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

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Date	**12-June-2020**
Summary of changes	

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:

- All figures showing mapped consequences have been re-issued with a new hazard scores.
- All likelihood scoring tables have been adjusted to reflect new scoring.
- All risk matrices have been adjusted to reflect new hazard scores.
- Risk scores have been adjusted downwards in tables and in text.

Notwithstanding the reduction in hazard and risk scores, the original report conclusions and recommendations remain valid.

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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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^2 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.

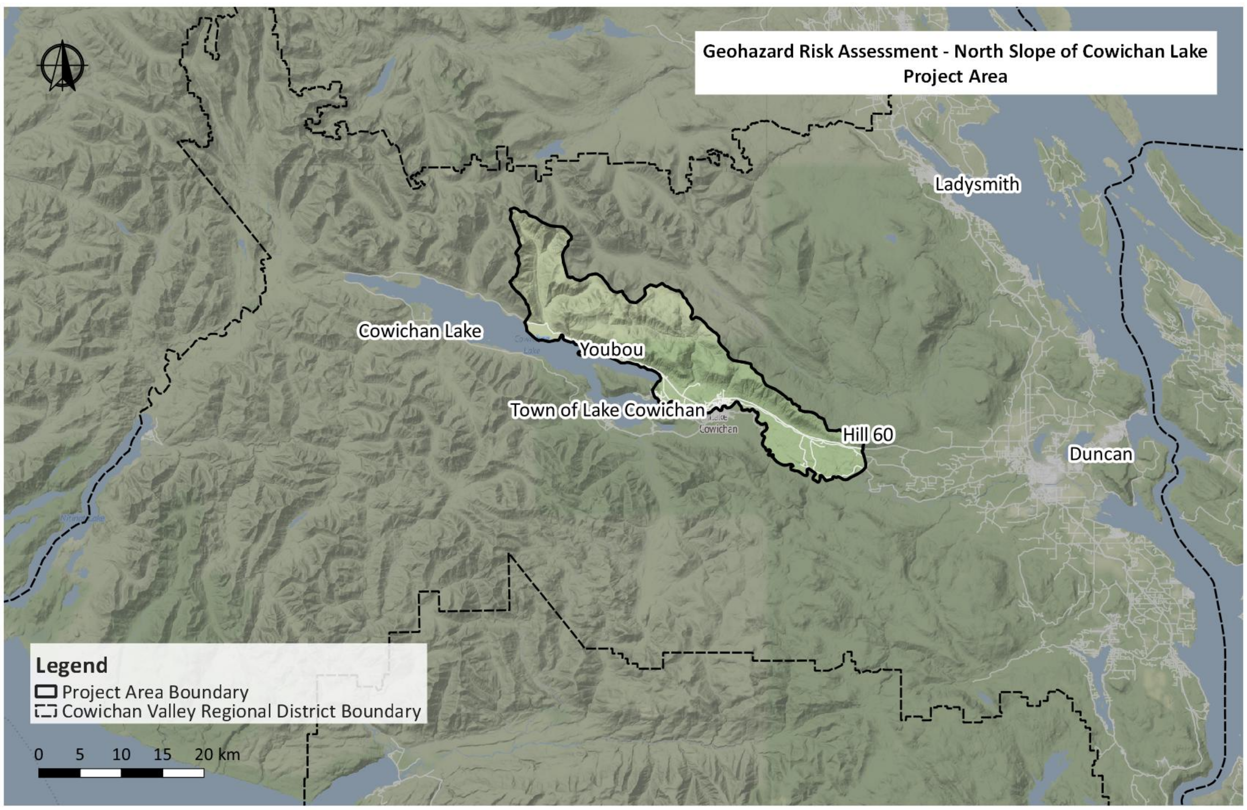


Figure 1: CVRD boundary and project area along the north slope of Cowichan Lake.

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).

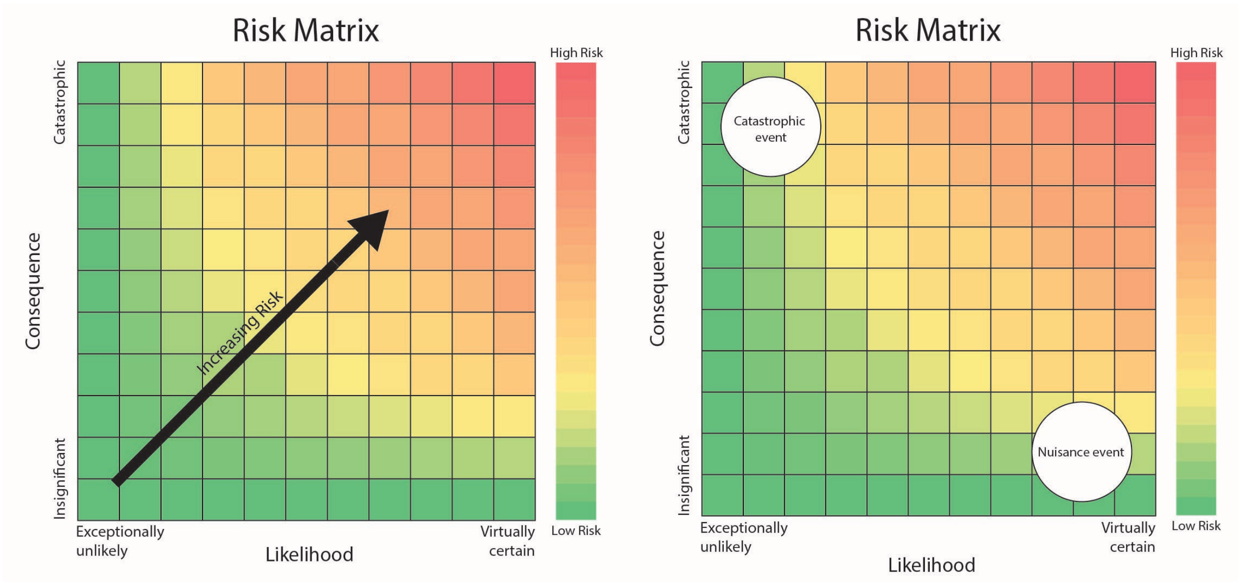


Figure 2: Risk as a function of likelihood and consequence – nuisance and catastrophic risk.

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).

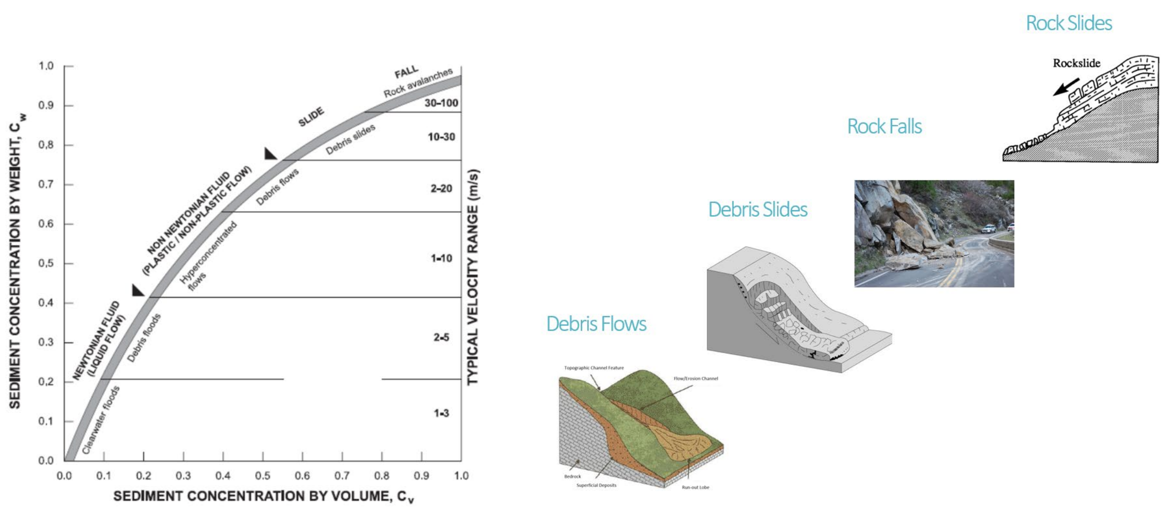
Finally, methods were derived from recent consultant experience completing natural hazard risk assessments for other communities (also under the NDMP). Over time, these have evolved based on experience and data availability. The methods applied to this project all consider forthcoming guidance on natural 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.

