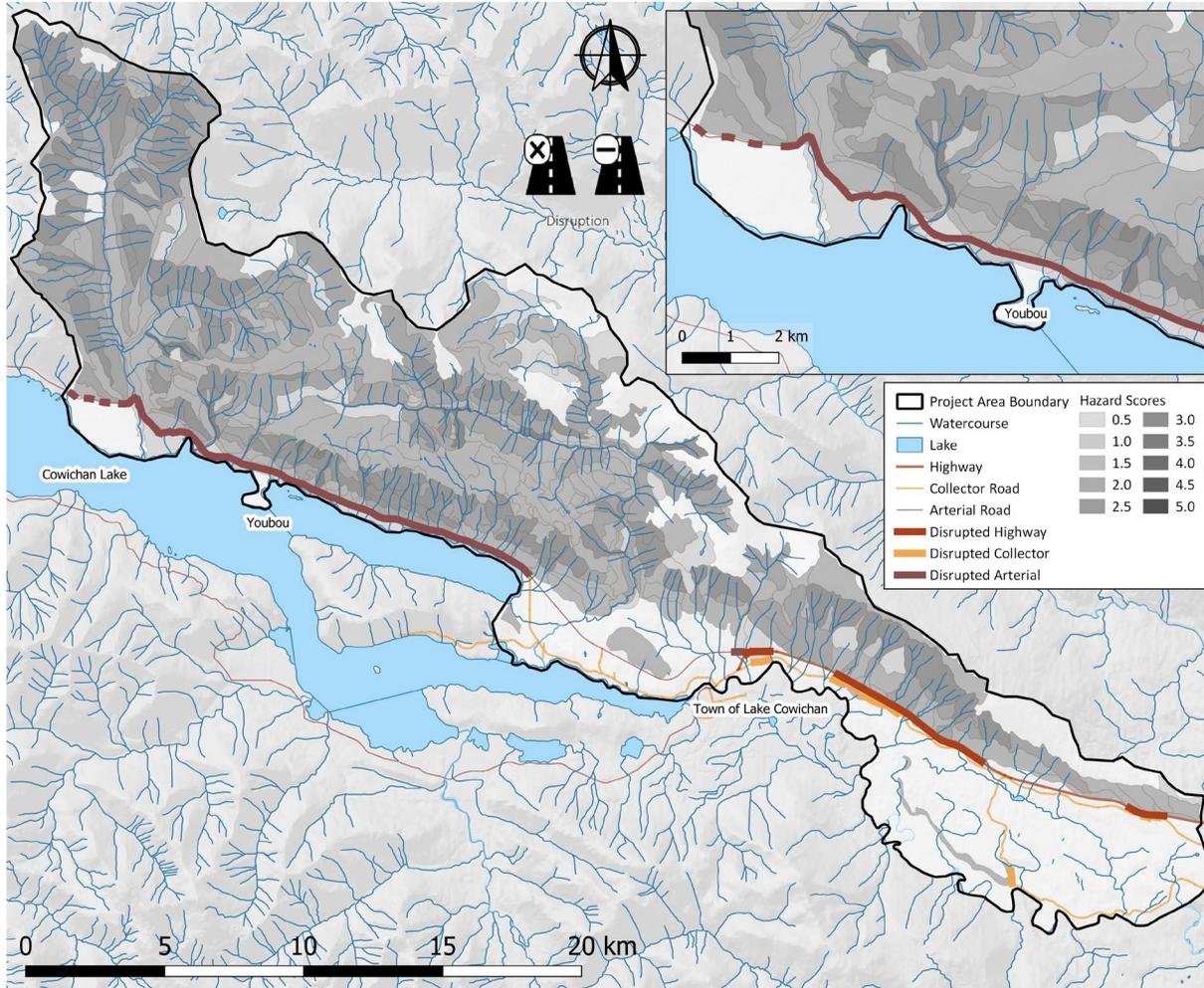


Figure 24: Disruption due to geohazard within the project area.

Table 8: Summary of disruption impacts (points of potential disruption to roads).

Annual Exceedance Probability	Highway	Arterial	Collector
<0.001%	Not calculated	Not calculated	Not calculated
0.001% to <0.0033%	1	1	1
0.0033% to <0.01%	-	1	-
0.01% to <0.033%	1	1	3
0.033% to <0.1%	1	1	-
0.1% to <0.33%	-	1	-
0.33% to <1%	-	-	-
1% to <3.3%	-	-	-
3.3% to <10%	-	-	-
10% to <30%	-	-	-
>30%	-	-	-
<b>Total points of disruption</b>	<b>3</b>	<b>5</b>	<b>4</b>
<b>Total length in zone (km)</b>	<b>5.4</b>	<b>11.5</b>	<b>2.4</b>

In the project area, the total number of disruption points is **12** and the total length of exposed road is **18.4 km**, which is further described in Section 6.2.4.

This impact is relatively high, which is to be expected for this project area since the main access road for this area runs along the toe of the north slope of Cowichan Lake. It should be kept in mind that the severity of disruption at each point will depend on the capacity of the crossing. If there is a high bridge with a lot of space for debris to pass through, then damage or blocking of the road may be reduced. If, however, there are small culverts, then debris material would be more likely to pile up on and upstream of the road and cause damage.

In the project area, most culverts are less than 1,000 mm in diameter and culverts of this dimension will typically not pass a debris flow. To reduce the impacts of debris flows, culverts should be 1,500 mm and ideally larger than 2 m by 2 m, so that debris flows can pass and so machinery can clear them of debris post-event (MECCS, 2004).

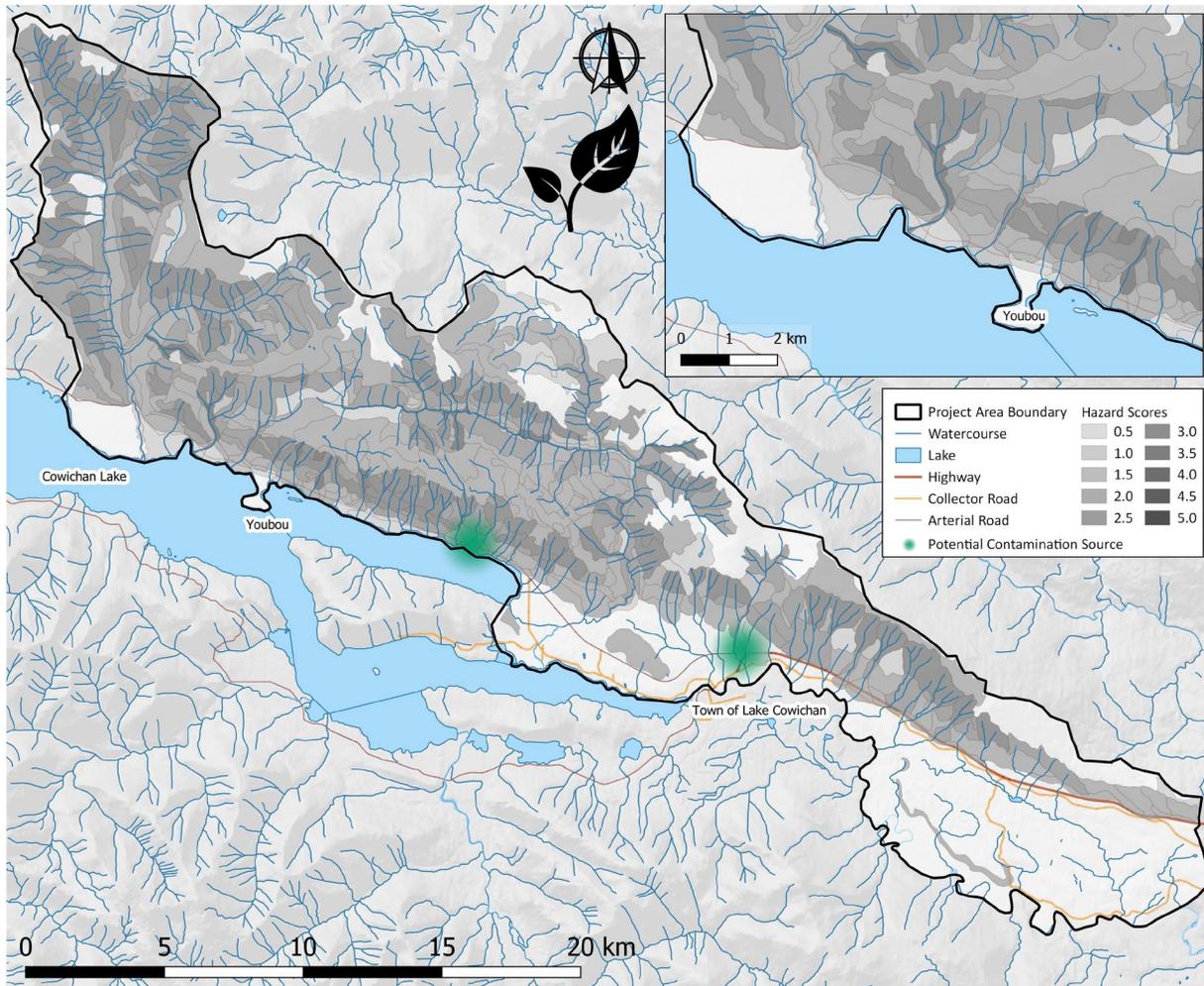
In addition to roads, the power infrastructure that runs along the road could be affected, depending on the location of the hydro poles. Finally, some drinking water infrastructure could also be affected, including wells and storage.

For this assessment, roads were used for scoring since spatial information was available and debris flows blocking the road would cause widespread impact. Other types of infrastructure, such as power, could be assessed with pole location information. In addition, water infrastructure could be added to this assessment and added to the scoring in the future.

### 5.2.5 Environment

Geohazard can have an impact on the environment in a number of ways. Geohazard can cause erosion, damaging vegetation along creeks, and spread contaminants as they are picked up and transported into a receiving water body of an environmentally sensitive area.

Figure 26 presents the locations of sources of contamination that could be transported by a debris flow. No qualitative results are presented as no impacts were recorded by stakeholders at the workshops.



**Figure 25: Environmental impacts due to geohazard within project area**

The windshield survey was conducted by CVRD staff in December 2018 to identify commercial and institutional buildings that may have materials on site that would be a source of contamination within the project area. Windshield and walking surveys are systematic observation tools, which are commonly used to better understand a community.

Of the 31 sites recorded in the survey, only 2 were located in a hazard zone. One of the 2 sites is a warehouse and storage facility and is close to the Town of Lake Cowichan, as shown in Figure 25. The other site is home to buildings associated with the Youbou Sanitary Sewer System and is located along Youbou Road. Both sites could be sources of contamination if damaged by debris flows, due to the materials stored on site.

The map of environmental impacts shows that there are limited expected sources of contamination in the project area. This level of potential impact is relatively low, and significant environmental impacts due to the transport of contaminants would not be expected. There may be other environmental

impacts such as erosion or water quality that could be influenced by a debris flow, however, this was not assessed.

#### 5.2.6 Culture

As described in Section 3, geohazard can cause impacts to cultural sites, including both Indigenous and settler areas and items. Some input regarding cultural sites was provided at a high-level in the second workshop which took place in the Town of Lake Cowichan. However, this was not comprehensive and sufficiently spatial to be included in the risk assessment. As part of future work, additional input from Indigenous groups and cultural leaders should be elicited.

It was mentioned by a member of Cowichan Tribes that access to harvesting location for plants and fish would be a concern if there was any road disruption in that area. The location and the nature of the sites where access would be required have not been provided. Therefore, based on information received so far, the primary concern for cultural impacts in this area is access and moderate damage to cultural or historical assets may occur due to debris flows. This level of impact is moderate and this potential impact should be communicated to local First Nations. There may be other exposed assets or important areas that have not yet been assessed.

#### 5.2.7 Direct and Indirect Impacts

A comprehensive assessment of geohazard impacts includes direct and indirect impacts. However, as described above, it is more complex and resource intensive to assess some impacts. For this project, we approached the problem with a mix of quantitative and qualitative concepts and were able to capture some of the more intangible and indirect impacts by working with community stakeholders. It is important to consider both the direct and the indirect in assessments and future planning initiatives.

Some examples of direct impacts of debris flow are taken from other slope failure events in BC, as seen in Figure 24. These supported discussions with stakeholders ahead of asking for information on direct and indirect impacts.



Figure 26: Examples of direct debris flow impacts (Photos from (Smith, 2004)).

Indirect impacts of debris flows include effects where a loss of service in one area means that something depending on that service cannot function. For the community, this includes things like fire and ambulance services, gas station access, traffic delays, loss of property access, loss of recreation, and loss of utility services. It is important to include these impacts because they can sometimes be greater in terms of severity and duration than direct impacts. Some potential indirect impacts of debris flow in the CVRD are highlighted in Figure 27.



Regional Connections Disrupted



Disruption to Roads & Rail



Loss of Recreation



Loss of Utility Service

Figure 27: Examples of possible indirect impacts of debris flow in the CVRD (Photos from (Smith, 2004) and Ebbwater 2018).

In addition to the impacts to specific indicators mapped above, impacts were also recorded as being either direct (i.e., something that got damaged) or indirect (i.e., an impact that occurred outside the hazard area or after the geohazard event) based on input from stakeholders. The results of this qualitative analysis are presented in Figure 28 and Figure 29 as hotspot maps. On the hotspot maps, darker and larger impact areas represent areas with more impacts, as recorded in the workshop.

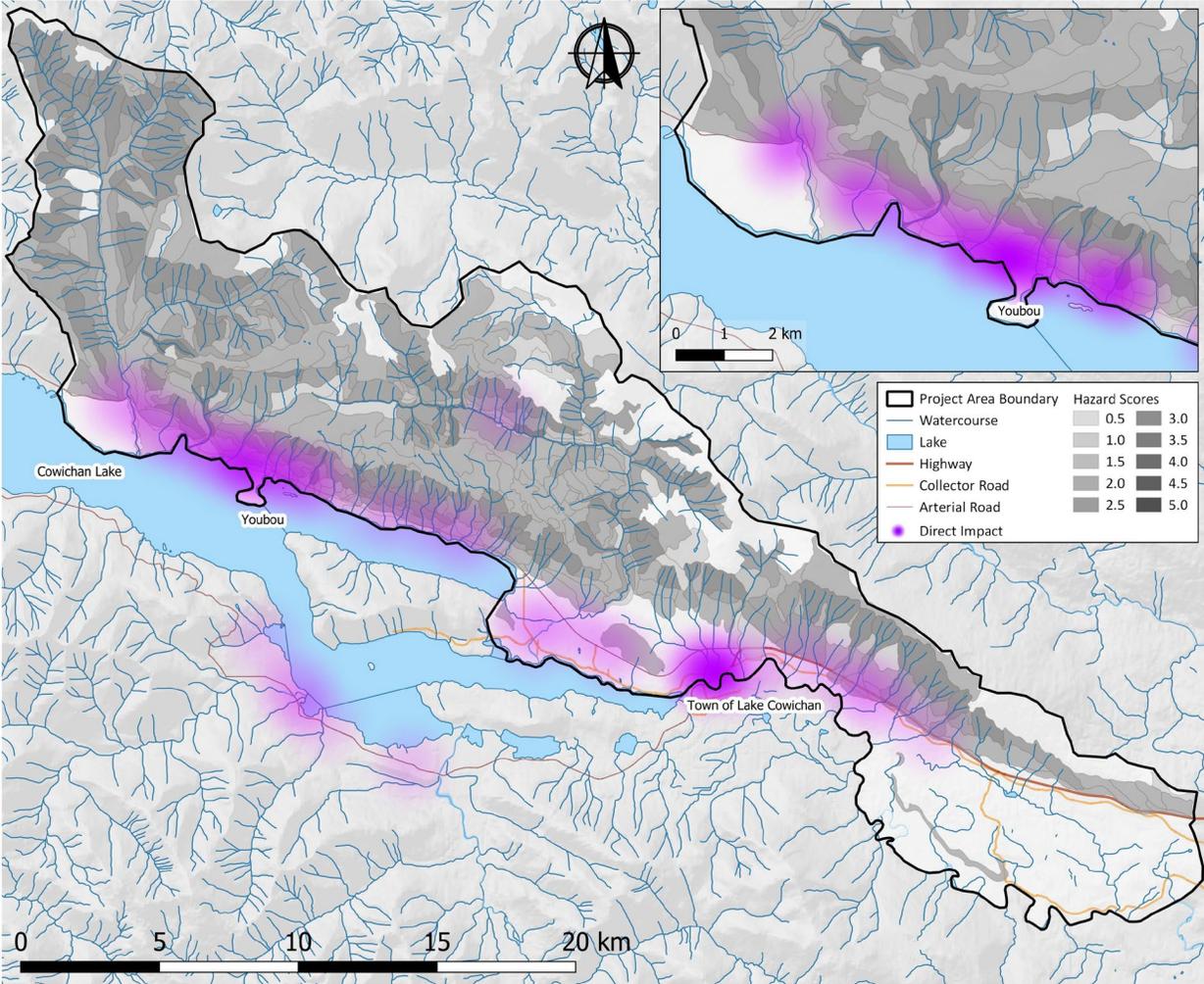
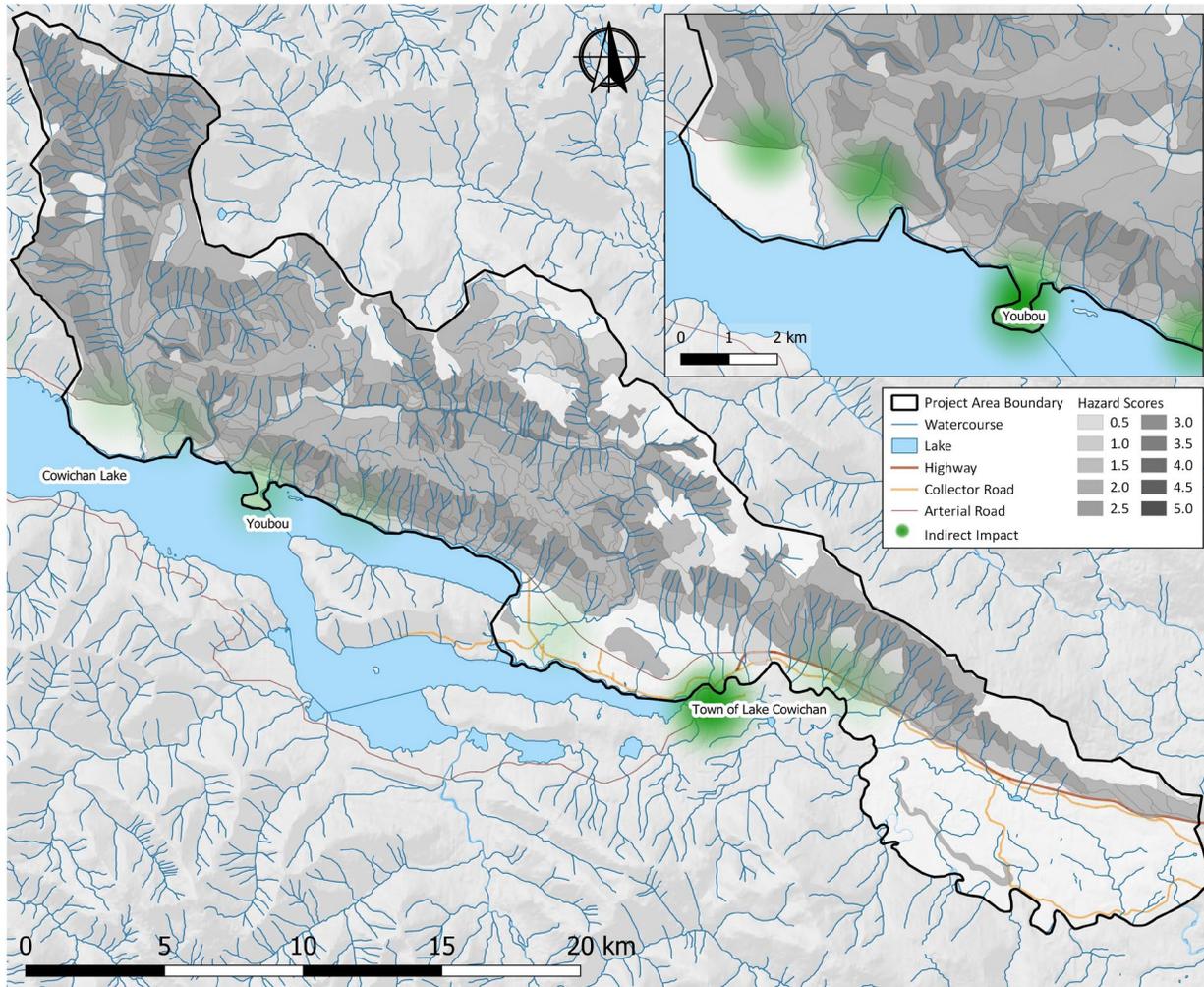


Figure 28: Direct impacts due to geohazard with input from stakeholders.



**Figure 29: Indirect impacts due to geohazard with input from stakeholders.**

The analysis of direct and indirect impacts shows that both are significant and spread across the project area. This highlights the need to consider indirect impacts (and their potential reduction) in any decision process. Many standard approaches to decision-making for geohazard, such as cost-benefit analyses, often discount or devalue indirect impacts.

Further, this project shows that the indirect impacts are very geographically dispersed, stretching along the project area, which highlights the need for a regional approach to managing the hazard. Finally, the types of indirect impacts (which are further described in Section 3) show that some indirect impacts are not specific to geohazard (such as anxiety and isolation). By working to consider and reduce both direct and indirect impacts, overall community resilience is improved.

### 5.3 Summary Impacts

In summary, the maps for each of these impact categories paint a picture of where there are potential effects of geohazard and provide some context for thinking about what kinds of measures might be appropriate to address these issues. Simply, the exposure and impact analysis and hotspot mapping

provide an indication of where efforts need to be targeted in order to get the biggest return on investment on any geohazard mitigation measures. Some specific commentary based on the results:

- There are significant impacts to people, the economy, and disruption. There are lesser impacts to the environment, although this assessment was more limited. The investigation into cultural impacts is preliminary, but access to harvesting sites is one issue identified. Due to the limited nature of the assessment for environmental and cultural indicators, impacts could be greater than reported.
- Impacts to people are dispersed—many community members would be impacted by debris flow, regardless of where they live in the project area, since disruption to infrastructure would affect people across the entire area. Direct impacts to people and property are, however, concentrated around Youbou.
- Direct impacts are concentrated at the toe of the slope, while indirect impacts are clustered within the population centres around Youbou and the Town of Lake Cowichan.

Given the above, the following notes can be made on how the results can inform future geohazard mitigation efforts:

- Indirect and direct impacts are equally important; they should all be considered in any mitigation planning process.
- The geographically dispersed nature of the impacts highlights the need focus not only on the areas that are at the toe of the slope (in proximity to Youbou, for example) but also nearby population centres that could be affected (such as the Town of Lake Cowichan).

The CVRD is planning to use the risk assessment and project area as a case study to develop policy for natural hazard management with considerations for climate change. Part of this approach is looking at developing tolerances to different types of risks. Some thoughts on planning for risk tolerance are provided in Section 7 of this report. A long-list of options to address geohazard risk is provided in Section 8 and general recommendations in Section 9.

### 5.3.1 Limitations

There are several limitations to the exposure and vulnerability assessment for the project area. The assessment is only as good as the input data, and so for many of the impact categories the input data could be improved. Population data for example, is recorded at a scale where absolute population is more or less consistent, and in sparsely populated areas this can mean dissemination areas are greater than the hazard areas, and assumptions based on building footprints were required.

Additionally, where qualitative methods were considered, the patterns observed are only as good as the input provided by stakeholders, which is based on individual experience. The methods applied do provide a robust snapshot of exposure to debris flow in the project area to support risk scoring and provide data to support next steps.

## 6 Geohazard Risk Assessment for the Project Area

The overall form of a risk assessment includes the combination of hazard’s likelihood with the consequences of that hazard (see Section 3). This is relatively straightforward if the underlying inputs are available. For this project, detailed hazard information was produced by Palmer and exposure and impact data was collected from stakeholders, public databases, and the CVRD’s data (as described in Sections 4 and 5). Some datasets, such as building footprints and sources of contamination, were delineated and identified specifically for this project to complete the risk assessment.

The focus of this project was to develop a risk assessment for the project area to build a case study that can be used for policy development. In addition to the current risk, climate change and future risk for the project area is also considered.

The approach presented below is based on expected methods to be presented in federal guideline materials that are currently in development; it is also substantially based on best practice. It is a very simple approach to estimating risk using a matrix of scores that are easy to understand. Scores are assigned to likelihood and impact, which are multiplied to give a risk score.

### 6.1 Methods

Risk scoring was completed for each impact category using the outputs of either a quantitative or qualitative assessment. Quantitative assessment was completed where possible with the best available data for most impact categories; however, a mostly qualitative method was applied for cultural impacts.

#### 6.1.1 Quantitative Assessment Hazard Likelihood Scoring

A likelihood score is assigned based on the information in Table 9 . The 5-point scale (or 11-point scale, when using 0.5 denominations) is based on a logarithmic scale. This is generally believed to appropriately represent the extreme value statistics associated with natural hazard events (Williamson, 2015). This type of scale of hazard likelihood is being used by several federal agencies, and is generally replacing the ad-hoc likelihood scoring (Stantec Consulting Ltd. and Ebbwater Consulting, 2017) presented in the current RAIT.

Table 9: Hazard Likelihood Scores.

Hazard Likelihood Scoring	Annual Exceedance Probability	Estimated Frequency (once every X years) (Indicative Lower Bound)
0.0	<0.001%	100,000
0.5	0.001% to <0.0033%	30,000
1.0	0.0033% to <0.01%	10,000
1.5	0.01% to <0.033%	3,000
2.0	0.033% to <0.1%	1,000
2.5	0.1% to <0.33%	300
3.0	0.33% to <1%	100
3.5	1% to <3.3%	30
4.0	3.3% to <10%	10
4.5	10% to <30%	3
5.0	>30%	<1

The hazard scoring is based on the outputs of the terrain model developed by Palmer (see Section 4). Figure 30 shows the hazard in the project area represented as scores.

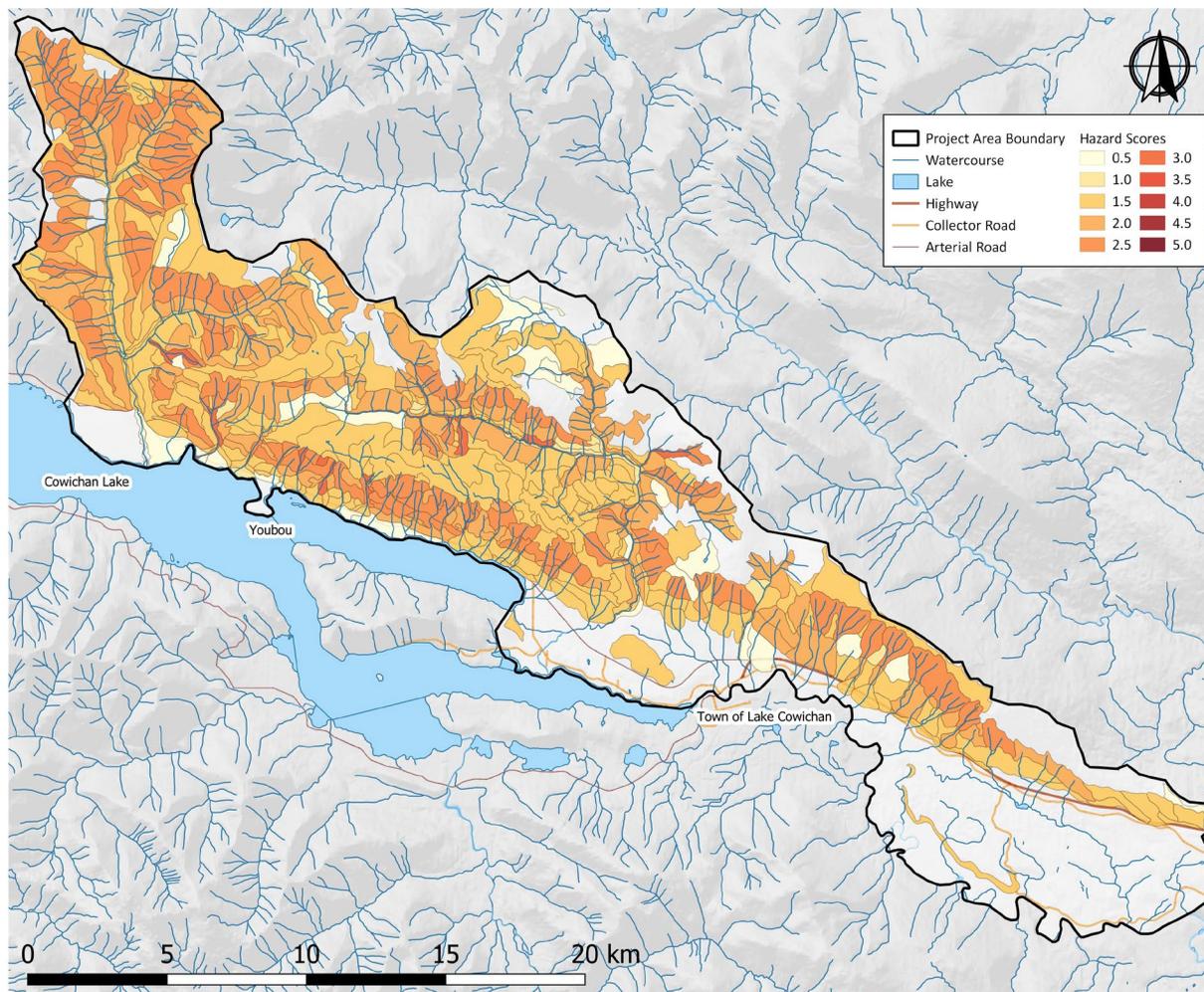


Figure 30: Hazard score map for project area.

### 6.1.2 Impact Scoring

Similar to the likelihood scores, an impact scoring system was drawn from materials created to support program development at several federal agencies (Public Safety Canada, Natural Resources Canada, National Research Council) (Table 8)<sup>12</sup>. For each impact category, a score from 1 to 5 is assigned, where 1 demonstrates the least (limited impact), and 5 demonstrates the largest (catastrophic impact). Like the likelihood scoring, the quantitative measures are represented on a logarithmic scale. Please note that where no impact is calculated, then the scoring is set to 0; this approach has been taken specifically for

<sup>12</sup> The scoring system presented here is the best-known representation of current thinking by senior level governments. The RAIT scoring system is being phased out and is a remnant of older federal programs.

this project to manage the presentation of aggregate information across the project area, and to not over estimate risk.

The quantitative measures are also presented using scalable systems, where impact is considered relative to a scale at which response might be expected; in this case, Vancouver Island is used. Ratings for environmental impacts are based on potential source of contamination and ratings for cultural impacts were based on limited input from the workshop 2. Ratings for each of the impact categories was calculated or estimated based on the results of the exposure and vulnerability assessment described above.

**Table 10: Impacts ratings for risk assessment.**

Level	Score	Measure
<b>Mortality: Number of deaths and/or missing persons attributed to disasters</b>		
Catastrophic	5	Deaths greater than 100 per 100,000
Major	4	Deaths greater than 10 but less than 100 per 100,000
Moderate	3	Deaths greater than 1 but less than 10 per 100,000
Minor	2	Deaths greater than 0.1 but less than 1 per 100,000
Limited	1	Deaths less than 0.1 per 100,000
<b>Affected People: Number of directly affected people attributed to disasters*</b>		
Catastrophic	5	Affected people greater than 100 per 100,000
Major	4	Affected people greater than 10 but less than 100 per 100,000
Moderate	3	Affected people greater than 1 but less than 10 per 100,000
Minor	2	Affected people than 0.1 but less than 1 per 100,000
Limited	1	Affected people less than 0.1 per 100,000
<i>*Affected People Score based on ratio of the number of people directly affected compared to the population of Vancouver Island</i>		
<b>Economic Consequences: Direct economic loss attributed to disasters in relation to approx. CVRD GDP</b>		
Catastrophic	5	Direct economic loss of 4% or more of GDP**
Major**	4	Direct economic loss of 0.4% to 4% of GDP
Moderate	3	Direct economic loss of 0.04% to 0.4% of GDP
Minor	2	Direct economic loss of 0.004% to 0.04% of GDP
Limited	1	Direct economic loss of <0.004% of GDP
<i>**Economic Consequences Score based on Calculation of Score = Property Value in the hazard area/GDP of Vancouver Island * 100%</i>		
<b>Critical Infrastructure and Disruption: Damage to critical infrastructure attributed to disasters</b>		
Catastrophic	5	>100 of CI facilities damaged or disrupted
Major	4	>10 to 100 CI facilities damaged or disrupted
Moderate	3	>1 to 10 CI facilities damaged or disrupted
Minor	2	1 CI facility damaged or disrupted
Insignificant	1	1 CI facility temporarily (<6hours) disrupted
Critical infrastructure (CI) facilities are represented by the CI sectors in the National Strategy for Critical Infrastructure (Government of Canada, 2009) and include:		
<ul style="list-style-type: none"> <li>• Energy and utilities</li> <li>• Information and communication technology</li> </ul>		<ul style="list-style-type: none"> <li>• Water</li> <li>• Transportation</li> <li>• Safety</li> </ul>

Level	Score	Measure
<ul style="list-style-type: none"> <li>Finance</li> <li>Health</li> <li>Food</li> </ul> Critical Infrastructure included here are bridges, sewers and roads		<ul style="list-style-type: none"> <li>Government</li> <li>Manufacturing</li> </ul>
<b>Environmental: Damage to the environment</b>		
Catastrophic	5	Catastrophic damage to environment.
Major	4	Major damage to the environment.
Moderate	3	Moderate damage to the environment.
Minor	2	Minor damage to the environment.
Insignificant	1	Insignificant damage to the environment.
<b>Cultural: Damage to cultural or heritage assets</b>		
Catastrophic	5	Catastrophic damage to cultural or heritage assets.
Major	4	Major damage to cultural or heritage assets.
Moderate	3	Moderate damage to cultural or heritage assets.
Minor	2	Minor damage to cultural or heritage assets.
Insignificant	1	Insignificant damage to cultural or heritage assets.

### 6.1.3 Risk Scoring

The risk scores can be presented numerically, or for simplified communications, can be presented graphically (see Section 3) and/or qualitatively as shown in Table 11 and Table 12.

Table 11: Example of quantitative risk matrix.

		Impact Score				
		Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Likelihood Score	Almost certain (5)	Medium	High	Extreme	Extreme	Extreme
	Likely (4)	Low	Medium	High	Extreme	Extreme
	Possible (3)	Low	Medium	Medium	High	Extreme
	Unlikely (2)	Very Low	Low	Medium	Medium	High
	Rare (1)	Very Low	Very Low	Low	Low	High

Table 12: Risk scoring descriptions.

Risk Score	Qualitative Description
1–2	Very Low
3–4	Low
5–9	Medium
10–15	High
>15	Extreme

As described in Section 3.2.3, risk scores can be presented for single hazard scenarios, or as an integral of multiple hazard and impact combinations. For this project, there is a mix of hazard scores across the project area as described above, and therefore a probabilistic assessment is possible. The total probabilistic score is presented as the sum of all risks<sup>13</sup> for each indicator where quantitative information is provided. The mode of risk (i.e., the combination of likelihood and consequence that has the highest score) is also provided. This is also used in the summary graphic to represent each indicator. This approach was taken to simplify the messaging, and to better account for the spatial and temporal likelihood associated with geohazard (i.e. it is unlikely that all identified hazard areas will fail at the same time). In addition, each quantitative indicator has its own risk graphic that aims to illustrate the spread of risk across multiple likelihoods and scores. The representation of probabilistic risk is sometimes presented as three-dimensional graphics, which although mathematically correct, require significant interpretation by users. Therefore, in this case, we have chosen a simpler, more illustrative approach to communicate the range of risks under each indicator.

## 6.2 Results

The following sections present the results of the risk scoring exercise for the project area for each indicator.