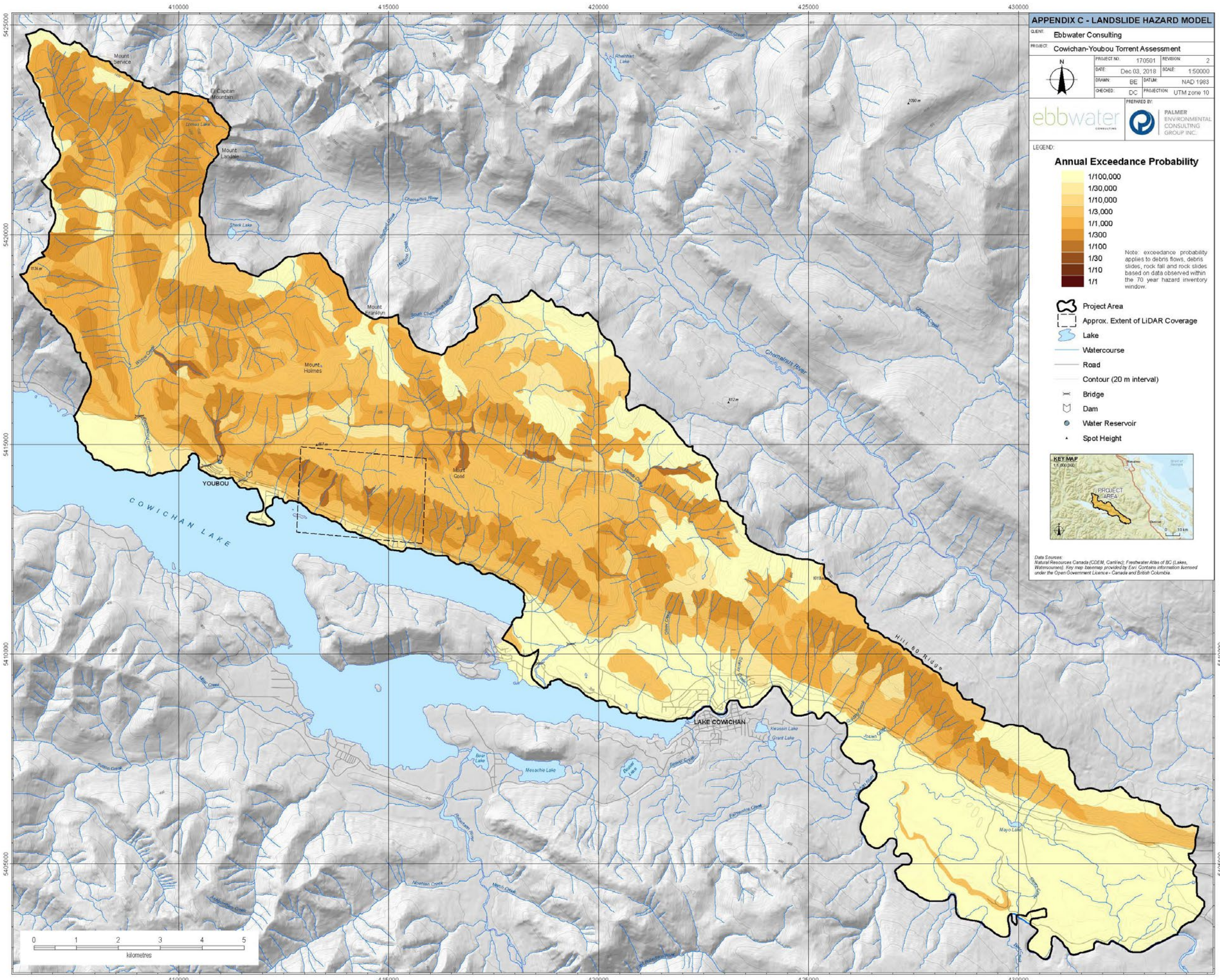


Figure 4: Landslide hazard model results (Palmer Consulting Environmental Group Inc., 2018).

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.

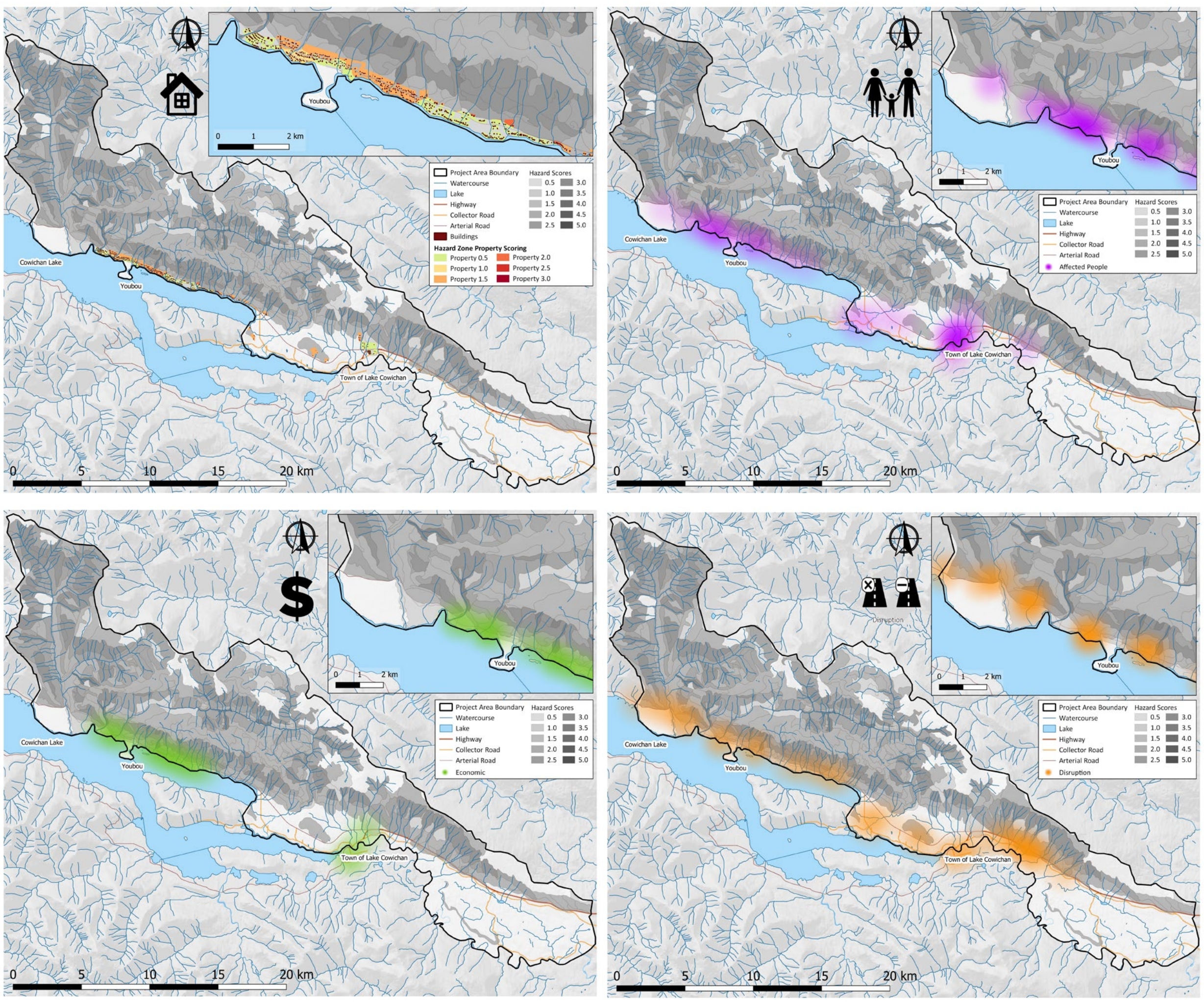


Figure 5: Impacts to people, affected people, economy, and disruption (mix of qualitative and quantitative measures, represented from left to right).

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.

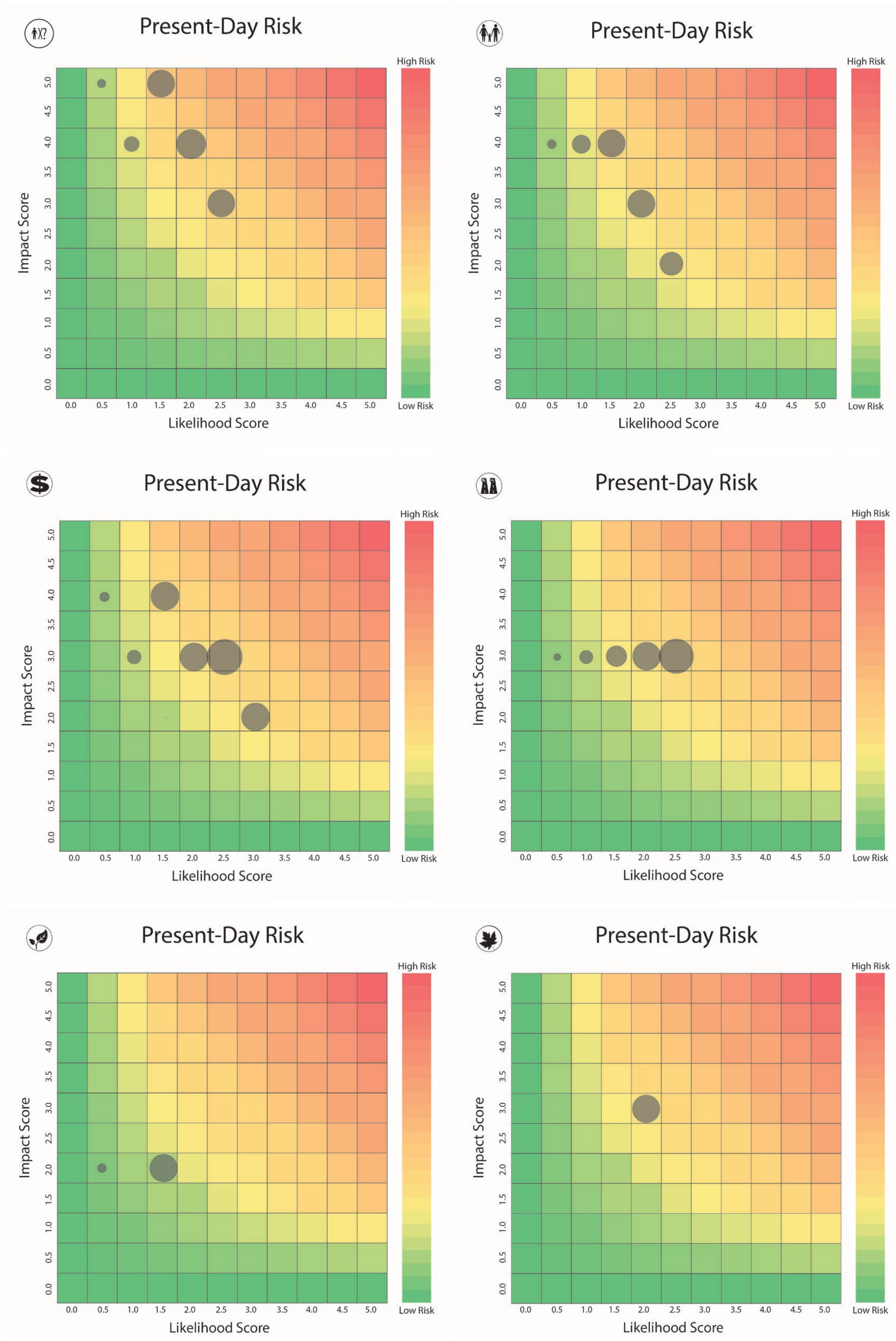


Figure 6: Risk to people, affected people, economy, disruption, environment, and culture (mix of qualitative and quantitative measures, represented from left to right).

Table 1: Risk summary for project area.

Impact Category	Absolute Impact or Qualitative Metric Used	Comments	Risk Score (Based on Mode)
People (Mortality and/or Missing)	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.	**6 – MEDIUM**
Affected People	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.	**6 – MEDIUM**
Economic Consequences	$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.	**7.5 – MEDIUM**
Disruption	12 locations of overlap between hazard areas and road	Several disruption points were identified and weighted based on the importance of the asset.	**7.5 – MEDIUM**
Environment	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.	**3.0 – LOW**
Cultural	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.	**6.0 – MEDIUM**

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.

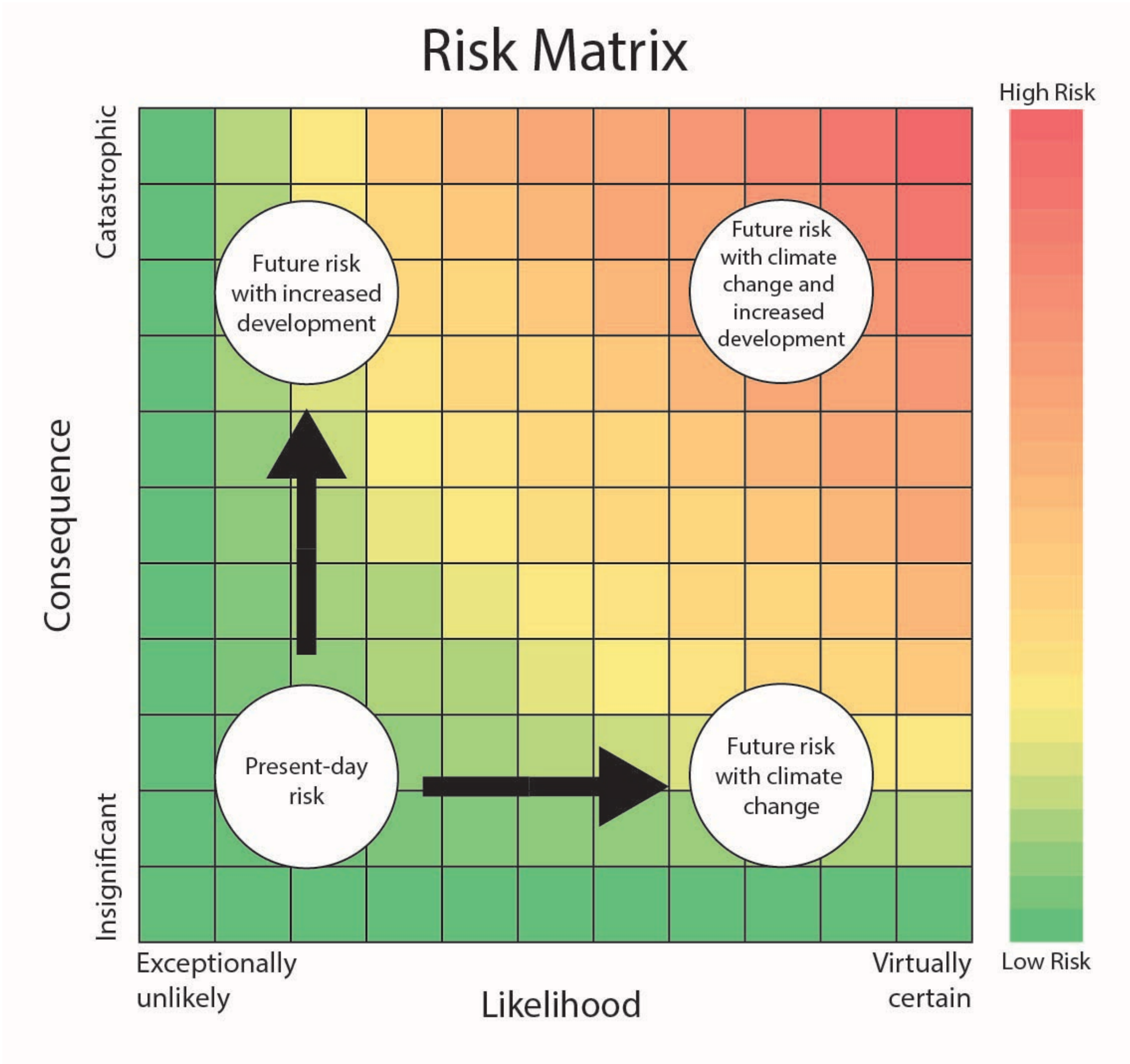


Figure 7: Risk as a dynamic concept

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.