### 6.2.1 People (Mortality and/or Missing)

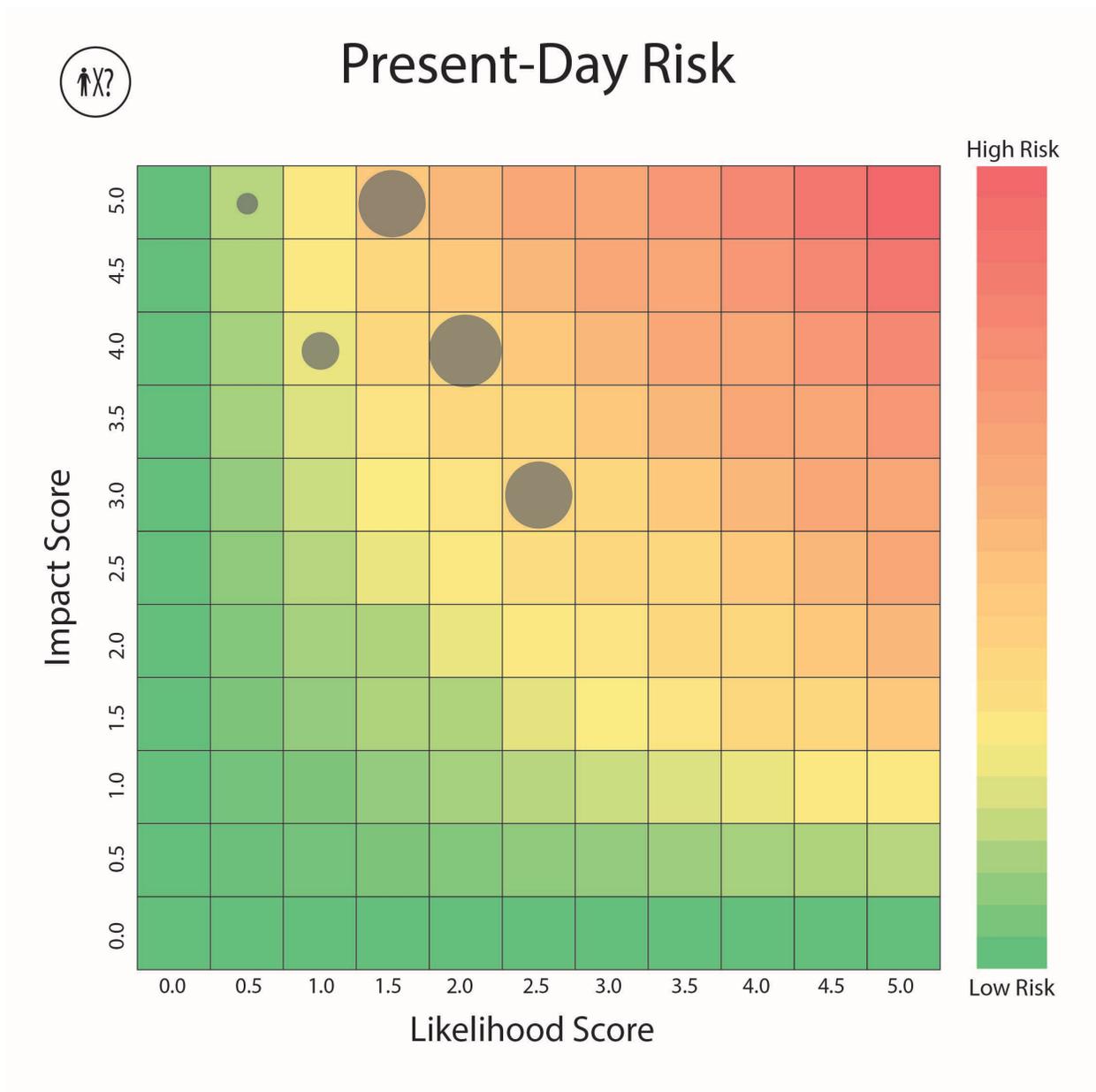
As described in Section 5.3.1, residential buildings in high hazard areas are used as a proxy for risk to life (mortality and/or missing) for people. It was found that buildings are concentrated at the toe of the north slope of Cowichan Lake in the project area. There are several buildings in close proximity to Youbou Creek at the northeastern end of the project area, which are in moderate hazard areas. Thankfully, many of the areas with greater concentrations of residential buildings, such as the Youbou peninsula and areas of the Town of Lake Cowichan, have a hazard rating of zero. Table 9 shows the distribution of residential buildings (being used as a proxy for mortality and/or missing) across hazard zones.

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<sup>13</sup> Note that to get the overall risk score, the sum of all risks is divided by 2 to account for the 11-point (as opposed to 5-point) hazard scoring system.

Table 13: Risk to people (mortality and/or missing).

Hazard Rating	Residential Buildings (Proxy for People)	Impact Score	Risk Score
0.0	N/A	N/A	N/A
0.5	280	4.0	2.0
1.0	44	3.0	3.0
1.5	238	4.0	6.0
2.0	14	3.0	6.0
2.5	2	2.0	5.0
3.0	0	0.0	0.0
3.5	0	0.0	0.0
4.0	0	0.0	0.0
4.5	0	0.0	0.0
5.0	0	0.0	0.0



**Figure 31: Risk figure – mortality and/or missing.**

The overall risk score for people (mortality and/or missing) is **11.5**, which is considered **HIGH**. The mode of risk (i.e., the greatest individual risk score) is **6 (MEDIUM)** and is a function of a likelihood score 1.5 and an impact score of 4.0 or a likelihood score of 2.0 and an impact score of 3.0—these are presented on the overall risk matrix later in this section.

The exposure for mortality and/or missing is not fully captured by the modal risk score. As Figure 31 shows, there are concentrations of exposure for several likelihood scores and general a cluster of impacts in the upper left hand corner of the distribution. This confirms that the risk is generally a combination of relatively low likelihood hazards and but a large number of people exposed.

It should be noted that reducing the exposure (and therefore impact) in the highest likelihood zones would have a significant effect on the overall risk score.

### 6.2.2 Affected people

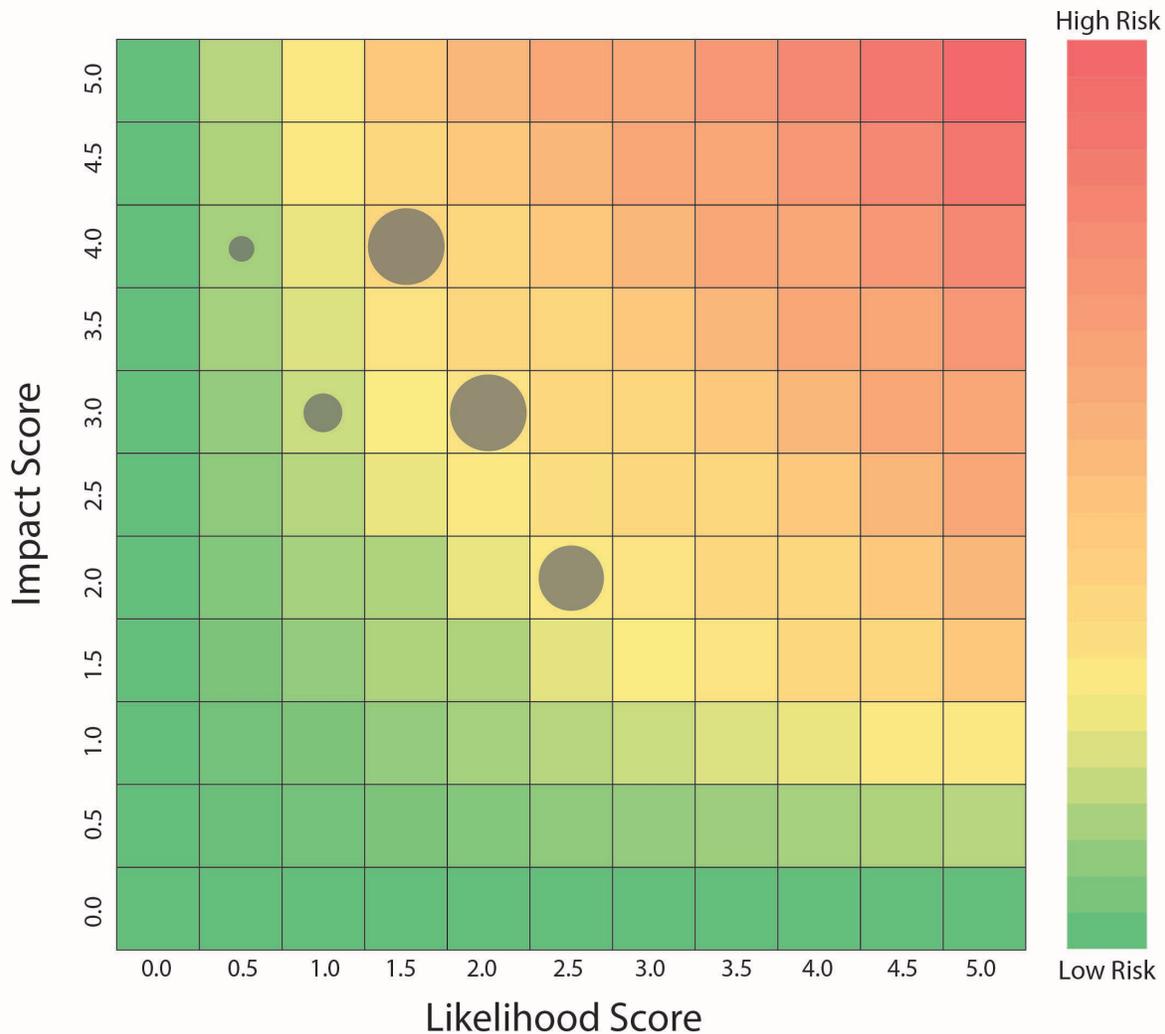
The exposure score for affected people was calculated using census data and then validated using building footprints and data from the NRCan exposure database. It was found that approximately 950 people are in affected areas with non-zero hazard scores. Table 9 shows the distribution across hazard zones.

Table 14: Risk to affected people.

Hazard Rating	Residential Buildings x 1.66 (proxy for affected people)	Impact Score	Risk Score
0.0	N/A	N/A	N/A
0.5	465	4.0	2.0
1.0	73	3.0	3.0
1.5	395	4.0	6.0
2.0	23	3.0	6.0
2.5	3	2.0	5.0
3.0	0	0.0	0.0
3.5	0	0.0	0.0
4.0	0	0.0	0.0
4.5	0	0.0	0.0
5.0	0	0.0	0.0



## Present-Day Risk



**Figure 32: Risk figure – affected people.**

The overall risk score for affected people is **11**, which would be considered **HIGH**. The mode of risk (i.e., the greatest individual risk score) is **6 (MEDIUM)** and is a function of a likelihood score of 1.5 and an impact score of 4.0 or a likelihood score of 2.0 and an impact score of 3.0—these are presented on the overall risk matrix later in this section.

The exposure for affected people is not fully captured by the modal risk score. As Figure 32 shows, there are concentrations of exposure for several likelihood scores and general a cluster of impacts in the upper left hand corner of the distribution. This confirms that the risk is generally a combination of relatively low likelihood hazards but a large number of people exposed.

### 6.2.3 Economic Impacts

The exposure score for economy was calculated using property value data. As described in Section 5.2.3, there over \$400 million of exposed value in hazard areas. Table 15 shows the distribution of all property (being used as a proxy for economy) across hazard zones.

**Table 15: Risk to economy.**

Hazard Rating	Property Values (\$ Millions)	Impact Score	Risk Score
0.0	0	0.0	0.0
0.5	150	3.0	1.5
1.0	21	3.0	3.0
1.5	159	4.0	6.0
2.0	26	3.0	6.0
2.5	34	3.0	7.5
3.0	15	2.0	6.0
3.5	0	0.0	0.0
4.0	0	0.0	0.0
4.5	0	0.0	0.0
5.0	0	0.0	0.0



## Present-Day Risk

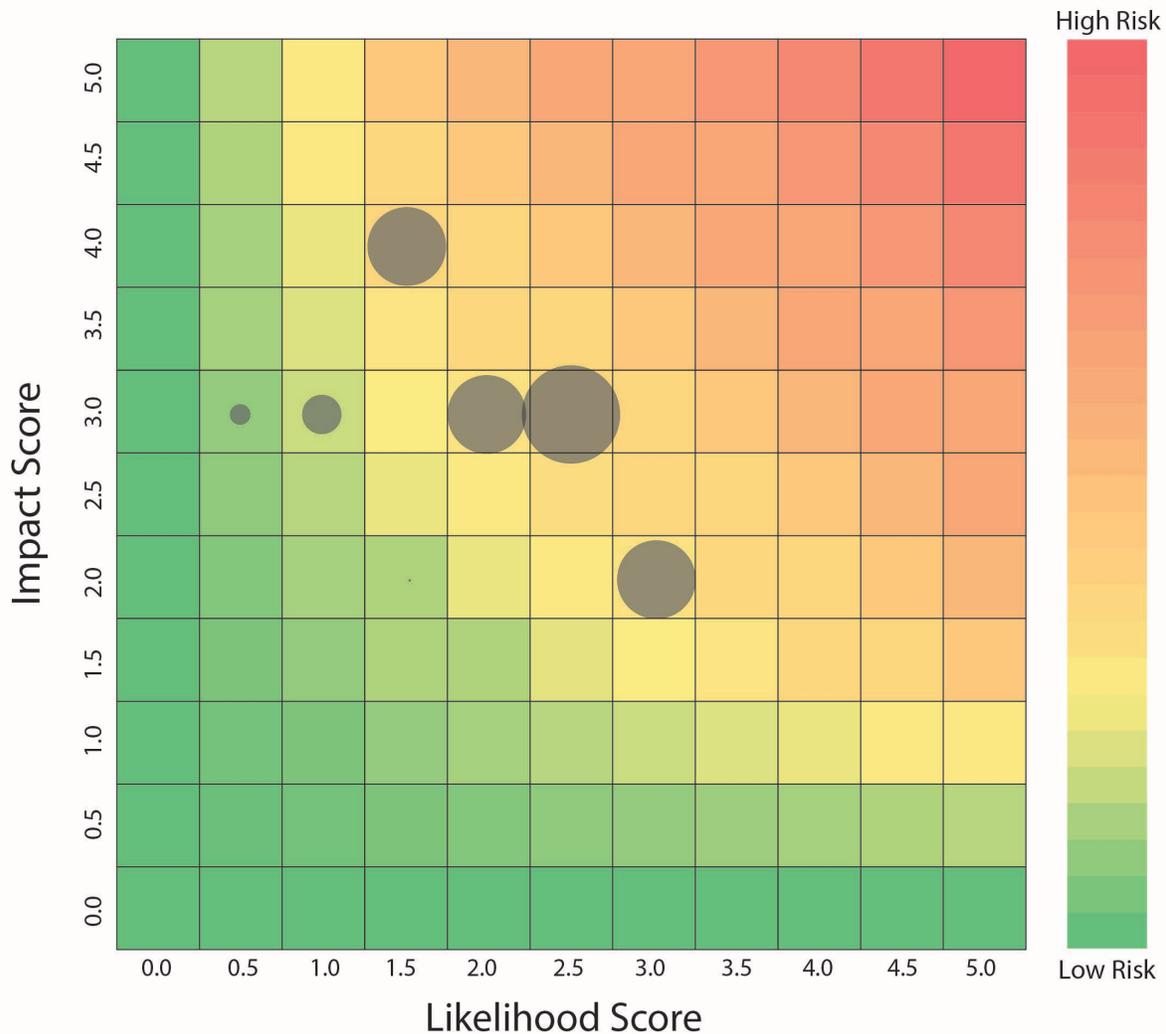


Figure 33: Risk figure – economic.

The overall risk score for economy is **15**, which would be considered **EXTREME**. The mode of risk (i.e. the greatest individual risk score) is **7.5 (MEDIUM)** and is a function of a likelihood score of 2.5 and an impact score of 3.0—this is presented on the overall risk matrix later in this section.

The exposure for economy is not fully captured by the modal risk score. As Figure 33 shows, there is a distribution of scores across multiple impacts and likelihoods. This highlights the distributed nature of this indicator, which suggests a more widescale approach to managing the risk (unlike other indicators where risk is concentrated, and where actions taken on few high-risk locations will have a big impact on overall risk).

### 6.2.4 Disruption

Risk to disruption is meant to represent the potential for widespread interruption of services, which can affect many other indicators (e.g., loss of power will affect businesses and residences). The qualitative assessment described a wide variety of potential disruptions to service in the area (e.g., to roads, to power, to drinking water, etc.). However, data and methods were not available to quantify all of these metrics, and a simplified approach that looks at potential disruption points along roads was used as a proxy for disruption generally. Table 16 highlights the number of crossings in each hazard zone and the associated impact and risk scores.

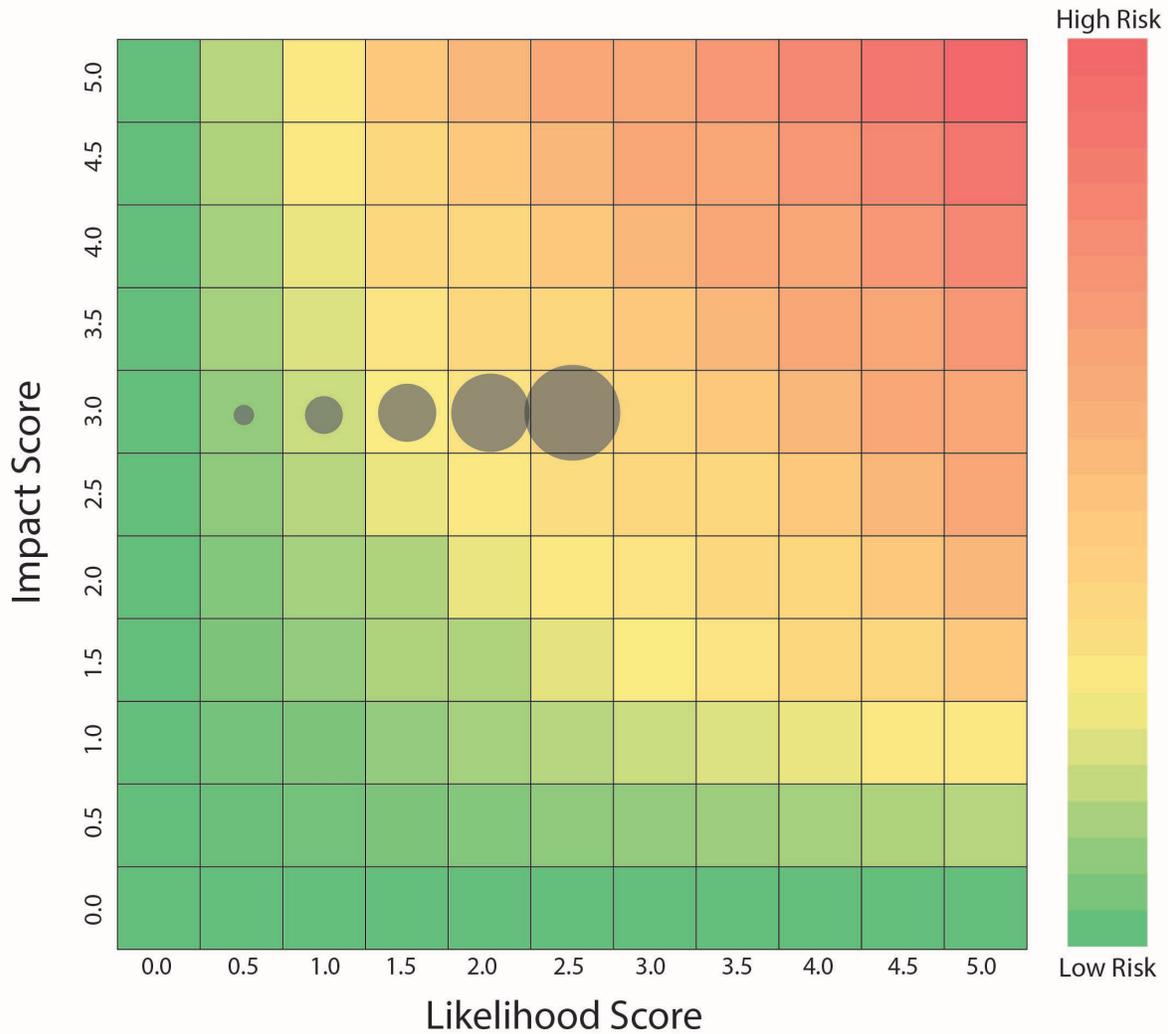
**Table 16: Risk to disruption.**

Hazard Score	Highway	Arterial	Collector	Impact Score*	Risk Score
0.5	1	1	1	3.0	1.5
1.0	-	1	-	3.0	3.0
1.5	1	1	3	3.0	4.5
2.0	1	1	-	3.0	6.0
2.5	-	1	-	3.0	7.5
3.0	-	-	-	0.0	0.0
3.5	-	-	-	0.0	0.0
4.0	-	-	-	0.0	0.0
4.5	-	-	-	0.0	0.0
5.0	-	-	-	0.0	0.0

\*Note the impact score is based on weighted disruption, where highways are assumed to have a weighting of 3, arterial roads 2, and collector roads 1.