2. 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.

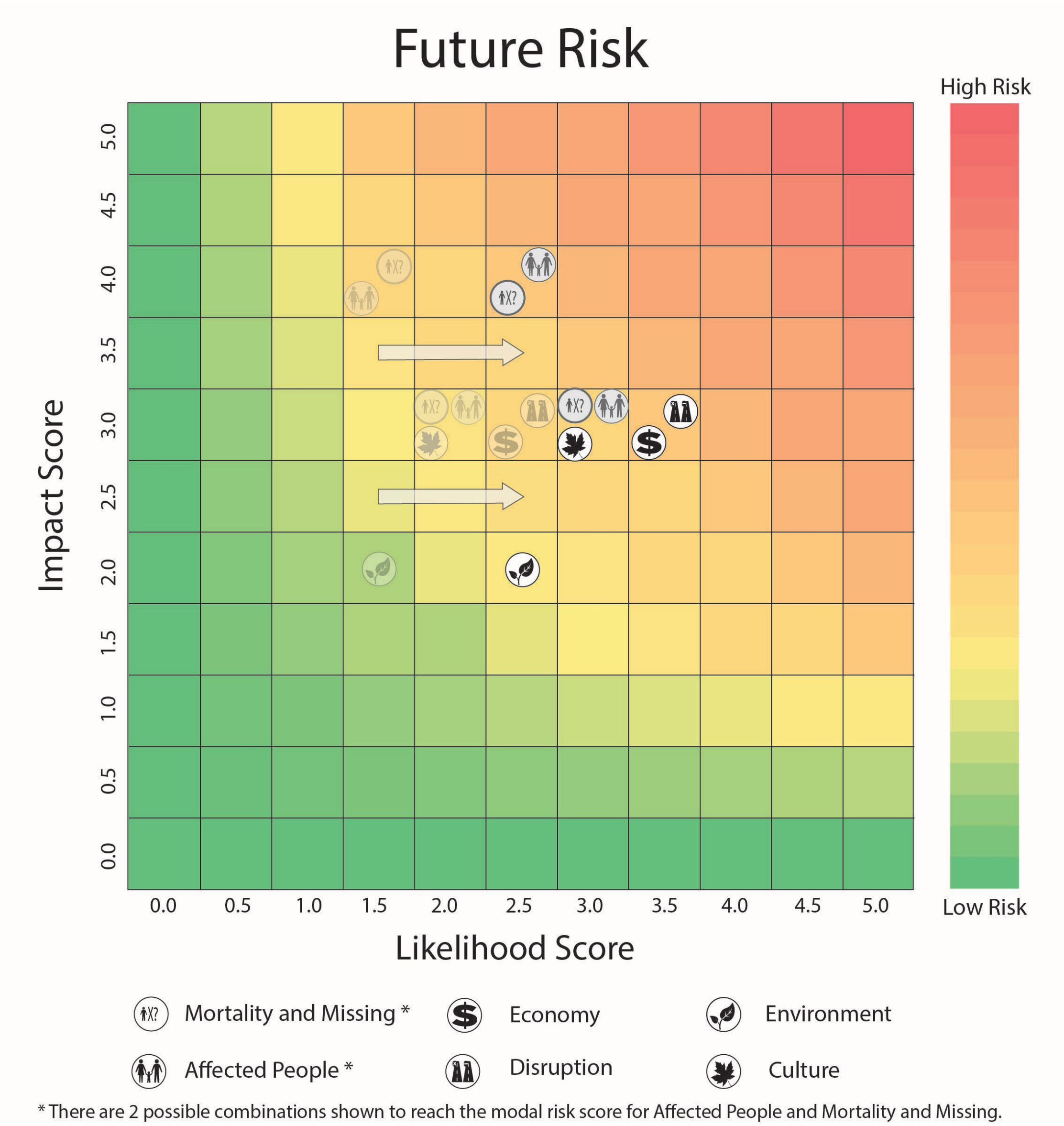


Figure 8: Present-day and future risk (present-day risk is represented by lighter icons, and future risk by darker icons).

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 adaption, appropriate disaster risk and response planning, and supportive infrastructure strategies.

Contents

Figures

TABLES

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^2 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.

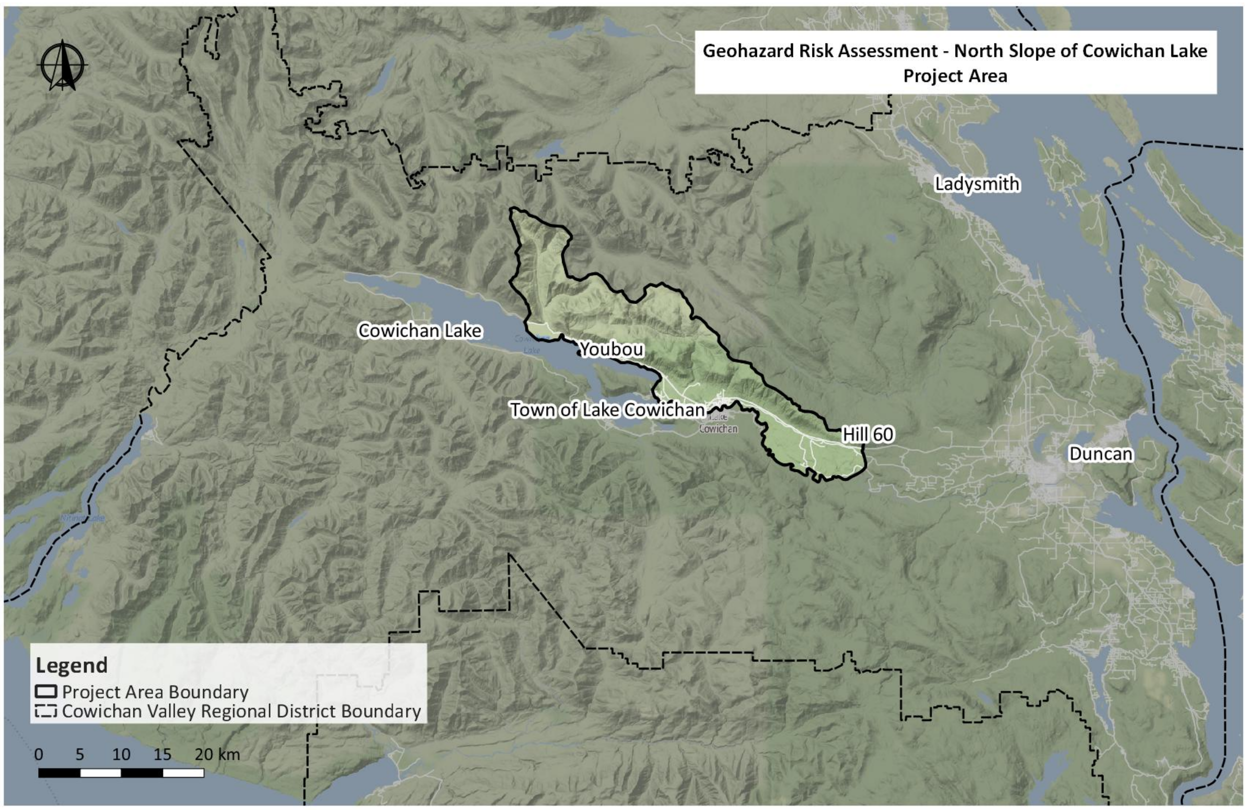


Figure 1: CVRD boundary and project area along the north slope of Cowichan Lake.

Best practice dictates that natural hazard mitigation[1] 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:

[1] 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[2] 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.

[2] 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.

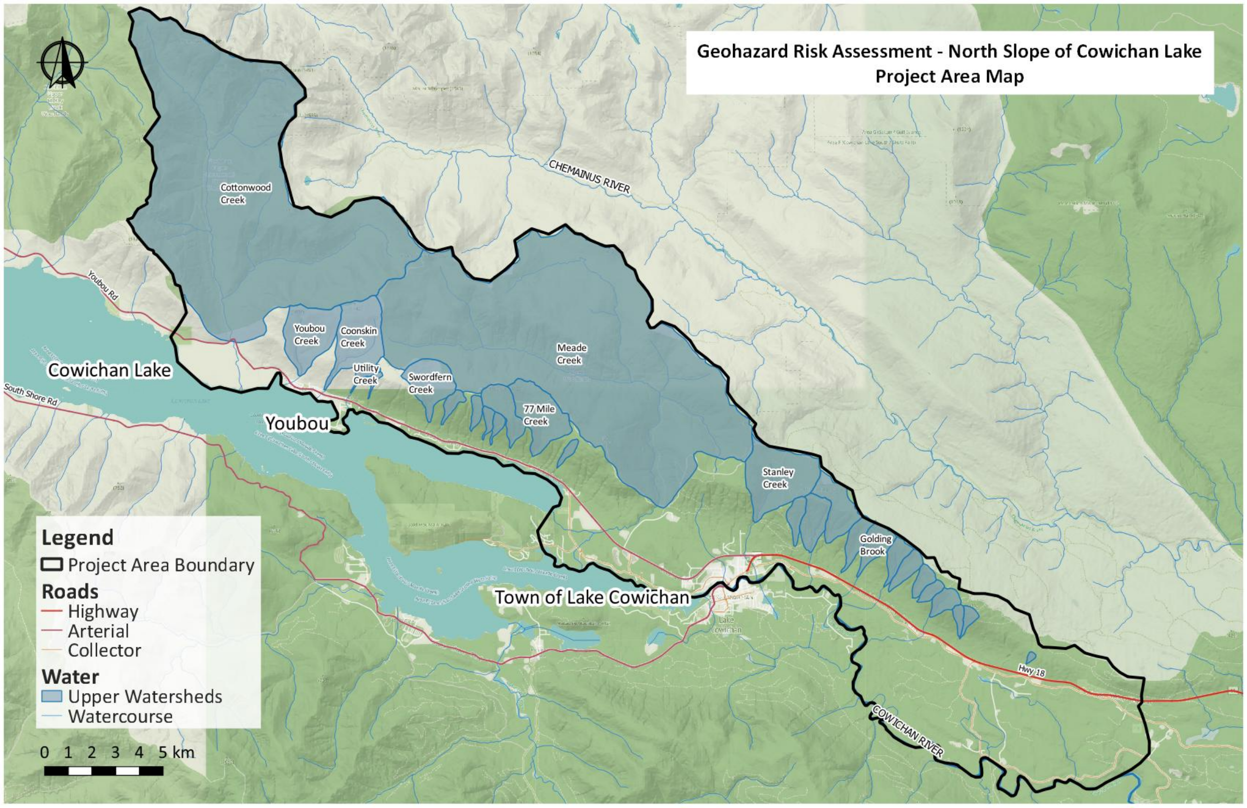


Figure 2: Project area map.

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[3]; 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 <u>Provincial Policy on Disaster Risk Reduction</u>

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.

[3] 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).

DPAs 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 a 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
National Disaster Mitigation Program (NDMP)	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.
Community Emergency Preparedness Fund (CEPF)	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.
Disaster Mitigation and Adaptation Fund (DMAF)	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. C*onsequence* 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?).

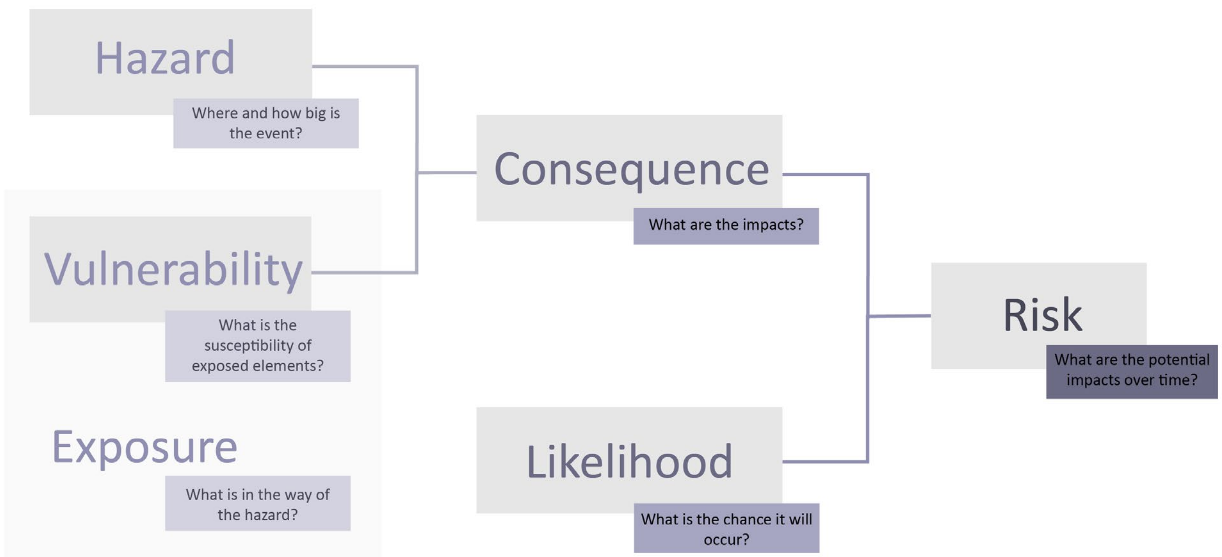


Figure 3: Risk as a function of consequence and likelihood (simplified).

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.

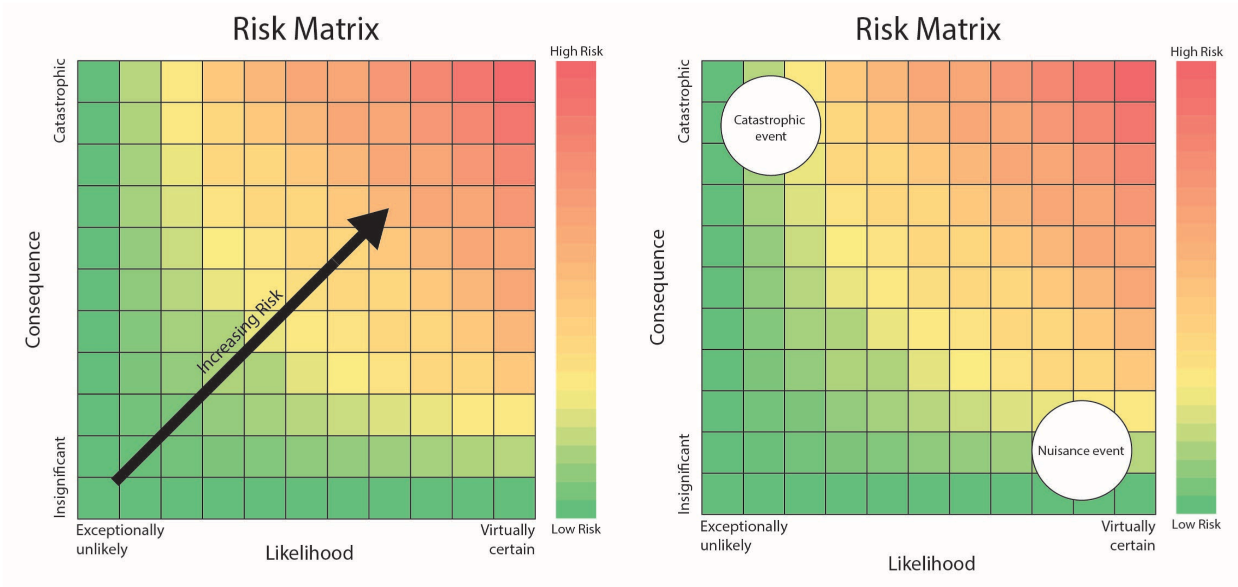


Figure 4: Risk as a function of likelihood and consequence – nuisance and catastrophic risk.