## Present-Day Risk



**Figure 34: Risk figure – disruption.**

The overall risk score for disruption is **11.25**, which would be considered **HIGH**. The mode of risk (i.e., the greatest individual risk score) is **7.5 (MEDIUM)** and is a function of a likelihood score of 2.5 and an impact score of 3.0—this is presented on the overall risk matrix later in this section.

The exposure for disruption is not fully captured by the modal risk score. As Figure 34 shows, there is a distribution of scores across multiple likelihoods, but the impact stays relatively consistent. This suggests that disruption could be managed methodically by reducing risk (i.e., by improving crossings) for the highest likelihood crossings first.

There are limitations to the approach taken. First, there is an assumption that disruption to roads represents overall disruption. Although not ideal, the approach taken where road density and classification are considered has been found to be generally representative of infrastructure services (Lyle, Long, and Beaudrie, 2015). This approach also does not consider time of disruption, which is a key element in overall impacts. However, this level of analysis would require additional understanding of the likelihood of repair, given resources in the region during a major storm event, and the simple proxy of non-temporal disruption was assumed to be adequate. Finally, a potential refinement to the methods would be to do some geographical analysis to further explore potential redundancies in the system (i.e., where there are more than two ways to access a given property). This could be done at a fine scale (to cadastral lots), but also at a regional scale with consideration of access to the larger project area using private roads.

### 6.2.5 Environment

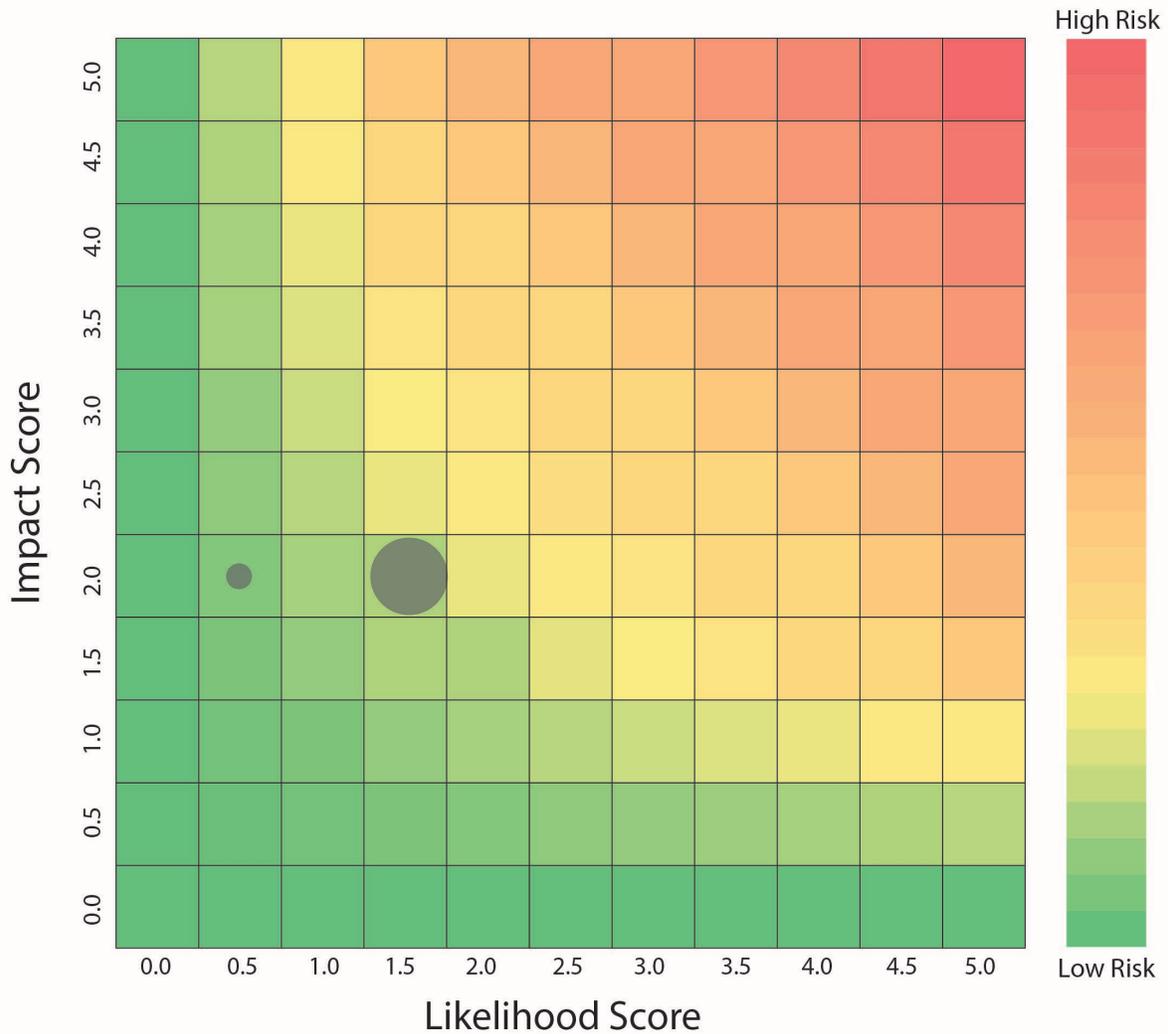
Environmental risk is meant to capture damage that might be expected to the natural environment, either because it is disturbed or because contaminants are released as a result of the hazard event. Limited quantitative data was collected, which is presented in Table 17.

Table 17: Risk to environment.

Hazard Rating	Contaminant Sources	Impact Score	Risk Score
0.0	-	0.0	0.0
0.5	1	2.0	1.0
1.0	-	0.0	0.0
1.5	1	2.0	3.0
2.0	-	0.0	0.0
2.5	-	0.0	0.0
3.0	-	0.0	0.0
3.5	-	0.0	0.0
4.0	-	0.0	0.0
4.5	-	0.0	0.0
5.0	-	0.0	0.0



## Present-Day Risk



**Figure 35: Risk figure – environment.**

The overall risk score for environment is **2.0** which is considered **LOW**. The mode of risk (i.e., the greatest individual risk score) is **3.0 (LOW)** and is a function of a likelihood score of 1.5 and an impact score of 2.0—this is presented on the overall risk matrix later in this section. The exposure for environment is not fully captured by the modal risk score. As Figure 35 shows, there are concentrations in the middle left of the graphic.

There are only two sources of potential contamination in the project area. There were many other potential sources of contamination surveyed and included in the initial dataset for the project area, but they were in areas with hazard scores of 0.

There may be other criteria that could be used to characterize potential environmental impacts due to debris flow. For example, there could be areas where habitat is lost or degraded due to hazard events. This would require additional data on habitat or other environmental indicators. While debris flow impacts can be severe at a given location, they do not cover as large an area as some other hazards, like floods, where contaminants can be picked up from many sources and transported greater distances.

Another possible impact to consider would be aquatic habitat in creeks and at the outlet of creeks. With larger sediment and debris flows into these areas, sensitive habitat could be disturbed. This could be studied with consistent mapping of sensitive areas.

The limitations of the available data sets mean that the risk score is likely to be higher than reported. I.e. with a more complete dataset more points would be impacted. For this reason, whilst the calculated risk score is **LOW** we expect the risk to environment to be **MEDIUM**. This increase in risk score related to the uncertainty in the information is based on principles defined by the AIDR, and is precautionary.

#### 6.2.6 Culture

There are several First Nations whose traditional territory overlaps with the project area. Lake Cowichan First Nation mentions on their website that they use a wide range of resources throughout their traditional territory including the creeks entering the lake, small lakes in the vicinity, and the uppermost portion of the Cowichan River (Nation, 2018). This encompasses much of the project area. Similarly, a member of Cowichan Tribes mentioned in workshop 2 that there are locations within the project area that are used for food harvesting.

In order to provide a provisional score for culture, it was assumed that lost access to cultural sites would be of significant concern; thereby removing the need to understand the exact location of harvesting sites (for plants and animals). It is assumed that moderate damage to cultural or historical assets may occur in the project area due to debris flow. The impact score for culture is therefore **3.0**. An aggregate likelihood score of **2.0** is also assigned, based on a weighted average of hazard zones rounded to this nearest half risk score. This results in a total risk score of **6.0** or **MEDIUM**.

There are significant limitations to this portion of the assessment, as more direct input from communities in the project area would be required to appropriately capture potential cultural impacts based on community values. This assessment does however provide a starting point for discussion and should ensure that culture is considered in the development of mitigation alternatives.



# Present-Day Risk

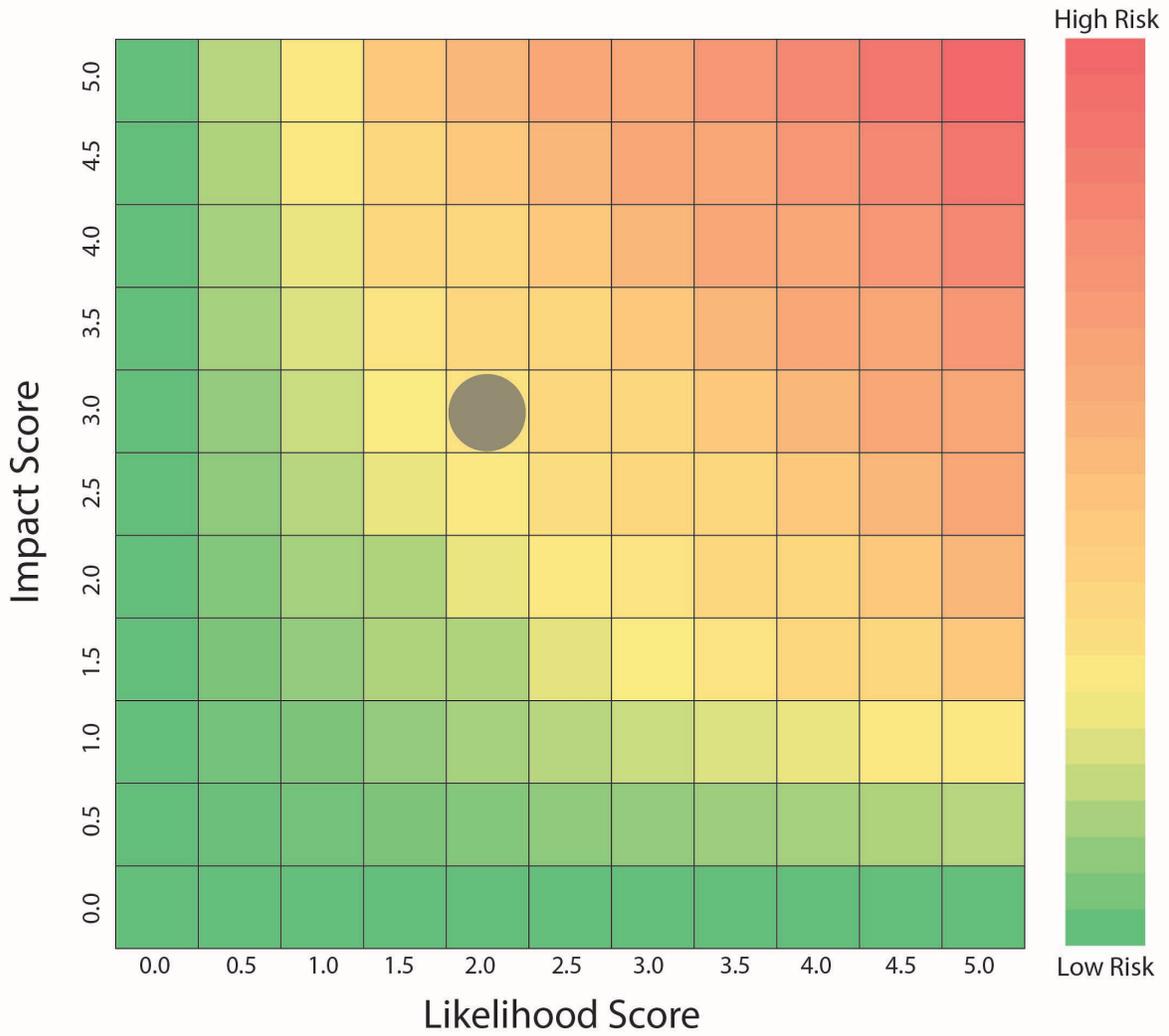


Figure 36: Risk figure – culture.

### 6.3 Summary Risk Scoring — Present-Day

Previous sections describe the distribution and characterization of impacts. These are summarized below in Table 18.

Table 18: Risk summary for project area.

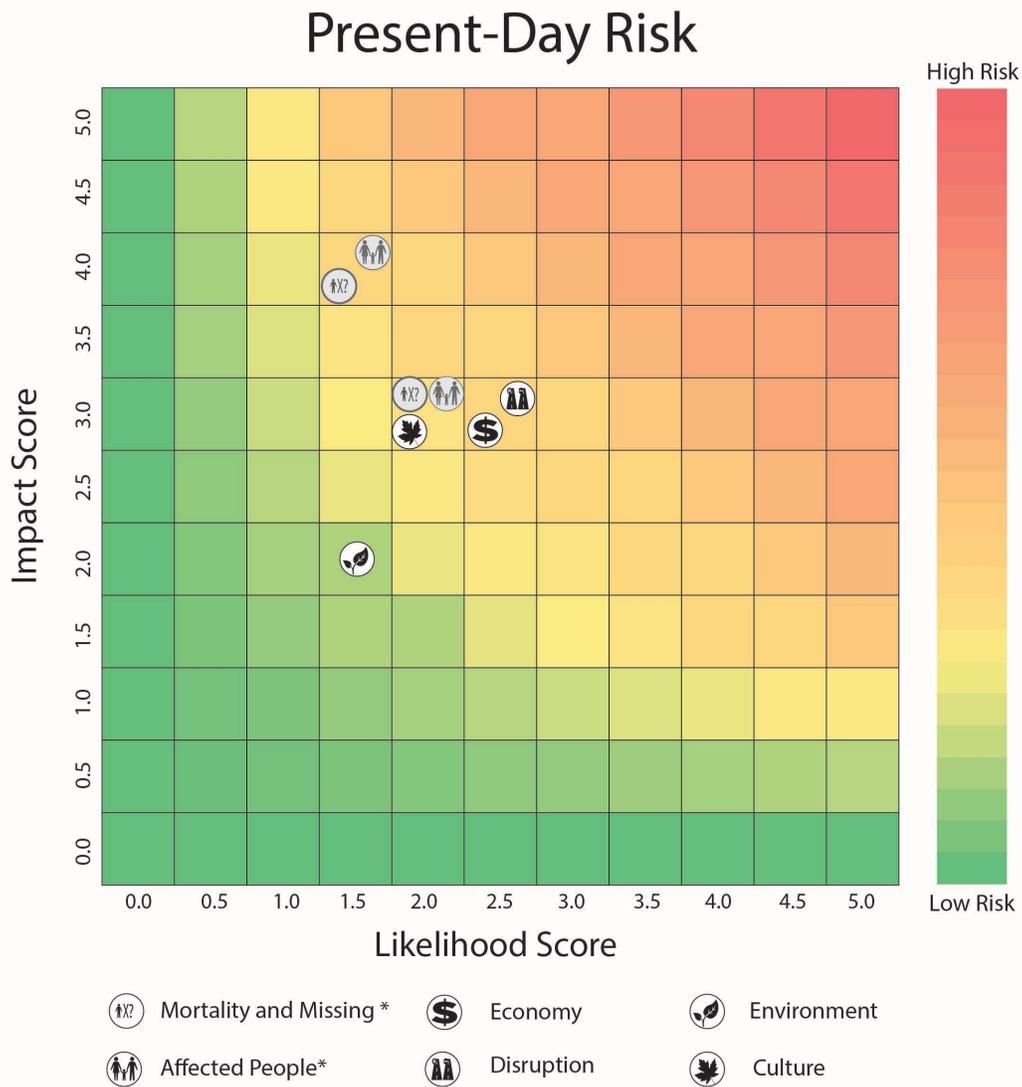
Impact Category	Absolute Impact or Qualitative Metric Used	Comments
<b>People (Mortality and/or Missing)</b>	2 residential buildings in moderate hazard areas	Some creeks have moderate hazard ratings for debris flow with homes and roads adjacent. Figures could be higher if an event occurred in the summer when the population is higher.
<b>Affected People</b>	950 people directly affected	A relatively high number of people will have homes or businesses impacted by moderate hazard ratings, especially when considering the scale of the CVRD and Vancouver Island. Figures could be higher if an event occurred in the summer when the population is higher.
<b>Economic Consequences</b>	\$400 M total exposed property	Scores vary with the level of property value in the affected area. This is significant when considered at the scale of Vancouver Island GDP.
<b>Disruption</b>	12 locations of overlap between hazard areas and road	Several disruption points were identified and weighted based on the importance of the asset.
<b>Environment</b>	2 potential sources of contamination	The environmental impact is relatively low (as compared to other impacts) with only 2 potential sources of contamination in hazard zones. This score does not cover all possible environmental impacts however, so may be higher in reality.
<b>Culture</b>	Qualitative — based on harvesting access	Some harvesting of fish and plants occurs in the project area. Access is important for First Nations and impacts are expected to be moderate.

Geohazard risk scores for the project area are summarized in Table 19 and shown in Figure 36. These show some of the trends discussed visually with both scores and associated colours.

Table 19: Geohazard risk assessment summary – present-day.

Element	Total Risk Score	Modal Risk Score
People (Mortality and/or Missing)	11.5	6
Affected People	11	6
Economic	15.0	7.5
Disruption	11.25	7.5
Environment	4.0	3.0*
Culture	-	6.0

\*believed to be an underestimate



\* There are 2 possible combinations shown to reach the modal risk score for Affected People and Mortality and Missing.