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.

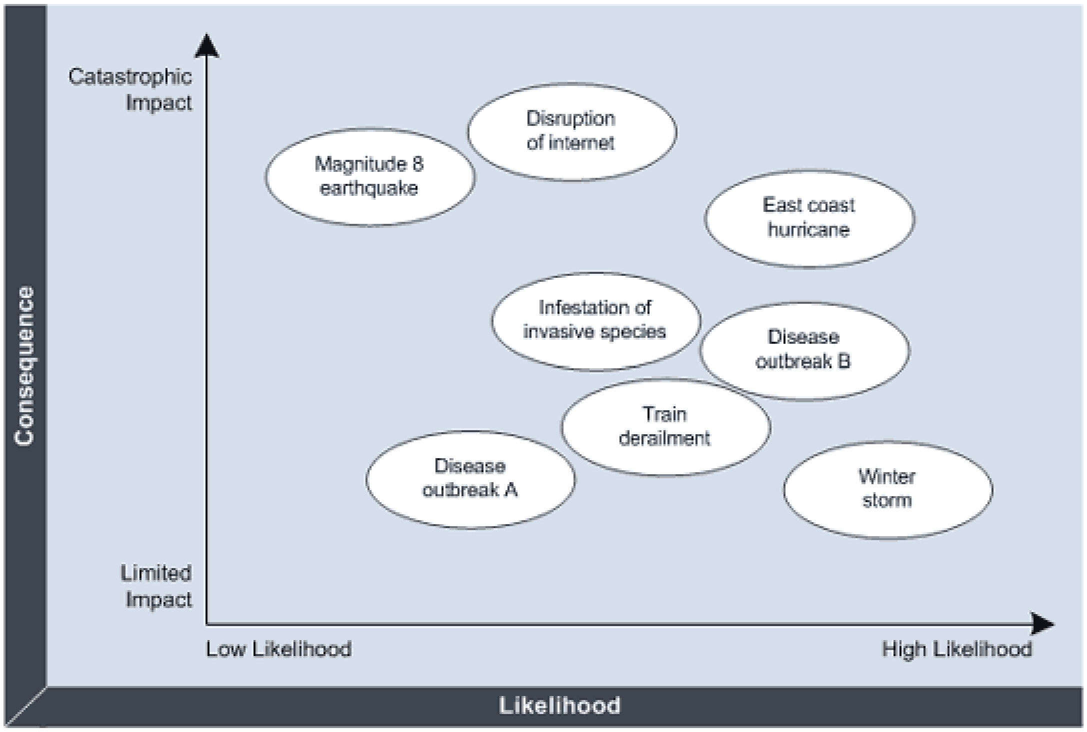


Figure 5: Consequence and likelihood of various natural and anthropogenic hazards (Public Safety Canada, 2013).

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).

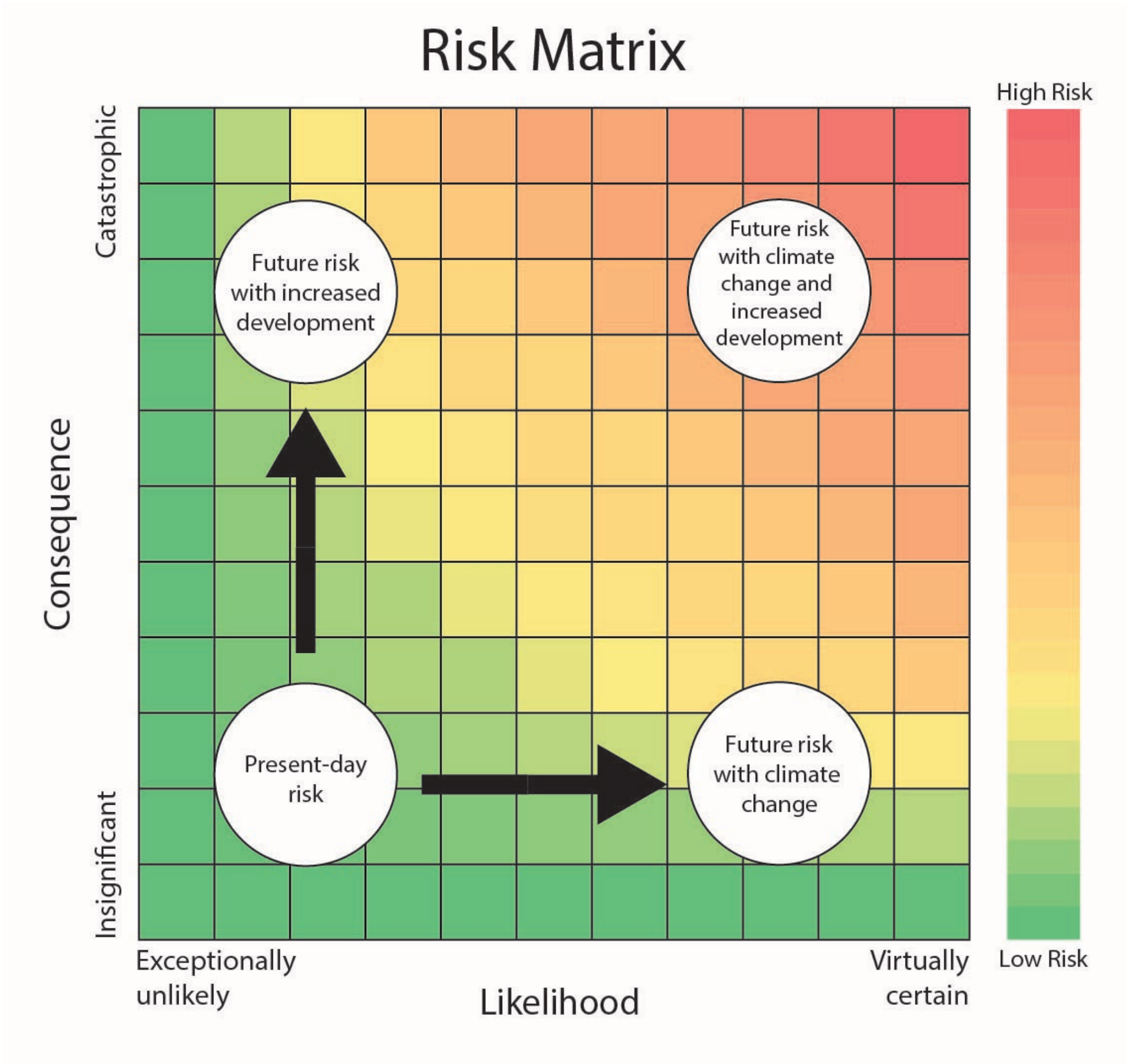


Figure 6: Dynamic risk with climate change and increased development.

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[4].

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
100%	Annual	100%	100%	100%	100%
30%	Once every three years	100%	100%	100%	100%
10%	Once every 10 years	93%	99%	100%	100%
3%	Once every 33 years	53%	78%	90%	95%
1%	Once every 100 years	22%	39%	53%	63%
0.1%	Once every 1000 years	2%	5%	7%	10%

[4] 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.

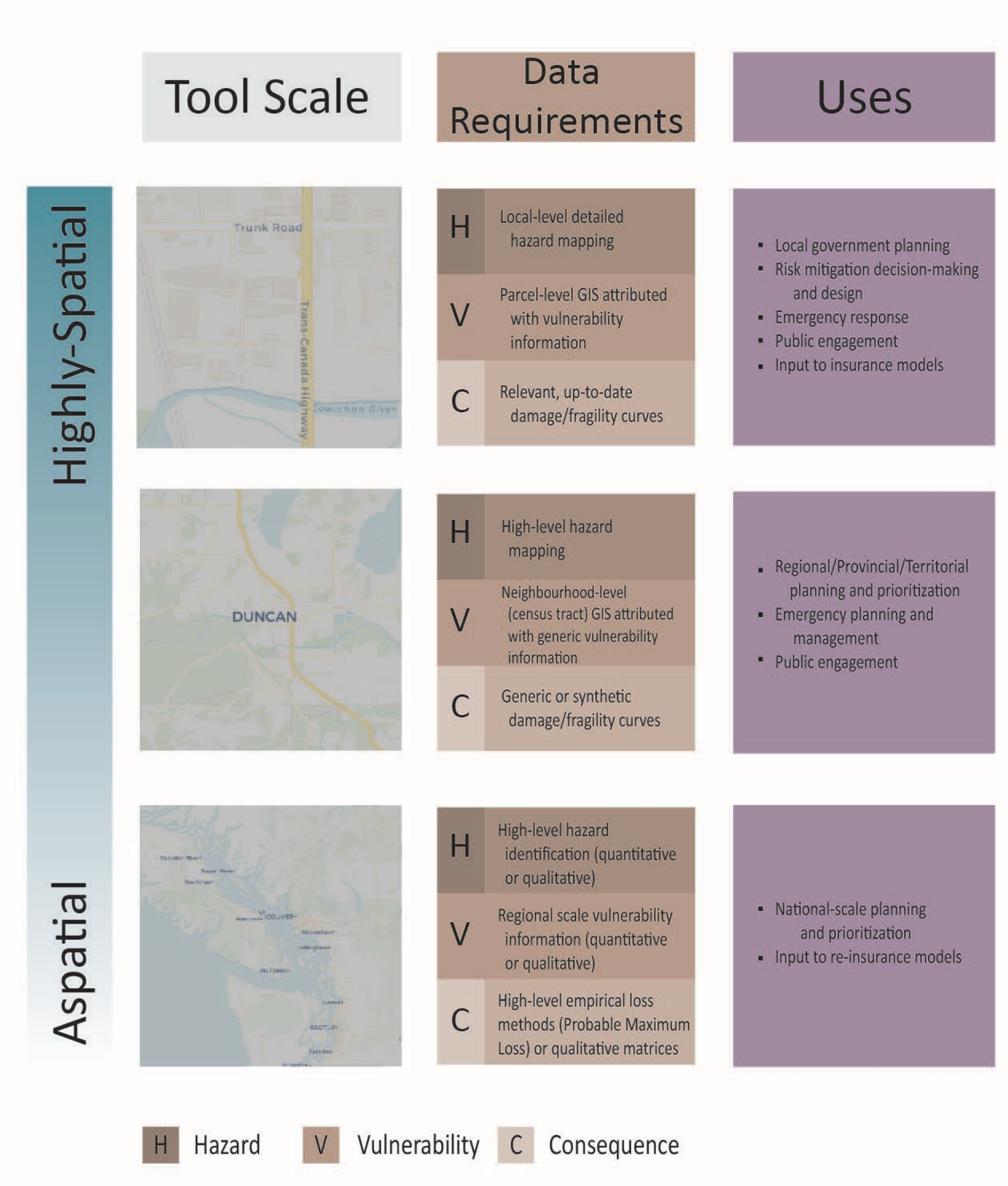


Figure 7: Scales of risk assessment.

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	• Building damage • Infrastructure damage	• Loss of life • Health effects • Loss of habitat and environment
Indirect	• Loss of business • Traffic disruption • Emergency response costs	• Inconvenience of event recovery • Increased vulnerability of survivors

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.

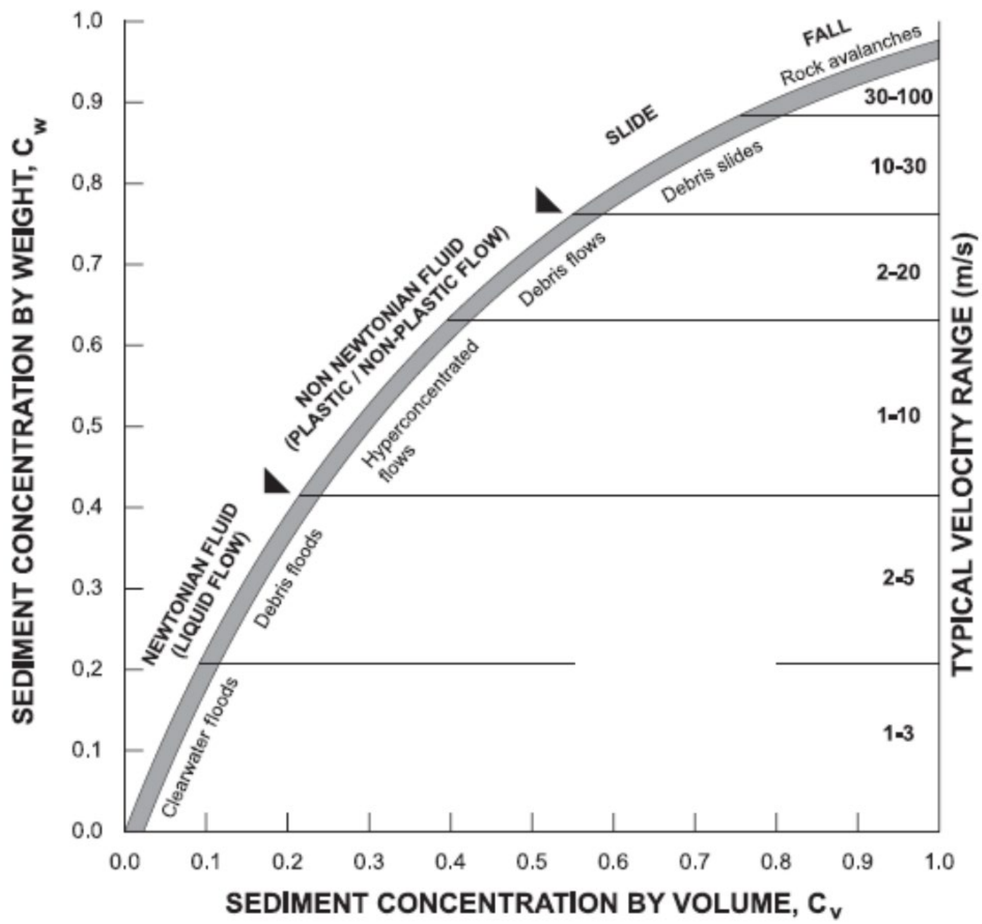


Figure 8: Watershed morphometrics graph (Jakob and Jordan, 2001).

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[5] 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.

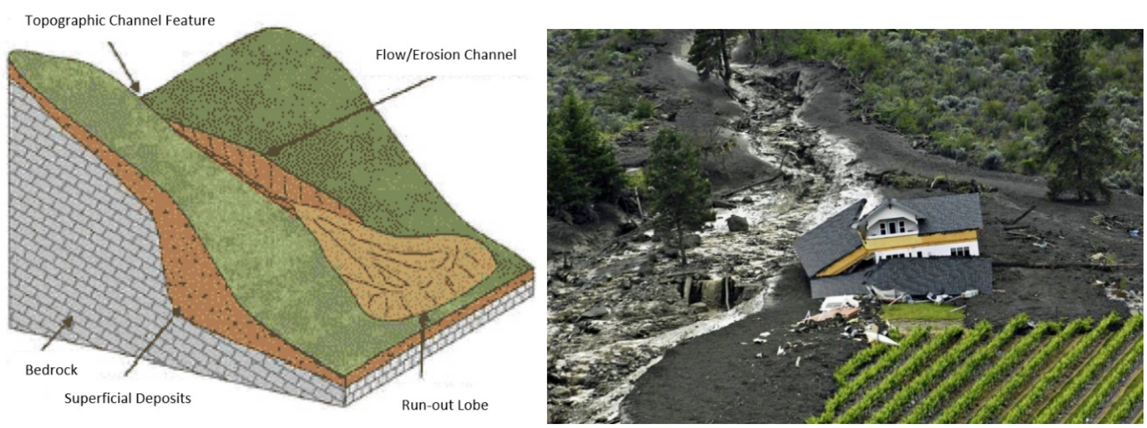


Figure 9: Channelized debris flows (Smith, 2004).