Figure 37: Geohazard risk assessment summary matrix (using modal risk scores).

The analysis shows that there is considerable risk in the project area. Of primary concern is the risk to life. The economy, affected people, culture, and disruption indicators also show high levels of risk. Risk

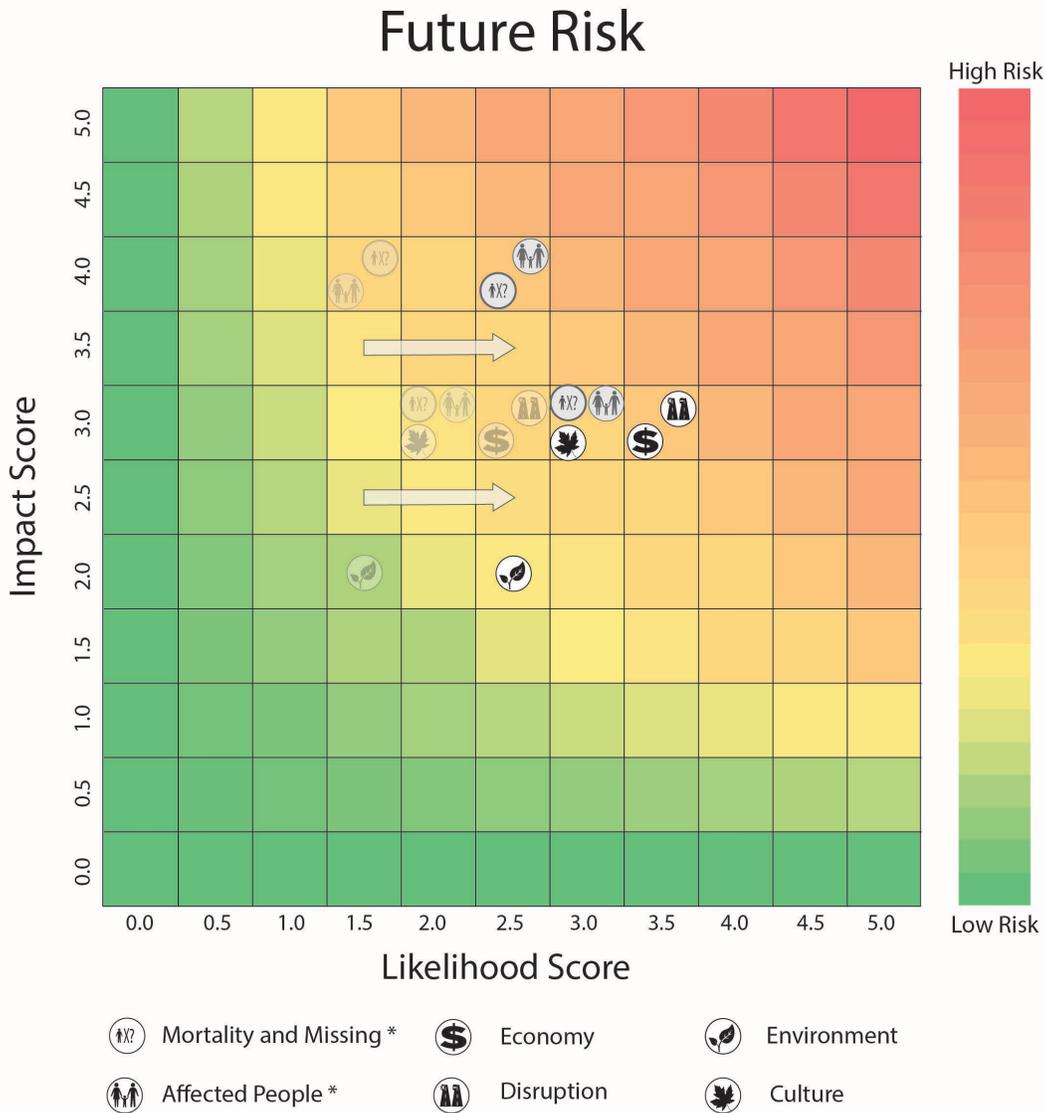
to environment, although lower, is potentially an underestimation as this assessment was limited in scope.

#### 6.4 Summary Risk Scoring — Future

As discussed in earlier sections, risk is dynamic and will change with time. There is no exact science to describe the future, however, in this instance, consideration was given to the potential increased likelihood of geohazard events in the region, which will affect overall risk. An assumption was made to increase all likelihood scores by 1 point (given the logarithmic nature of the scoring system, this is a 10-fold increase). This was based on two parallel and reinforcing assumptions:

1. Research described in Section 4.4 suggests that the region will soon reach a tipping point in its 24-hour extreme rainfall conditions that will be higher than the currently estimated threshold for triggering geohazards. This is because of climate change.
2. Further, additional information cited in Section 4.4 suggests that potential human-induced changes to the landscape can affect the likelihood of triggering debris flows by as much as 10-fold.

Given these potential changes, it is proposed that a 10-fold increase (i.e., a 1-point increase) in likelihood is not unexpected in the future. This results in an increased risk, as shown in Figure 37.



\* There are 2 possible combinations shown to reach the modal risk score for Affected People and Mortality and Missing.

**Figure 38: Future risk.**

The projected future risk is **HIGH** in many categories, as all indicators shift in likelihood and ultimately risk. Missing and Mortality, Affected People, Economy and Disruption Impacts all move from the **MEDIUM** to the **HIGH** risk zone with a risk score of 10 or greater. Environmental risk becomes **MEDIUM** and cultural risk stays in the **MEDIUM** zone.

### 6.5 Discussion

In summary, the results of the risk assessment show that many current risk scores are **MEDIUM**; this is a result of moderate hazard scores combined with moderate exposure scores. Some specific trends on the results of the risk scoring include:

- The risk scores for people and affected people are **MEDIUM**. Risk is clustered in a few locations.

- Risk to disruption and economy is **MEDIUM**. However, the risk is more dispersed.
- Risk to environment and culture is **MEDIUM** to **LOW** and is relatively dispersed. There is more uncertainty in these scores as they are based on more limited assessments

In future it is expected that the risk will increase with all but culture and the environment moving into the **HIGH** risk category.

All efforts have been made to provide the maximum level of resolution in the hazard areas however some spatial variability still exists. To achieve a better resolution hazard extent further modeling such as modelling of runout areas would be required, this would likely increase the hazard extents and increase encounter probabilities. The results provided are therefore considered minimum estimates.

The scoring in Table 14 is based on the available information and on the judgment of the consulting team. Given the qualitative nature of some of the measures, and the assumptions made (for example, to scale the assessment to the whole of the CVRD or Vancouver Island in comparison to the project area) there is some variability in possible scores. However, the overall assessment is within expected bounds and should be considered robust enough for the purposes of this project; some recommendations to refine the assessment in the future are provided in Section 10.4.

This assessment provides spatial outputs to support next steps for the CVRD and also overall risk scoring, which can be used for comparison with other areas. In addition, this assessment provides the necessary information to satisfy the funding requirements of this project. Additional formats of the risk assessment are presented in the Appendices for direct submission to the NDMP.

#### 6.5.1 Limitations

Risk assessment always has many inherent limitations including the quality and quantity of exposure and hazard data. For this project, detailed and fine-scale hazard data was collected by Palmer. While this is helpful for the hazard assessment in general, fine-scale hazard ratings present some challenges for risk assessment. Exposure had to be assessed for small areas and aggregated, and hazard scores were applied for a given indicator using the mode of risk. In addition, some features that could influence the hazard were not considered for the quantitative assessment. For example, the bridges or crossings were not included in the hazard modelling to determine the effect of the capacity of the road crossing. This is something that would likely have an impact on the severity of the damage in the event of a debris flow. However, some culverts were surveyed during the site work, and ministry of transportation culvert sizes were compiled. While the capacity was not modelled, most crossings are undersized, and so it is reasonable to assume that these are disruption points.

In addition, some categories of exposure were scored with limited information, such as cultural and environmental impacts. This should be taken into consideration for next steps, such as developing risk tolerances. Likely more community input will be needed for the cultural parameter in particular.

## 7 Capacity Building for the Community

Building on the CVRD's ongoing efforts to manage risk and build resilience, this project intentionally engaged a broad set of stakeholders at two points in the process, in order to build awareness and understanding of impacts and risk, and to begin to consider establishing risk tolerances to shape policy. Due to the nature of geohazard as a "wicked problem", engaging stakeholders in this type of a process is an essential first step towards understanding and building resilience for the community. Joint understanding, ownership, action and ongoing learning is essential for a community to become truly resilient. Leaping to solutions without first understanding the complexity of the problem can yield poor results. Similarly, without a grounding in risk terminology and the trade-offs associated with risk tolerance selection, thresholds can be poorly defined, which may also affect long-term outcomes.

The following summarizes the results of stakeholder engagement and participation in this project. More detailed information, including workshop reports, is presented in Appendix C. Establishing risk tolerance and planning for resilience can help the people in the project area to work toward becoming a safe, prosperous, and resilient community.

### 7.1 Geohazard Risk as a Wicked Problem in the Project Area

Geohazard management is a classic "wicked problem". It has a high degree of technical complexity, multiple dimensions of uncertainty, and multiple objectives. This is made worse by high stakes and high emotions, as there is often intense political scrutiny. More often than not, it is also limited by available resources (data, methods, time, money, and personnel).

Wicked problems are also ones that will not stay solved and are characterized by a tangle of interconnected influences. Managing geohazards in the project area is no different, and typically in these cases, there is no single solution and there are many trade-offs to be made.

Stakeholders were asked what elements of geohazard risk in the project area made for a wicked problem, and these are summarized as a word cloud in Figure 32.



Figure 39: Natural hazard as a wicked problem as reported by stakeholders

This exercise aimed to increase the understanding and capacity of stakeholders, but also serves as a useful means of understanding particular aspects of this region and its hazards. This in turn can be used to inform next steps. Specifically, by looking at the word cloud above, a few inferences can be drawn, which have been divided into Sendai categories to provide some framing:

- **Understanding Risk**
  - There are many potential and diverse types of impacts that need to be considered (e.g., environmental, different populations), which requires that any decision processes consider as many of these as possible, and acknowledge missing impact types. The risk assessment presented above makes an effort to include as many of these impact types as possible.
  - Exposure is time sensitive (e.g., summer vs. winter populations), which potentially requires multiple risk scenarios in order to properly consider the timing of a hazard event. This is mentioned as a qualifier in the risk assessment above and may need to be refined in the future, as specific risk reduction and management efforts are considered.
  - Data is lacking, which may hamper efforts to develop robust risk assessments and decision processes.
  - Public capacity to understand this complex issue is a challenge and current awareness is low, meaning that a concerted effort will be required to effectively engage the public in the future.

- **Strengthening Disaster Governance**
  - There is an awareness that impacts are multi-jurisdictional, and that solutions for one area may adversely affect others, which means that efforts to develop and nurture partnerships across jurisdictions will be key to success.
  - There is a recognition that government liability is an issue, and this can serve to support buy-in from all jurisdictions and levels of government.
- **Investing in Disaster Risk Reduction**
  - The fact that a major geohazard event has not occurred in recent memory hampers the ability of stakeholders and decision makers to address the problem. This can be addressed by working through robust decision processes that can support the argument for investment.
  - There is also a recognition that uncertainty is a challenge to action. This again can be addressed through robust decision processes that explicitly consider uncertainty.
- **Build Back Better**
  - No particular responses related to building back better, likely as the region has not recently observed a geohazard event. However, there was a recognition that avoiding increased future risk is important. By laying the groundwork to understand where the hazards are greatest (through this project), and then by developing appropriate policies, this can be achieved in the future.

## 7.2 Components of a Safe, Prosperous, and Resilient Community

Communities do not want elaborate geohazard control infrastructure, per se, they want safe and prosperous places to live; this should be at the heart of any hazard mitigation plan.

Stakeholders in the project area provided a robust list of considerations for what constitutes a safe, prosperous, and resilient community:

- Personal resilience.
  - Engagement, training (enhance understanding).
  - Recovery time.
  - Addressing impacts, such as post-traumatic stress disorder, anxiety, and fear.
  - Understanding the services available and what vulnerabilities are.
- Knowing how to respond to crisis.
  - Advance warning and communication systems.
  - Response plans (community, individuals, businesses).
  - Business/employment continuity.
  - Supportive behaviours (e.g., do not get in the way or make it worse).
  - Communications within and outside the CVRD.
- Smart development in the future (e.g., decisions in hazard areas).
- Safe and reliable infrastructure.
- Preparedness for areas at risk.
  - Linking up emergency services.
- Confidence to invest in business.

- Security about the future.
- Insurance.
  - Awareness of available insurance products and effects on disaster response funding.



Figure 40: Keywords from stakeholders on what makes a safe, prosperous, and resilient community.

The outcome of this exercise serves as a base for future decision-making objectives, as well as potential solutions that would be appealing to the community as a whole. For example, the word cloud and summary of statements clearly shows that the community is keen to feel prepared and secure in the present and for the future. This can then become an objective in a decision process—where different solutions are scored against present-day and future feelings of security. Further, the discussion with the stakeholders clearly highlighted that there is understanding that the hazards cannot be stopped, and that being prepared through warning systems and appropriate emergency response measures is important. This can and should be one of the options or sub-options presented to the community as part of a decision process (this is also captured in Section 8 below).

### 7.3 Summary

Through the process of conducting community workshops, there is now a base understanding of the existence and complexity of the geohazards in the project area. Further, the information gathered from the community will serve to support future decision processes that have the goal of reducing and/or managing the natural hazard risk in the region.

## 8 Geohazard Risk Reduction Strategies

An assessment of geohazard risk is presented in Section 6. This section provides additional detail on how to adapt and plan to manage geohazards and draws on ideas from the disaster risk reduction community, as well as climate adaptation terms. These two fields have until recently been working on parallel tracks, each with their own terminology. More recently, there has been a recognition that the ideas and concepts are similar, and that climate adaptation needs to be woven directly into disaster risk reduction.

Best practice for considering risk mitigation measures includes considering all components of risk, and applying measures that fall under the following categories:

- Vulnerability Reduction (i.e., adapt or accommodate)
- Hazard Reduction (i.e., protect or resist)
- Exposure Reduction (i.e., retreat or move)

### 8.1 Vulnerability Reduction (Adapt)

This strategy is one where a collection of options is used to reduce the exposure and/or sensitivity of vulnerable assets to a geohazard event. Typical options used in an Adapt strategy include:

- Using planning options to ensure that no new critical infrastructure is built in at-risk areas of the zone.
- Careful regulation of subdivision and density approvals in geohazard areas to avoid increasing the zone vulnerability in the future.
- Developing and implementing geohazard monitoring and warning systems.

### 8.2 Hazard Reduction (Protect)

The Protect strategy examines the effect of applying particular options (usually debris flow traps, dams, or deflection berms) to reduce the hazard by preventing debris from accessing valued elements in zones.

### 8.3 Exposure Reduction (Retreat)

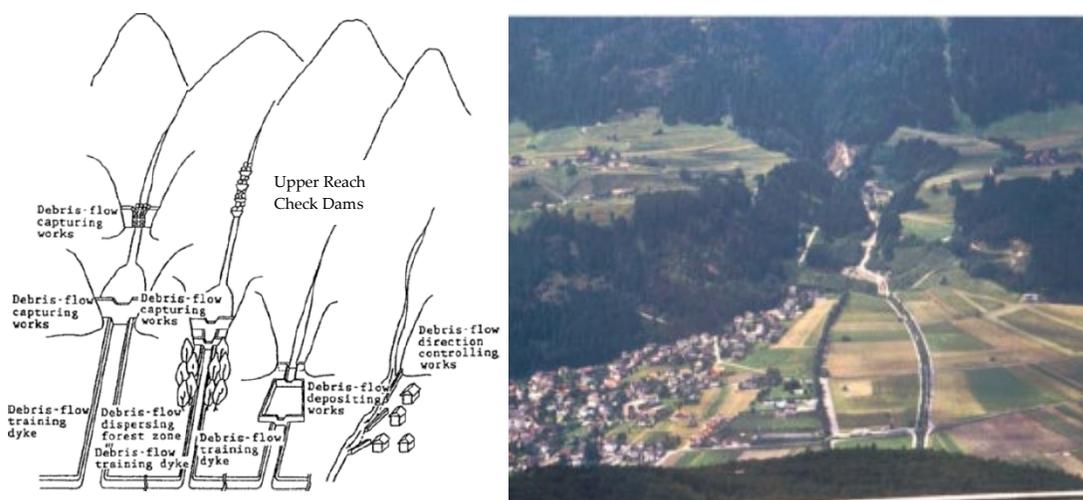
A Retreat strategy is often considered a special form of exposure-reducing strategy in which vulnerable assets are actively moved away from high risk areas over time. While not applicable in all areas, it may be viable to encourage the movement of vulnerable assets out of geohazard-prone areas. This might involve opportunistic buyouts as homes and businesses come up for sale over the next 40–60 years, with more aggressive buyouts 60–90 years from now; opportunistic removal of roads, other infrastructure, and contaminants as land is vacated; and aggressive re-naturalization in the future.

### 8.4 Geohazard Mitigation Options for Project Area

A long-list of options, which includes measures in each of these categories, is presented in Appendix E. The protection options presented here are all structural measures that reduce the hazard. The adaptation options are primarily non-structural and include both building-level measures and things like warning systems. It should be noted that there will be some significant limitations for adaptation

options, considering the nature of the hazard (e.g., the magnitude of forces on structures and rapid onset). Finally, if there are no other feasible options to step down the risk, then strategic retreat may be needed in some areas. This should be based on established risk tolerances following a detailed assessment of mitigation options for the areas of concern.

At a high level, simplified approaches are shown in Figure 34. On the left is an image of structural mitigation measures for debris flow, with illustrations of options like retention basins and deflection berms. Some of these measures have been implemented in Canada and many of them have been implemented abroad in places like Japan, Hong Kong, and Austria. On the right is an example of non-structural mitigation. Here, spatial planning policies have been implemented for an alluvial fan. As you can see in the image, there is agriculture on the fan (limited exposure to hazard) and residences away from the fan. This reduces risk as the vulnerable elements are away from the hazard area.



**Figure 41: Examples of structural mitigation (left)(Okubo *et al.*, 1997) to reduce debris flow hazard, and an example of non-structural mitigation (right) in an area near Innsbruck, Austria, with spatial planning on an alluvial fan.**

At a high level, potential measures to reduce risk were screened for this project and categorized as follows:

#### **Non-Structural Mitigation (see Table 20)**

- Category 1: Exposure reduction – spatial
- Category 2: Exposure reduction – temporal
- Category 3: Vulnerability reduction
- Category 4: Improved response and/or recovery

#### **Structural Mitigation Measure Categories (see Table 21)**

- Category 1: Surface protection – erosion control
- Category 2: Deviating the path of landslide debris
- Category 3: Dissipating the energy of debris flows

- Category 4: Arresting and containing landslide debris or rock fall

For each measure, the table includes the category of the measure, the name of the measure, and a general description. In addition, some information on the mode of action (how does this measure reduce risk), effectiveness (how effective is it at reducing a component of risk), and context (how is this currently implemented in the CVRD). Finally, obstacles and opportunities (what could get in the way of implementation and what are some opportunities for implementation), and the impact categories the measure addresses (mortality and/or missing people, affected people, disruption, economic, environment, and/or culture impacts) are noted.

Table 20: Non-Structural landslide mitigation measures.

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Categories
<b>Non-Structural Mitigation – Category 1: Exposure reduction - spatial</b>					
<b>Update OCP/designate DPAs</b>	<ul style="list-style-type: none"> <li>• Planning documents could identify hazard zones spatially and implement a Designated Permit Area (DPA) for these zones (Porter and Dercole, 2011).</li> </ul>	<ul style="list-style-type: none"> <li>• Exposure and vulnerability reduced over time as new construction or renovations comply with the DPA.</li> </ul>	<ul style="list-style-type: none"> <li>• The OCP is produced by the CVRD for each electoral area.</li> <li>• Current CVRD OCP (for Electoral Area I) Policy 2.7 makes reference to hazardous lands and debris flows but does not include localized hazard mapping</li> </ul>	<ul style="list-style-type: none"> <li>• Implementation would depend on the timeline and process of updates to the OCP; the CVRD is currently in the midst of harmonizing and modernizing the electoral area OCPs. This is an excellent opportunity to update and modernize the DPAs.</li> <li>• This can reduce risk over time only in combination with other measures (this is a policy tool to implement other measures, and not a measure in of itself).</li> </ul>	<ul style="list-style-type: none"> <li>• Affected People</li> <li>• Mortality and/or Missing</li> <li>• Disruption</li> <li>• Economic</li> <li>• Environment</li> <li>• Culture</li> </ul>
<b>Acquire exposed or repetitive loss properties</b>	<ul style="list-style-type: none"> <li>• Repetitive loss properties (if applicable) or properties in high hazard zones could be acquired (Porter <i>et al.</i>, 2007).</li> <li>• Reducing exposure by removing assets from harm’s way is the surest means of reducing risk.</li> </ul>	<ul style="list-style-type: none"> <li>• Exposure reduction by removing people, structures, and assets of value from hazard areas.</li> </ul>	<ul style="list-style-type: none"> <li>• This has been done in other jurisdictions in BC. EMBC has recently expressed willingness to consider property acquisition for funding.</li> </ul>	<ul style="list-style-type: none"> <li>• Depending on property values, there can be significant financial obstacles.</li> <li>• Public support for this approach can also be a challenge.</li> </ul>	<ul style="list-style-type: none"> <li>• Affected People</li> <li>• Mortality and/or Missing</li> </ul>

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Categories
<b>Non-Structural Mitigation – Category 2: Exposure reduction – temporal</b>					
<b>Monitoring system</b>	<ul style="list-style-type: none"> <li>• Inspections of gullies and sidewalls can help to detect any signs of instability.</li> <li>• Monitoring should include tracking the build-up of material along the gully bottom (more material is a concern), which is more likely to saturate and initiate/enlarge debris flow) and detecting signs of instability along gully walls.</li> <li>• Regular slope inspections as part of monitoring system to evaluate the ongoing need for slide likelihood reduction measures (Porter and Dercole, 2011), (Porter <i>et al.</i>, 2017).</li> </ul>	<ul style="list-style-type: none"> <li>• A monitoring system provides timely slope condition information to support decision-making.</li> <li>• This can help with emergency management preparations and provide input to a warning system.</li> </ul>	<ul style="list-style-type: none"> <li>• This would be a new system/program for the CVRD.</li> <li>• On Private Managed Forest Lands, slope inspections and monitoring may be the responsibility of the landowner.</li> </ul>	<ul style="list-style-type: none"> <li>• Gully inspections would not require much in the way of equipment, etc.</li> <li>• Some level of monitoring and tracking could be a cost-effective option and significantly decrease risk to life.</li> <li>• It would likely be cost prohibitive to instrument all possible source slopes.</li> </ul>	<ul style="list-style-type: none"> <li>• Affected People</li> <li>• Mortality and/or Missing</li> </ul>

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Categories
Warning system	<ul style="list-style-type: none"> <li>• Install system for alerts and evacuation notices to residents related to possible debris flow.</li> <li>• This type of system would be based on statistical analysis of rainstorms that have and have not triggered debris flows (Porter <i>et al.</i>, 2007).</li> </ul>	<ul style="list-style-type: none"> <li>• A warning system uses data from the monitoring system and warns people if the slope/gully condition is deemed to be potentially hazardous.</li> <li>• This requires a voluntary or involuntary system to evacuate, which can be challenging.</li> </ul>	<ul style="list-style-type: none"> <li>• The District of North Vancouver (DNV) implemented a similar system, which has been calibrated using local data. If unavailable, data of areas with similar conditions could be used for calibration.</li> </ul>	<ul style="list-style-type: none"> <li>• Inputs required for data collection.</li> <li>• This is also a relatively cost-effective option.</li> <li>• There is a good example (DNV) to learn from for this option.</li> </ul>	<ul style="list-style-type: none"> <li>• Mortality and/or Missing</li> </ul>
<b>Non-Structural Mitigation - Category 3: Vulnerability reduction</b>					
Impact-resistant construction	<ul style="list-style-type: none"> <li>• Possible DPA around significant renovations or new builds within hazard areas.</li> <li>• Impact-resistant construction relates to the strength and configuration of structures as a strategy to reduce vulnerability.</li> <li>• This could apply to private residences, but also public infrastructure (Porter <i>et al.</i>, 2007).</li> </ul>	<ul style="list-style-type: none"> <li>• Reduces vulnerability of individual structures.</li> <li>• Limited effectiveness for higher hazard levels.</li> </ul>	<ul style="list-style-type: none"> <li>• Modifications to structures.</li> </ul>	<ul style="list-style-type: none"> <li>• Some will be modifications to private structures and others to public.</li> <li>• Could be implemented over time.</li> <li>• Limited (none found) examples of building codes/DPAs in Canada.</li> </ul>	<ul style="list-style-type: none"> <li>• Mortality and/or Missing</li> </ul>

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Categories
<b>Bedroom relocation</b>	<ul style="list-style-type: none"> <li>• Vulnerability reduction measure for homes.</li> <li>• Relocation of bedrooms to the downslope side of a home reduces the temporal vulnerability of that residence in the event that a debris flow occurs at night (Porter <i>et al.</i>, 2007).</li> </ul>	<ul style="list-style-type: none"> <li>• This reduces risk as it reduces the exposure of people during the night.</li> <li>• This is effective if only a portion of the house is affected by a landslide event.</li> <li>• Limited effectiveness for higher hazard levels.</li> </ul>	<ul style="list-style-type: none"> <li>• This is something that has been considered by the DNV.</li> <li>• This could be integrated into planning documents.</li> </ul>	<ul style="list-style-type: none"> <li>• This would be a new approach and would require public support.</li> <li>• It would be applied over time.</li> </ul>	<ul style="list-style-type: none"> <li>• Mortality and/or Missing</li> </ul>
<b>Non-Structural Mitigation – Category 4: Improved response and/or recovery</b>					
<b>Emergency management planning</b>	<ul style="list-style-type: none"> <li>• Emergency management planning should be based on the best available information of hazards and likely consequences.</li> <li>• New information from risk assessment should be integrated into emergency management plans (Porter and Dercole, 2011).</li> </ul>	<ul style="list-style-type: none"> <li>• Reducing vulnerability over time with better response planning.</li> <li>• Improve life safety with effective evacuations.</li> </ul>	<ul style="list-style-type: none"> <li>• Integrated with current Emergency Management Plans and relevant supporting authorities.</li> </ul>	<ul style="list-style-type: none"> <li>• Some capacity-building effort will be needed to integrate new information from risk assessment.</li> <li>• Likely a low-regrets option.</li> <li>• Would perform better with a warning system in place.</li> </ul>	<ul style="list-style-type: none"> <li>• Affected People</li> <li>• Mortality and/or Missing</li> </ul>

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Categories
Establish risk tolerances (to support public education and implementation of other measures)	<ul style="list-style-type: none"> <li>Engage stakeholders and possibly members of the public to establish risk tolerances.</li> <li>This can be applied to asset management, land development divisions, and life safety measures.</li> <li>This should be for the occurrence of a geohazard event beyond the previous standard/design guideline of 1.5 for the land parcel itself (Porter and Dercole, 2011), (Porter <i>et al.</i>, 2007).</li> </ul>	<ul style="list-style-type: none"> <li>Establishing risk tolerances will help to set a threshold for “acceptable risk”.</li> <li>With this determined, areas of “unacceptable risk” can be identified.</li> </ul>	<ul style="list-style-type: none"> <li>CVRD has expressed interest in establishing risk tolerances across the region.</li> <li>This will help to support risk mitigation and strategic planning around hazards.</li> </ul>	<ul style="list-style-type: none"> <li>The process of eliciting risk tolerances is challenging, requiring sufficient background information and consideration for process.</li> <li>This can help to address other hazards.</li> </ul>	<ul style="list-style-type: none"> <li>Affected People</li> <li>Mortality and/or Missing</li> <li>Disruption</li> <li>Economic</li> <li>Environment</li> <li>Cultural</li> </ul>
Risk communication strategy	<ul style="list-style-type: none"> <li>Communication with stakeholders and public as appropriate related to understanding geohazard risk (Porter and Dercole, 2011).</li> </ul>	<ul style="list-style-type: none"> <li>Helps to improve public understanding of problem.</li> <li>Can build local capacity and resilience.</li> </ul>	<ul style="list-style-type: none"> <li>CVRD has already developed excellent communication plans on climate and risk. This could build on previous work.</li> </ul>	<ul style="list-style-type: none"> <li>This can be integrated into the ongoing climate communications work by the CVRD.</li> </ul>	<ul style="list-style-type: none"> <li>Mortality and/or Missing</li> </ul>

Table 21: Structural landslide mitigation measures.

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Category
<b>Structural Mitigation – Category 1: Surface protection – erosion control</b>					
<b>Restoration of Vegetation or Geosynthetics</b>	<ul style="list-style-type: none"> <li>Restoration of vegetation to promote interception of precipitation, attenuate runoff, and promote stronger root networks OR addition of geosynthetics to achieve soil stabilization.</li> </ul>	<ul style="list-style-type: none"> <li>Effective for some small areas but not large debris flow zones.</li> </ul>	<ul style="list-style-type: none"> <li>Appropriate for site-level application in some zones.</li> </ul>	<ul style="list-style-type: none"> <li>Not appropriate for large-scale application across the project area.</li> </ul>	<ul style="list-style-type: none"> <li>Affected People</li> <li>Mortality and/or Missing</li> <li>Disruption</li> <li>Environment (if restoration)</li> </ul>
<b>Structural Mitigation – Category 2: Deviating the path of landslide debris</b>					
<b>Increase conveyance capacity of channel and crossing (culvert/bridge)</b>	<ul style="list-style-type: none"> <li>Increases to channel/crossing capacity to make space for debris flow conveyance (Porter <i>et al.</i>, 2017).</li> <li>Possible for some zones where there is space to increase capacity.</li> <li>This is a common option for debris flow management.</li> </ul>	<ul style="list-style-type: none"> <li>This reduces the hazard by inhibiting the build-up of material behind crossings.</li> <li>Sudden failure of crossings can be avoided.</li> </ul>	<ul style="list-style-type: none"> <li>Modifications to road at creek crossings.</li> </ul>	<ul style="list-style-type: none"> <li>Road ownership to be addressed.</li> <li>Could be expensive and should be combined with other road works.</li> </ul>	<ul style="list-style-type: none"> <li>Affected People</li> <li>Mortality and/or Missing</li> <li>Disruption</li> </ul>
<b>Diversion channel away from development</b>	<ul style="list-style-type: none"> <li>Construction of diversion channel to transport debris away from exposed elements (Porter <i>et al.</i>, 2017).</li> <li>This is considered to be a reasonable option for debris flow management.</li> </ul>	<ul style="list-style-type: none"> <li>This reduces the hazard by providing an alternative pathway for material away from vulnerable areas.</li> </ul>	<ul style="list-style-type: none"> <li>Modifications to land where new channel would be needed.</li> </ul>	<ul style="list-style-type: none"> <li>Land would need to be acquired.</li> </ul>	<ul style="list-style-type: none"> <li>Affected People</li> <li>Mortality and/or Missing</li> <li>Disruption</li> </ul>

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Category
<b>Deflection berms</b>	<ul style="list-style-type: none"> <li>• Earth or structural berms to deflect potential debris flow away from exposed elements.</li> <li>• These tend to require a large footprint and be constructed on relatively gentle slopes (Porter <i>et al.</i>, 2007), (BGC Engineering Inc., 2010).</li> <li>• This is a common option for debris flow management.</li> </ul>	<ul style="list-style-type: none"> <li>• This reduces the hazard by deflecting material away from vulnerable areas.</li> </ul>	<ul style="list-style-type: none"> <li>• Modification to land where berm would be placed.</li> </ul>	<ul style="list-style-type: none"> <li>• Land would need to be acquired.</li> </ul>	<ul style="list-style-type: none"> <li>• Affected People</li> <li>• Mortality and/or Missing</li> </ul>
<b>Structural Mitigation – Category 3: Dissipating the energy of debris flows</b>					
<b>Debris-restraining structure</b>	<ul style="list-style-type: none"> <li>• Physical nets/geo-grids/stakes can be used to restrain movement of source material.</li> <li>• Large diameter for larger debris.</li> </ul>	<ul style="list-style-type: none"> <li>• Reduces the severity of the hazard by trapping large debris.</li> </ul>	<ul style="list-style-type: none"> <li>• Installed in the channel.</li> </ul>	<ul style="list-style-type: none"> <li>• Sufficient space and access for installation required.</li> </ul>	<ul style="list-style-type: none"> <li>• Affected People</li> <li>• Mortality and/or Missing</li> </ul>
<b>Structural Mitigation – Category 4: Arresting and detaining landslide debris or rock fall</b>					
<b>Debris-resisting barrier</b>	<ul style="list-style-type: none"> <li>• Barrier installed to block the flow of debris.</li> </ul>	<ul style="list-style-type: none"> <li>• Reduces hazard by providing a barrier to downslope flow of material.</li> </ul>	<ul style="list-style-type: none"> <li>• Barrier constructed upstream of vulnerable area.</li> </ul>	<ul style="list-style-type: none"> <li>• Sufficient space and access for installation required.</li> </ul>	<ul style="list-style-type: none"> <li>• Affected People</li> <li>• Mortality and/or Missing</li> </ul>
<b>Debris-flow detention basins</b>	<ul style="list-style-type: none"> <li>• Construction of a debris-flow trap (detention basin) could be considered to contain material flowing down the slope (Porter and Dercole, 2011),(Porter <i>et al.</i>, 2017).</li> </ul>	<ul style="list-style-type: none"> <li>• Reduces the hazard by providing space for the flow material to accumulate.</li> </ul>	<ul style="list-style-type: none"> <li>• Detention basin constructed upstream of vulnerable area.</li> <li>• This option has recently been selected for Cougar Creek, Canmore, at a cost of \$43M.</li> </ul>	<ul style="list-style-type: none"> <li>• Good option for debris flow hazard reduction but can be costly.</li> <li>• Sufficient space and access for construction required.</li> </ul>	<ul style="list-style-type: none"> <li>• Affected People</li> <li>• Mortality and/or Missing</li> </ul>

## 9 Best Practice for Natural Hazard Risk Reduction and Increased Resilience

Natural hazard risk is a challenging issue, especially in an era of changing climate. Best practice hazard management and risk reduction requires a paradigm shift in thinking and management when compared to how natural hazards have been generally managed in Canada. The approach described below works towards a best practice approach, as informed by experience working in a Canadian context.

### 9.1 Plan with Resilience in Mind

Resilience is the ability of a system, community, or society exposed to hazards to **resist, absorb, accommodate, adapt to, transform, and recover from the effects of a hazard** in a timely and efficient manner (UNISDR, no date).

It can be framed around the ability to withstand and bounce back from both acute shocks (natural and human-induced) such as floods, earthquakes, debris flows, wildfires, chemical spills, power outages, as well as chronic stresses occurring over longer time scales, such as increased average temperatures resulting from climate change, or socio-economic issues, such as homelessness and unemployment.

Using resilience as a framework allows for a focus on positive solutions and the end result of a healthy and thriving community, as opposed to a reliance on planning for hazards and risk, which are inherently negative. Further, a resilience framework allows for the consideration of multiple hazards, multiple likelihoods, and a wide variety of impacts, all over multiple time horizons. Resilience is the gold standard for this field, but involves considerable resources, political will, and effort to achieve. In particular, striving for resilience requires foundational effort in the understanding of hazard and risk, which in itself requires considerable effort and resources.

### 9.2 Plan for Risk not Hazard

International best practice in the form of the Sendai Framework, to which the Government of BC is a signatory, and which the CVRD will base its disaster strategy on, provides some guidance on how to mitigate risks and increasing costs associated with natural disasters. A major tenet of this framework is a *risk-based* approach to disaster management, where hazard, vulnerability, likelihood, and consequence all play a role (Figure 41). This is a shift away from how hazards have historically been managed in Canada, where design standards—based on a single hazard, often the 200-year event for flood or a given safety factor for slopes—are the norm.



Figure 42: Components of natural hazard risk (GFDRR, 2016).

Common sense clearly dictates that an understanding of what is at stake (exposure and consequence) should play a role in any hazard planning. To lay the foundation for geohazard management, best practice dictates that you should develop a strong understanding of risk and enable resilience. The CVRD has indeed taken an approach that reflects this best practice with a strong focus on the influence of a changing climate. This section provides background information on best practice for understanding and managing natural hazard risk. This provides a framework for the results and recommendations presented later in this report.

### 9.3 Reduce Risk as Practicable, Manage the Rest

Once a solid understanding of risk is established, it is possible to consider pathways forward. In some cases, it is possible to reduce the risk by managing the hazard, exposure, or vulnerability. However, this often comes at a great cost, and therefore, there are necessary trade-offs that need to be understood (e.g., is reducing the risk worth X number of dollars?). This is often managed through the concept of risk tolerance (sometimes also called a risk threshold), which divides acceptable risk from unacceptable risk. Unacceptable risk can then be reduced through risk reduction measures, and any remaining residual risk can be managed through response, financing, and other such measures. These ideas are further explored in Section 7.

### Forms of Risk Acceptance

**Unacceptable risk** is the level of risk at which, given costs and benefits associated with further risk reduction measures, action is deemed to be warranted at a given point in time.

**Acceptable risk**, or tolerable risk, is the extent to which a disaster risk is deemed acceptable or tolerable, and depends on existing social, economic, political, cultural, technical, and environmental conditions.

**Residual risk** is the disaster risk that remains even when effective disaster risk reduction measures are in place, and for which emergency response and recovery capacities must be maintained. The presence of residual risk implies a continuing need to develop and support effective capacities for emergency services, preparedness, response, and recovery, together with socioeconomic policies, such as safety nets and risk transfer mechanisms, as part of a holistic approach.

## 9.4 Stop Fighting Nature

The approach to dealing with natural hazards has evolved with time. During the International Decade of Natural Disaster Risk Reduction, the UN expressed the view that the approach to disaster management was too compartmentalized, and that protection and defences in isolation was no longer appropriate (Office of the United Nations Disaster Relief Coordinator, 1991). Complete protection from natural hazards through the construction of dams and debris flow barriers, for example, is often too expensive for many areas and also an inefficient use of resources. Several jurisdictions in Canada have opted to implement large-scale structural measures with a combination of municipal funds and contributions from senior levels of government. The Town of Canmore, for example, is constructing a debris dam that will retain over seven times the volume of the peak 2013 event for a total of \$48 million. These kinds of decisions are a matter of priorities; when large sums are spent on one watershed, it means there is less to be spent in other areas.

## 9.5 Embrace Uncertainty

There are multiple sources of uncertainty associated with the future frequency and severity of debris flows and associated damages. These include climate change, but also future resource extraction and land development in terms of changes to slopes through logging and road construction, as well as future community development.

Climate is changing—this fact is known. However, the rate of change in the region is not clear (see Section 2.3). This is best managed by acknowledging the uncertainty, and then explicitly designing for it. If a structural response is implemented, it should be designed to change over time and build in co-benefits if possible. Furthermore, all responses should be designed with the idea of “safe failure” and multiple benefits, so that even if the infrastructure does not function for its initial purpose, it continues to provide value to the community. Finally, if considering uncertainty as a key component of design, the clearest way to reduce risk is to reduce exposure, which is an effective measure across all levels of hazard.

## 9.6 Make Good Decisions Based on More than Dollars and Cents

Risk reduction measures need to be cost effective, however, making sound decisions needs to be based on more than just the price tag. First of all, plans implemented in the near future can reap savings many times the initial cost as people and industry are protected from losses in the future. For example, often geohazard studies will only consider direct impacts of mass movement, indicating the overlap between the hazard area and houses, for example. However, considering the impact of a road closure, or the interruption of power supply due to these events, is important for both more effective response planning, as well as prioritizing the protection of key assets. Often these indirect impacts are intangible and cannot be monetized—traditional cost-benefit approaches will fail. And therefore, robust decision processes that explicitly consider timelines, trade-offs, and the multiple characteristics of risk are key to success (additional information on the application of this to the CVRD is presented in Section 7).

## 9.7 Consider Governance and Financing

It is common sense that without the ability to implement mitigation or management concepts for disaster risk reduction, risk will not be reduced. And therefore, in addition to addressing the more technical aspects of risk and risk reduction (such as a risk assessment), it is equally important to consider governance, finance, and policy mechanisms that can be used to implement solutions.

### 9.7.1 Strengthen Disaster Risk Governance

It is important to have a strategy that is strongly rooted in risk science, but that also reflects an understanding of the need for strengthened disaster risk governance. There are many challenges associated with creating appropriate governance models, especially for local governments, who generally lack resources. The CVRD is well positioned to take a leadership role in bringing together partners to create a governance framework to support disaster risk reduction; the region has come together before to manage natural resource issues through agencies like the Cowichan Watershed Board. A similar platform could be created to convene stakeholders from the public sector, private sector, non-governmental organizations, and institutions to ignite discussions and chart a collaborative path forwards to increasing community resilience.

### 9.7.2 Investing for Resilience and Enhancing Preparedness

Without funds to invest in risk reduction and resilience, there will be no action. At a local government level, it is challenging to find appropriate funding and resources to support meaningful risk reduction. Large investments are generally in the domain of senior level governments, but local governments can play a role through advocacy. Further, there is a role for local governments to act as an intermediary between insurers and individuals within their jurisdiction.

## 9.8 Timeline of Geohazard Risk Policy Development in Hong Kong

The example of policy development in Hong Kong is included here because they were one of the first places to implement risk tolerance-based standards for geohazards, specifically landslides. This hazard is similar to the hazards analyzed in the project area, except that the landslides on the north slope of Lake Cowichan are primarily channelized.

The development of this policy is well documented in a paper by Malone (2005), which describes the evolution in Hong Kong from the slope stability agency in response to high mortality events in the early 1970s to full implementation of quantitative risk assessment and the use of risk tolerance criteria. A timeline of these events is presented in Figure 42.

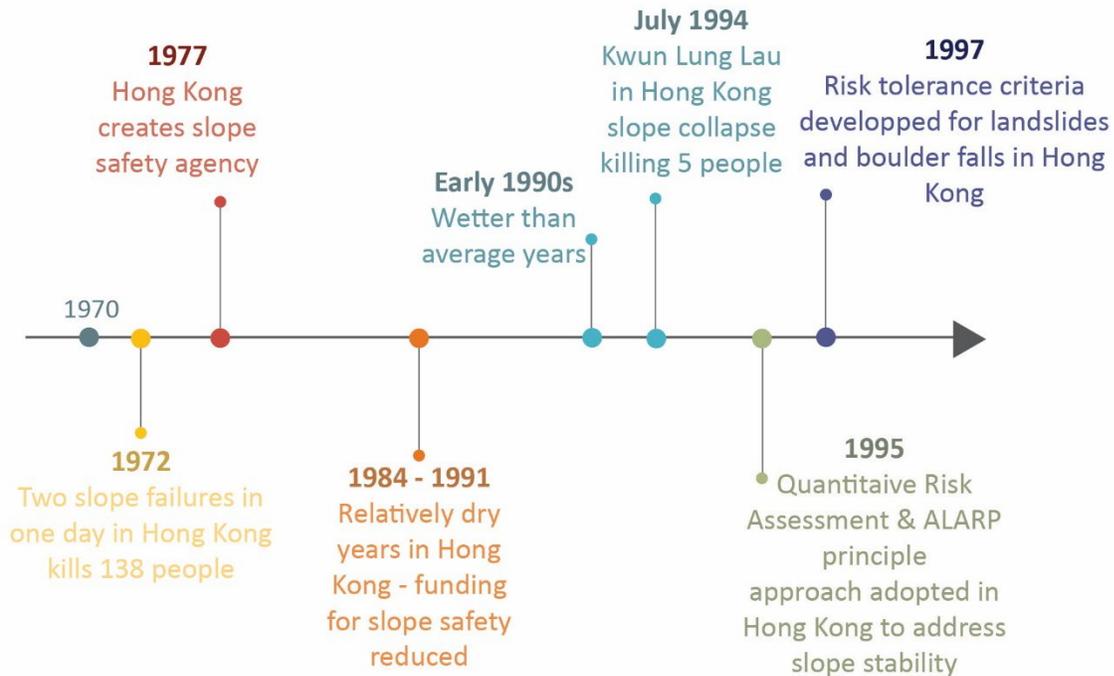


Figure 43: Timeline of policy development for landslide hazard in Hong Kong (Adapted from (Malone, 2005)).

What is interesting about the evolution of this policy is that it highlights what some of the triggers tend to be, namely highly damaging or high-mortality events. It also highlights that during dry years with no or few events, landslide hazards can fall out of the public consciousness and not be seen as a problem. As the paper mentions, it is important to plan for the wet years, because the wet years will come.

### 9.9 CVRD Baseline for Hazards Management

With the launch of the "[New Normal](#)" program, the CVRD has already started to address exactly this. This program considers the new normal conditions for natural hazards, including flood, drought, heat, and now also debris flow (CVRD, 2018). Indeed, the CVRD is following international best practice by adopting a risk-based approach (including studies of hazard, as well as vulnerability) with considerations of climate. This approach of understanding risk and then building governance capacity is in line with the Sendai Framework (Sendai), the international agreement for Disaster Risk Reduction (UNISDR, 2015).

The CVRD has shown leadership through their willingness to work through a best practice approach as opposed to a reliance solely on engineered and reactive measures for geohazard mitigation, which are prone to fail in the long term and are often not resilient to a changing climate. This will not only create a more resilient community in the long term, but it also creates opportunity for senior-level government

funding to support geohazard mitigation by aligning the outcomes and direction of this project with senior-level government policy direction.

### 9.10 Summary

Natural hazard management is an inherently challenging problem. There are clear pathways to reduce disaster risk or manage residual risk, including:

- Improving the base understanding of risk, which is being achieved for this area, through this project.
- Creating appropriate governance and policy to support disaster risk reduction.
- Financing actions.
- Pre-disaster planning for building back better.

Progress along these pathways is challenging and is generally achieved after a disaster has occurred (as in Hong Kong and the District of North Vancouver). However, the steps taken to date have placed the CVRD in an enviable position to reduce their risk to natural hazards.

## 10 Conclusions and Recommendations

The results of the geohazard risk assessment for the north slope of Cowichan Lake highlight that there are significant risks. Acknowledging and understanding these risks is a first and important step in reducing and managing these risks in the future. Reducing risks from geohazards in the project area will not be a quick or easy task, but will require a long-term strategic approach to the problem. However, there are some actions that can be taken immediately to support disaster risk reduction in the project area.

The following section outlines a series of recommendations. These include specific recommendations arising from the technical analyses presented in this report. These are followed by recommendations to support a broader strategic approach to disaster risk reduction. Finally, recommendations related to improving and refining the methods applied in this report are presented.

### 10.1 High Priority Action

High priority actions were identified through the technical and policy analysis. Of utmost importance is the need to address the **risk to life**. First, the CVRD should consider disclosing the level of hazard and risk to those that are most affected (i.e., homeowners in the highest hazard zones). Then, with the support of the broader disaster risk reduction strategy and the development of risk thresholds, the CVRD can consider means to reduce the risk. The most effective means to reduce the risk will be to retreat from the highest hazard areas—this will require a strong will on the part of CVRD leadership. In the interim, the CVRD can support homeowners to reduce their risk through simple actions—for example, by moving sleeping quarters to the safest part of the house and by understanding when risk is highest temporally (e.g., after wet periods followed by intense rainfall).

### 10.2 Quick Wins and No-Regrets Actions

Many geohazard mitigation planning strategies take time and/or money to implement; this is clear from the many ideas and concepts presented above. There are however some no-regrets actions that can be taken by the CVRD immediately. This will serve to reduce risk and also ensure that momentum built throughout this process is not lost.

- **Continue to promote education and preparedness.** The CVRD should continue to provide updates to stakeholders and residents on their efforts to act on geohazard mitigation planning. This will likely be focused first on stakeholders as the process of developing risk tolerances moves forward. There are advantages to engaging the public early and seeking input to ground any future policy within the local community.
- **Develop and nurture connections with partners.** Working with local partners, such as forestry companies and land developers, will help make the implementation of future policies smoother. Both of these groups have an effect on geohazard risk—forestry activities can increase the severity of the hazard and developers may add additional exposure to areas.
- **Avoid any increase in geohazard risk.** The CVRD should consider a policy statement that they will avoid increasing geohazard risk, specifically by zoning or providing development guidance for

areas that are in the currently recognized hazard area. This also may be applied to the use of land—for forestry or other types of development—upslope from vulnerable areas.

### 10.3 Framework for Building Resilience

The goal of this project was to characterize geohazard risk for the project area to provide an example of what this risk looks like and how it is expected to change over time with climate change. Ultimately, the goal for the CVRD is to build resilience to natural hazards in the region for local communities—now and into the future.

This is very much in line with international goals for disaster risk reduction and best practice. In an effort to support communities that are building resilience to disasters, the United Nations Office for Disaster Risk Reduction has outlined “[Ten Essentials for Making Cities Resilient](#)”, which is an operational framework for implementing the Sendai Framework at a local level. While the ten essentials are framed for cities, they are relevant to the CVRD and smaller communities as well. They provide an excellent framework for long-term strategic planning for disaster risk reduction and are presented here to guide the CVRD in their efforts to develop a Disaster Risk Reduction Strategy for the region.

The ten essentials are summarized in the following sections. As can be seen in Figure 43, these essentials for resilience include actions that fall into three general categories (1) corporate/city/local governance, (2) integrated planning, and (3) response planning.

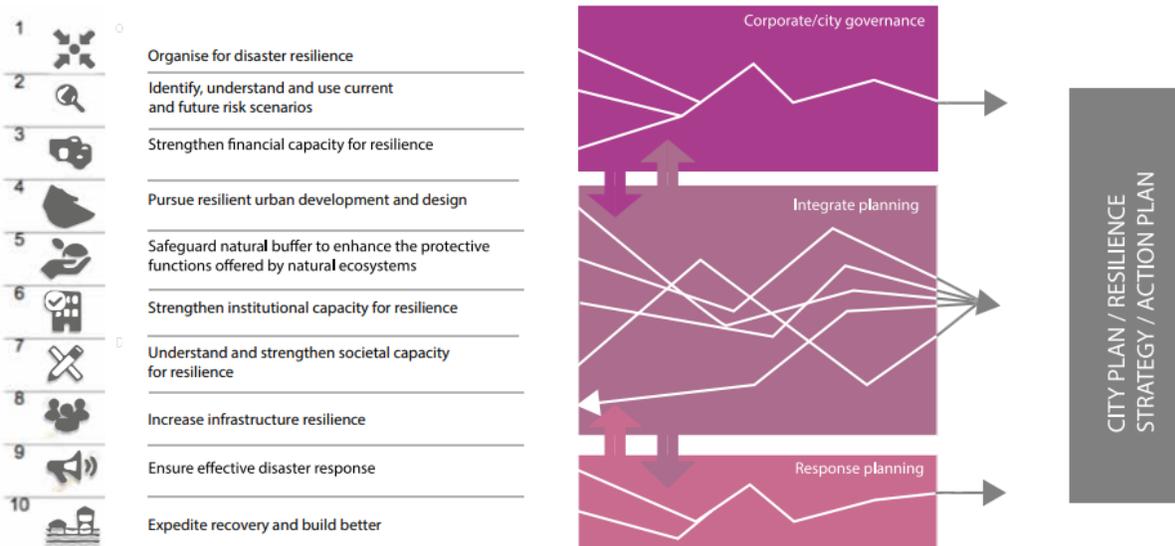


Figure 44: Ten essentials for making cities disaster resilient (United Nations Office for Disaster Risk Reduction, 2017).

### 10.3.1 Organize for Disaster Resilience (Essential 1)

*"Put in place an organizational structure and identify the necessary processes to understand and act on reducing exposure, its impact and vulnerability to disasters."*

<b>Progress</b>	The CVRD has recognized that natural hazard risk is an important issue. This may support buy-in for the development of a resilience strategy.
<b>Next Steps</b>	<p>Ultimately, the CVRD should consider developing a resilience strategy that considers all aspects of disaster risk reduction and management focused on understanding the existing policies, governance structure, and understanding of risk, and the gaps to achieving progress. Some key obstacles to this are political buy-in and funding—these are further discussed below.</p> <p>Of particular consideration is the involvement of the local First Nations in this process. A concerted effort should be made to engage and involve local First Nation leaders in any governance models.</p> <p>In summary, the CVRD currently has policy to support natural hazard risk management. The challenge that is presented by the current policies is the potential for inconsistency by relying on individual (and potentially different) professional opinions. The professional reliance model can also create a resource challenge for CVRD staff, who require time and expertise to review and approve professional reports. Streamlining this process by providing base information (such as the work within this report) and a consistent approach to risk reduction (by setting target thresholds for example) would improve natural hazard risk, consistency, and staff resources.</p>

### 10.3.2 Identify, Understand, and Use Current and Future Risk Scenarios (Essential 2)

*"(Local governments) should identify and understand their risk, including hazards, exposure and vulnerabilities, and use this knowledge to inform decision making."*

<b>Progress</b>	The CVRD has made significant progress on this through the completion of the geohazard risk assessment project, along with parallel pilot projects in the region.
<b>Next Steps</b>	<p>Currently, the CVRD is working on several case studies to inform regional policy on climate adaptation and mitigation and natural hazard risk reduction.</p> <p>The CVRD should consider reviewing methods and results from each of the pilot assessments to support the development of future risk assessments in the region. Further, the CVRD should consider aggregating the existing risk assessments, to better understand the overall risk in the region, and to better understand the relative risk</p>

	<p>spatially and by hazard. This effort will allow for more targeted efforts to reduce risk and will allow for the CVRD to develop consistent policies.</p> <p>The CVRD should continue to incorporate best available knowledge of the effects of climate change on natural hazards and risk on the communities it serves, its assets, and its systems.</p> <p>This assessment covered a relatively small project area. The CVRD is home to slopes of different configurations, gradients, and with diverse geology. The defined project area is meant to be an example area to support policy development for geohazard risk across the CVRD and not representative of all geohazard types. This assessment could be expanded in the future to look at the whole CVRD.</p>
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**10.3.3 Strengthen Financial Capacity for Resilience (Essential 3)**

*"Understand the economic impact of disasters and the need for investment in resilience. Identify and develop financial mechanisms that can support resilience activities."*

<b>Progress</b>	<p>This project, along with the parallel pilot projects, has created a base understanding of the economic risks associated with natural hazards. Further, the outcomes of this project (e.g., the RAIT form) should support the CVRD to leverage future funds from senior level governments and build new relationships with other stakeholders, such as financial institutions and insurers.</p>
<b>Next Steps</b>	<p>The CVRD should continue to pursue funding from senior level governments, using the base understanding of risk and potentially return-on-investment (ROI) calculations to support funding requests. Further, the CVRD should consider looking into alternate mechanisms to fund resilience (e.g., insurance, disaster bonds, etc.). This will likely be achieved through a targeted project to look at finance mechanisms for disaster resilience; this is an emerging field with possibilities, but one that currently lacks clear and simple guidance.</p>

**10.3.4 Pursue Resilient Urban Development and Design (Essential 4)**

*"The built environment needs to be assessed and made resilient as applicable, informed by risk identified in previous studies."*

<b>Progress</b>	<p>For geohazard, this has not yet explicitly been considered in CVRD land use and planning policy, nor in corporate decision-making documents.</p>
<b>Next Steps</b>	<p>In the case of geohazard, this mostly means getting out of the way. Some changes to infrastructure can be made, however, to reduce the severity of the hazard. For example, road crossings over debris flow-prone creeks should have sufficient capacity to transport expected volumes so that these do not build up behind the crossing.</p>

	<p>Consideration of the hazard (using information in this report), along with the risk, should guide all future infrastructure projects in the region (i.e., through design specifications).</p> <p>The information in this report (along with any risk tolerance policy) should be used by Building Inspectors to support decisions and help land owners understand their specific hazard and risks. For example, the report can be used to support siting of infrastructure at a lot-level or larger scale.</p>
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### 10.3.5 Safeguard Natural Buffers to Enhance Ecosystems' Protective Functions (Essential 5)

*"Safeguard natural buffers to enhance the protective functions offered by natural ecosystems. Identify, protect and monitor critical ecosystems services that confer a disaster resilience benefit."*

<b>Progress</b>	<p>The CVRD is well known for being an active steward in the management of its natural areas (e.g., through the State of the Environment Reports), and this has undoubtedly limited some of the potential hazards and risks in the region. However, there is more that could be done, especially when considering others with land tenure in the region.</p>
<b>Next Steps</b>	<p>For geohazard in the CVRD, this is mostly related to forestry and its activities up the slopes. Deforestation and construction of roads due to forestry are a primary driver of the increased frequency of debris flows—this is even greater than projected changes due to climate change. This is effectively a great opportunity for the CVRD, as there is potentially a means of controlling hazard levels by working collaboratively with partners, such as the forestry companies. Maintaining intact and healthy forests now and into the future could help to offset the expected increase in hazard events due to climate change. For example, to avoid any unnecessary increase in likelihood of geohazards from landscape changes, the CVRD could support a motion at the Union of BC Municipalities (UBCM) to update the <i>Private Managed Forest Land Act</i> [2003] to include natural hazards. It may also be possible to leverage the <i>Water Sustainability Act</i> [2018] to increase management of hazard lands in resource areas surrounding at-risk communities. Similarly, the ideas presented here could be integrated in emerging CVRD watershed management strategies.</p> <p>Staying out of the way of the hazard and leaving space for flows and fans will reduce risk over the long term, and so using available tools to buffer development from riparian areas will also reduce risk.</p>

**10.3.6 Strengthen Institutional Capacity for Resilience (Essential 6)**

*"It is important to ensure that all institutions relevant to a (local government's) resilience have the capabilities they need to discharge their roles."*

<b>Progress</b>	Throughout this project there were several touchpoints with CVRD staff on the complex issues of geohazard risk and resilience. This should have increased the institutional understanding of the problem.
<b>Next Steps</b>	<p>With this project and the other case studies complete, the results should be communicated widely amongst local stakeholders. The institutions that are relevant to the CVRD's resilience should be identified and a conversation should be facilitated around what those institutions and staff need to support resilience building. This will also require the buy-in of senior staff and elected officials, as they have control over mandates and roles. The results of the risk assessment work can be used to increase buy-in; the level of risk is moderate to high, and it is imperative that actions are taken to reduce it.</p> <p>One means of achieving this would be to undertake workshops with community planners and others as a forum for information sharing and the exploration of options for resiliency planning frameworks going forward, response options, and land use planning responses.</p>

**10.3.7 Understand and Strengthen Societal Capacity for Resilience (Essential 7)**

*"Ensure understanding and strengthening of societal capacity for resilience. Cultivate an environment for social connectedness which promotes a culture of mutual help through recognition of the role of cultural heritage and education in disaster risk reduction."*

<b>Progress</b>	The CVRD has already started to engage the public on the topic of climate change with the "New Normal Cowichan" program, which looks at drought, flooding, and water issues in the Cowichan Valley.
<b>Next Steps</b>	<p>Some of the lessons learned from past efforts with the New Normal program should be used to enhance the program with information on geohazards or launch a new initiative for natural hazards disaster risk reduction.</p> <p>Consider interdisciplinary approaches to community-based risk tolerance and reduction activities.</p>

### 10.3.8 Increase Infrastructure Resilience (Essential 8)

*"Assess the capacity and adequacy of, as well as linkages between, critical infrastructure systems and upgrade these as necessary according to risk identified in previous studies."*

<b>Progress</b>	<p>This project considered the impacts of geohazards on roads, creek crossings, power infrastructure, and water infrastructure.</p> <p>The CVRD has also recently completed climate-based risk assessments of its assets, as a component of its integrated asset management strategy.</p>
<b>Next Steps</b>	<p>The resilience of infrastructure can be enhanced in many ways, including improving the redundancy, flexibility, and robustness of infrastructure elements, taking into account both direct and indirect impacts and the interdependencies of systems.</p> <p>A CVRD-wide systems analysis could help to inform decision-making for infrastructure owners and operators, and would support working towards this goal. This would involve including departments internal to the CVRD, as well as external entities, such as BC Hydro and the Province (e.g., Ministry of Transportation and Infrastructure).</p> <p>In addition, if opportunities present themselves to collaborate with other local and regional governments on Vancouver Island to increase infrastructure resilience through coordination or shared studies, they should be seized and encouraged.</p>

### 10.3.9 Ensure Effective Disaster Response (Essential 9)

*"Ensure the creation and updating of disaster response plans are informed by risks identified by and communicated to all stakeholders through use of organizational structure."*

<b>Progress</b>	<p>This project engaged local stakeholders responsible for disaster response through workshops 1 and 2. This included members of the RCMP and Ambulance Services.</p>
<b>Next Steps</b>	<p>With the information from this project and other parallel risk assessments, disaster response plans should be reviewed and updated. Consider providing updated information to the CVRD's interagency Emergency Management Team to continue to build capacity and response playbooks.</p> <p>Updated and well-conceived emergency preparedness and response plans will help to lessen the impacts of hazards on local communities.</p> <p>Activities may include regularly updating plans, communicating the plan to all stakeholders, and guidelines or regulations regarding preparedness.</p> <p>Early warning systems can help in this endeavour as they provide information that can tie in with activating different aspects of a response plan.</p>

**10.3.10 Expedite Recovery and Build Back Better (Essential 10)**

*"Ensure of sufficient pre-disaster plans according to risks identified and that after any disaster, the needs of the affected are at the centre of recovery and reconstruction, with their support to design and implement rebuilding."*

<b>Progress</b>	At this time there is limited progress in this area, however there is definitely appetite for this as evidenced by the results of stakeholder workshops (see Section 7.2).
<b>Next Steps</b>	<p>Expediting recovery and building back better presents an opportunity when a hazard event does occur.</p> <p>There may be a tension between rebuilding quickly and rebuilding as safely and sustainably as possible. In addition, following a disaster there is often heightened political pressure to be reactive and show that something is being done, whether or not that is the best thing to do for the community in the long term.</p> <p>Having plans and strategies in place ahead of time can help to avoid these kinds of reactive mistakes and ensure that when something does happen, some thought has already been given to how best to respond.</p>

**10.4 Additional Ideas to Support Disaster Resilience**

The framework provided by the UNISDR provides an excellent base for evaluating existing progress and future efforts to improve resilience. However, it is new, and was developed to be applied generically across the world for all hazards. As a result, some additional ideas, as presented in Section 3.0, should also be considered. **Specifically, a decision-process to reduce and/or manage risk, needs to be developed. Ideally this would be supported by an understanding of risk tolerances and thresholds.** A risk threshold–type decision process has been applied previously in BC—in the District of North Vancouver for landslides and in the City of Vancouver for coastal flooding under climate change. Some lessons from these that could be used by the CVRD are presented here. It should be noted that the CVRD has already begun the process of understanding risk tolerances and thresholds in the region through a parallel project that should be completed in March 2019.

**10.4.1 Structured Decision Making**

As outlined at the outset of this project, the CVRD and its stakeholders, do not necessarily want elaborate geohazard-control infrastructure, they want safe and prosperous places to live and work. Identifying what success looks like for the community will enable the CVRD to better make decisions about geohazard mitigation options.

The obstacles to making progress on disaster risk reduction as outlined earlier in this report, pose a challenge to decision makers. One approach that is recommended based on success in other nearby jurisdictions, and that has been applied in the CVRD to other natural resource issues, is Structured Decision Making (SDM). This is a deliberative planning process where trade-offs between alternatives

are explicitly considered. This is particularly effective for problems where tough, values-based decisions will need to be made given available (likely limited) resources. The SDM process involves engaging stakeholders throughout the process to identify objectives (“the things that matter”); progress towards this has already been achieved through the outcomes of the workshops conducted for this project (see Section 7). Once the objectives have been defined, alternative solutions can be evaluated against the objectives. The advantage of an SDM process is that it makes the trade-offs between alternatives explicit, and strives to create the best possible alternative.

The stakeholder values identified in this project (see Section 7.2) along with an understanding of what types of impacts and values can be measured (e.g., the results of the risk assessment—see Section 4) can form the basis of future measures of success. For example, community members expressed concerns about important facilities and businesses having sufficient back-up power. A measure of success might be that services identified as being critical have a pre-defined amount of back-up power available. This type of measure can then be used in later steps to evaluate geohazard mitigation options.

This has been an effective decision process for other natural hazard projects in the CVRD, but does have the drawback of being resource intensive. Risk tolerances can be used within this framework, and some thoughts on this are provided below.

#### 10.4.2 Process of Getting to Risk Tolerance

The best practice material and the general recommendations above highlight the value in understanding regional risk tolerances. The CVRD should consider developing a corporate risk tolerance policy framework that will guide the organizations’ policies, as well as informing investments in mitigative actions based on community values.

However, establishing risk tolerance to natural hazards is a challenging process. This is because the problem is complex, but also because everyone will have different tolerances based on their experience, knowledge, and other diverse factors. These are reflective of personal risk tolerance and decisions we make every day. In our daily lives some of us are comfortable with certain risks (skiing or cycling in traffic, for example) and some of us are not. In addition, there are a variety of processes that can be employed to develop risk tolerances that can also be used to develop policy.

To develop risk tolerances for policy development, it is best to engage a broad audience, allow for sufficient time for the key concepts to be understood, and make sure that the questions being asked are put into context. Some examples were provided in the workshop 2 starting with everyday hazards. Participants were encouraged to think about daily activities that can be hazardous (e.g., crossing a street, driving a car) and think about their tolerance to those activities. Similarly, they were then asked to think about how often they would tolerate a major road in the community being blocked by debris flow. As expected, there was a diversity of opinion, with some participants tolerating the road being blocked every year and some only every 5 years, for example. This diversity of personal tolerance needs to be managed as part of the risk tolerance elicitation process.

## 10.5 Refinement of Technical Assessment

The technical risk assessment was completed based on currently understood best practice for natural hazard risk assessment and is considered robust. However, due to resource, data, or methodological limitations, it would be possible to improve the risk assessment in the future. Potential improvements include:

- Agent-based modelling (consideration of true population and individual behaviour) to estimate risk to people (mortality and/or missing).
- Refinement of damage estimates with a better understanding of the built form of individual structures and recent developments in vulnerability curves for debris flows (Papathoma-Köhle *et al.*, 2017).
- The disruption indicator could be improved with consideration of infrastructure other than roads, and with consideration of time. Further, secondary and cascading impacts would improve the overall understanding of critical infrastructure risk and interdependencies.
- A further potential refinement to the disruption methods would be to do some geographical analysis to further explore potential redundancies in the system (e.g., where there are more than two ways to access a given property). This could be done at a fine scale (to cadastral lots), but also at a regional scale with consideration of access to the larger project area using private roads. This would also support emergency planning.
- The environmental and cultural indicators are weak. It would be possible to improve these by eliciting expert opinion from the community. The AIDR has an excellent resource to support expert elicitation for scoring of environmental risks (see Table 6, page 62 of (Australian Institute for Disaster Resilience, 2015)).

## 11 Closing

The CVRD faces significant hazard due to geohazard and risk in the project area and seeks to reduce this risk to the community. This project, along with work previously conducted by the CVRD, lays the groundwork for a geohazard mitigation plan. This is in addition to many specific gains in understanding geohazard risk in the community, and the development of deliverables that will support future work.

Five specific project objectives were evolved to support the CVRD's needs. These have been addressed through this project as summarized below.

**Better understand hazard, vulnerability, and risk.** This project provides an assessment of geohazard in the project area with a focus on debris flow. Further, this project collected and analyzed multiple datasets of vulnerability and exposure information, and provides both a summary understanding of risk (for multiple impact categories), as well as a spatial understanding of where the greatest geohazard risks are found in the community. Finally, some factors that may change the hazard, such as climate and forestry, are discussed. Future development will also affect the level of risk, as this will affect exposure and vulnerability.

**Inform active and future planning.** This project provided numerous recommendations to support immediate and long-term strategic planning at the CVRD. In particular, notes are provided on next steps for the CVRD given a proposed disaster risk reduction framework.

**Lay a foundation for future funding.** As a component of this project, appropriate materials, including two types of risk assessment, have been provided. This provides a solid base of information for the CVRD to apply to various funding programs including the NDMP, the CEPF, and the DMAF.

**Prepare a foundation for mitigation planning.** In addition to the base information collected, analyzed, and reported in this document, we have provided a long-list of mitigation options for the north slope of Cowichan Lake. These should be considered as options and refined as plans move forward.

**Lay a foundation for stakeholder engagement and risk tolerance development.** Throughout the course of this project, several efforts were made to connect with stakeholders. The CVRD should continue to engage a broad group of stakeholders as it moves its plans forward and develops *disaster risk reduction policies and strategies*.

The CVRD is taking a proactive approach to understanding natural hazard risk in a changing climate. This approach is in line with the priorities of the Sendai Framework for Disaster Risk Reduction, which the Government of BC has recently adopted. In addition, the CVRD plans to implement geohazard management best practice by following in the footsteps of other Canadian and international jurisdictions to implement risk tolerance-based policy. With this assessment, the CVRD is now well placed to move these plans and policy development forward—in an integrated fashion, including modernized land use planning policies, climate adaptation, appropriate disaster risk and response planning, and supportive infrastructure strategies.

## 12 Glossary

Term	Definition	Source
All Hazards	Referring to the entire spectrum of hazards, whether they are natural or human-induced. Note: For example, hazards can stem from geological events, industrial accidents, national security events, or cyber events.	PSC
All-Hazards Approach	An emergency management approach that recognizes that the actions required to mitigate the effects of emergencies are essentially the same, irrespective of the nature of the incident, thereby permitting an optimization of planning, response, and support resources.	PSC
Annual Exceedance Probability (AEP)	The probability of an event of a given magnitude occurring in any given year, expressed as a percentage.	
Asset-At-Risk	Refers to those things that may be harmed by hazard (e.g., people, houses, buildings, or the environment).	RIBA
Asset Inventory or Database	An inventory of assets-at-risk, including the location, and sometimes vulnerability or resiliency measures.	
Critical Infrastructure (CI)	Processes, systems, facilities, technologies, networks, assets, and services essential to the health, safety, security, or economic well-being of Canadians and the effective functioning of government.  The ten CI sectors in Canada are: Health; Food; Finance; Water; Information and Communication Technology; Safety; Energy and Utilities; Manufacturing; Government; Transportation.	PSC
(Asset) Encounter Probability	The probability that an asset will be affected by a hazard of a given magnitude in a given time period.	
(Landslide) Encounter Probability	The probability that any given area will be affected by a landslide over a given time period.	
Exposure	A measure of the amount of a structure, life, or other asset-at-risk that could be impacted by a potential hazard. Example: parts or all of houses, schools, and livestock in a geohazard area are exposed to a potential geohazard.	
Flood	Overflowing of water onto land that is normally dry. It may be caused by overtopping or breach of banks or defenses, inadequate or slow drainage of rainfall, underlying groundwater levels, or blocked drains and sewers. It presents a risk only when people and human assets are present in the area where it floods.	RIBA
Frequency	The number of occurrences of an event in a defined period of time.	PSC
Geohazard	A hazard of natural geological or meteorological origin (i.e., this does not include biological hazards).	

Hazard	A potentially damaging physical event, phenomenon, or human activity that may cause the loss of life, injury, property damage, social and economic disruption, or environmental degradation. Hazards can include latent conditions that may represent future threats, and can have different origins: natural (geological, hydrometeorological, and biological) or be induced by human processes. Hazards can be single, sequential, or combined in their origin and effects. Each hazard is characterized by its location, intensity, frequency, and probability.	UNISDR
Hazard Assessment	Acquiring knowledge of the nature, extent, intensity, frequency, and probability of a hazard occurring.	MODIFIED NDMP TO MATCH HAZARD
Hazard Inventory or Database	An inventory of the location, nature, and extent of influence of any potential hazards in an area of concern. Generally compiled as a GIS database.	NDMP TEAM
(Natural) Hazard	Natural process or phenomenon that may cause loss of life, injury, other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.	UNISDR
Likelihood	A general concept relating to the chance of an event occurring. Likelihood is generally expressed as a probability or a frequency of a hazard of a given magnitude or severity occurring or being exceeded in any given year. It is based on the average frequency estimated, measured, or extrapolated from records over a large number of years, and is usually expressed as the chance of a particular hazard magnitude being exceeded in any one year.	RIBA
Melton Ratios	A metric based on watershed area and relief used to differentiate watersheds prone to clearwater flooding from those subject to debris flows and floods.	
Mitigation	This report was written primarily with a disaster risk reduction lens and has adopted standard terminology from this field. Mitigation, in this case, relates to strategies or measures that are used to directly reduce natural hazard impacts or risk. Whereas, mitigation is often used in climate adaptation literature to refer to local or global efforts to reduce greenhouse gas emissions.	
Morphometrics	Morphometrics describes measures of the shape or form of the watershed.	
Paraglacial	Paraglacial describes the period after deglaciation, when unstable conditions can occur.	
Probability	In statistics, a measure of the chance of an event or an incident happening. This is directly related to <i>likelihood</i> .	PSC
Quantitative Risk Assessment	A <i>risk assessment</i> that is completed using quantified or calculated measures of risk.	

Relief Ratios	Relief ratios are a measure of the watershed characteristics and describe the grade of a stream channel.	
Resilience	The ability of a system, community, or society exposed to hazards to resist, absorb, accommodate, and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.	UNISDR
Risk	The combination of the probability of an event and its negative consequences.	UNISDR
Risk Assessment	<p>A methodology to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods, and the environment on which they depend.</p> <p>Risk assessments (and associated risk mapping) include: a review of the technical characteristics of hazards, such as their location, intensity, frequency, and probability; the analysis of exposure and vulnerability, including the physical, social, health, economic, and environmental dimensions; and the evaluation of the effectiveness of prevailing and alternative coping capacities, with respect to likely risk scenarios. This series of activities is sometimes known as a risk analysis process.</p>	UNISDR
Risk Management	The systematic approach and practice of managing uncertainty to minimize potential harm and loss.	UNISDR
Vulnerability	The characteristics and circumstances of a community, system, or asset that make it susceptible to the damaging effects of a hazard.	UNISDR

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