[5] 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.

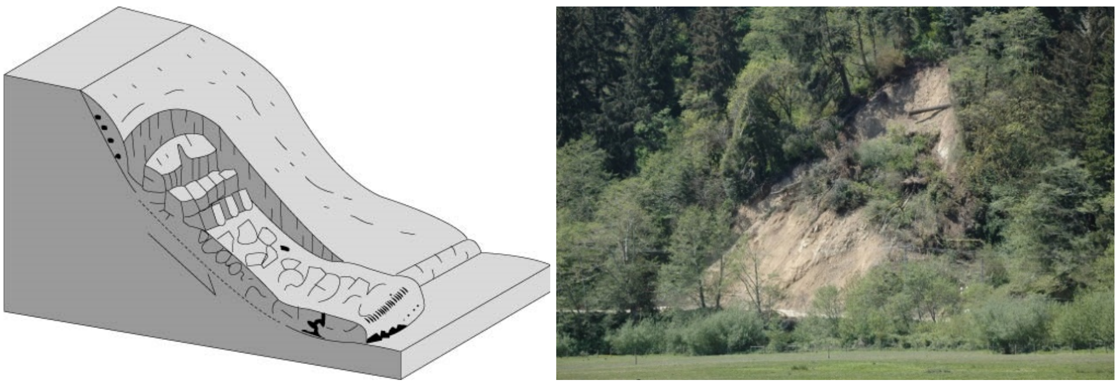


Figure 10: Debris slides (Smith, 2004).

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).

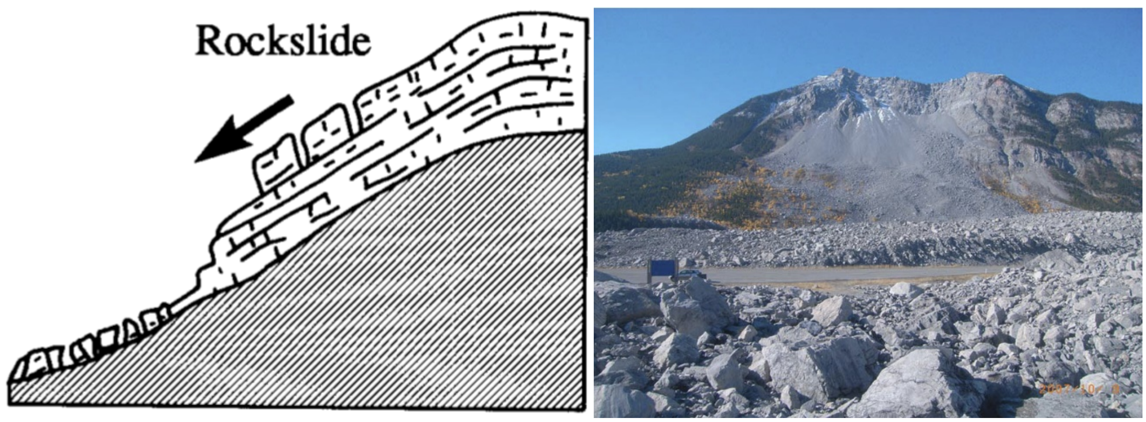


Figure 12: Rock slides (Smith, 2004).

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 (Handwerger *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[6]. 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.

[6] Relief ratios are a measure of the watershed characteristics and describe the grade of a stream channel.

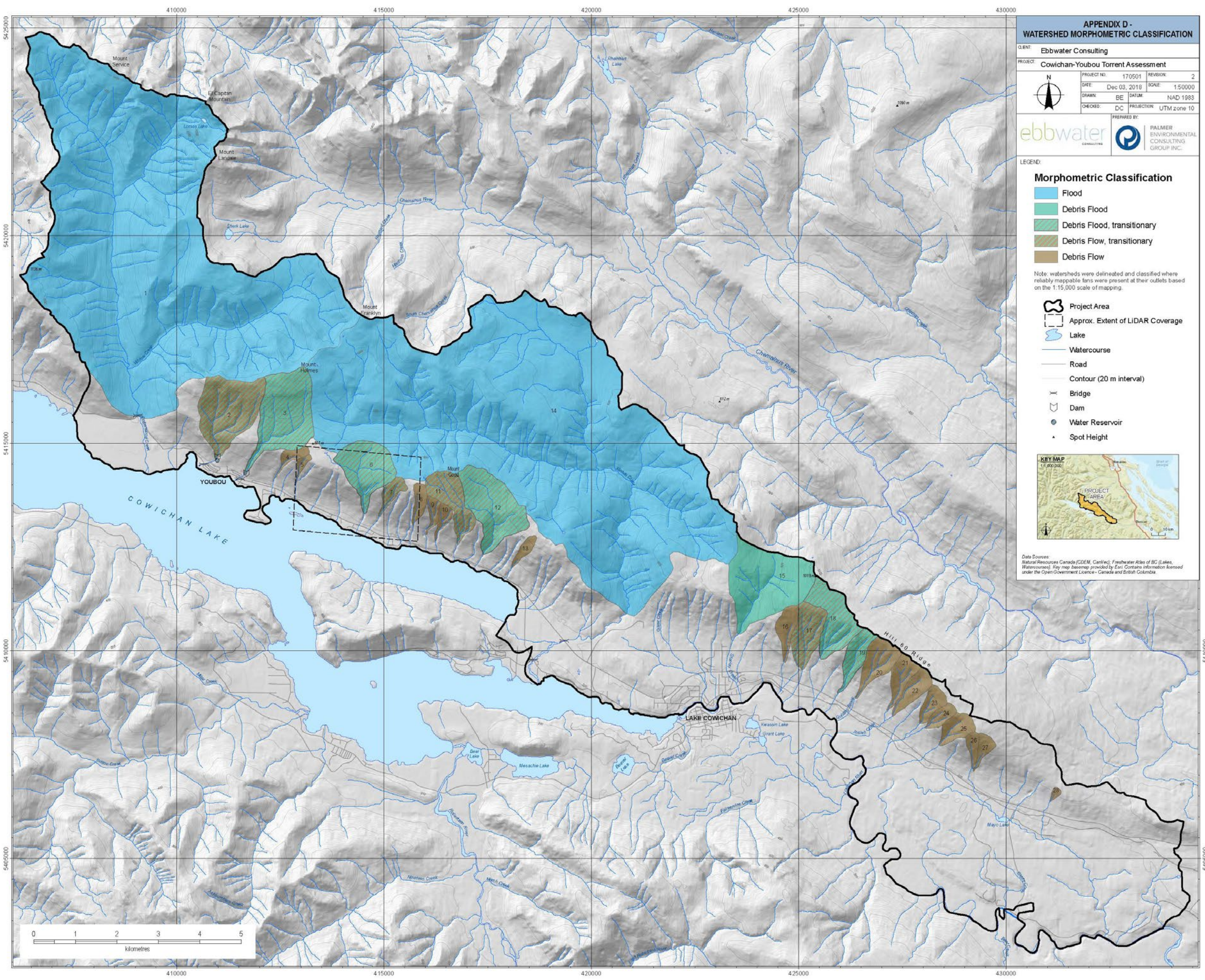


Figure 13: Watershed dominant morphometric classification (Palmer Consulting Environmental Group Inc., 2018).

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 transitionary 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.

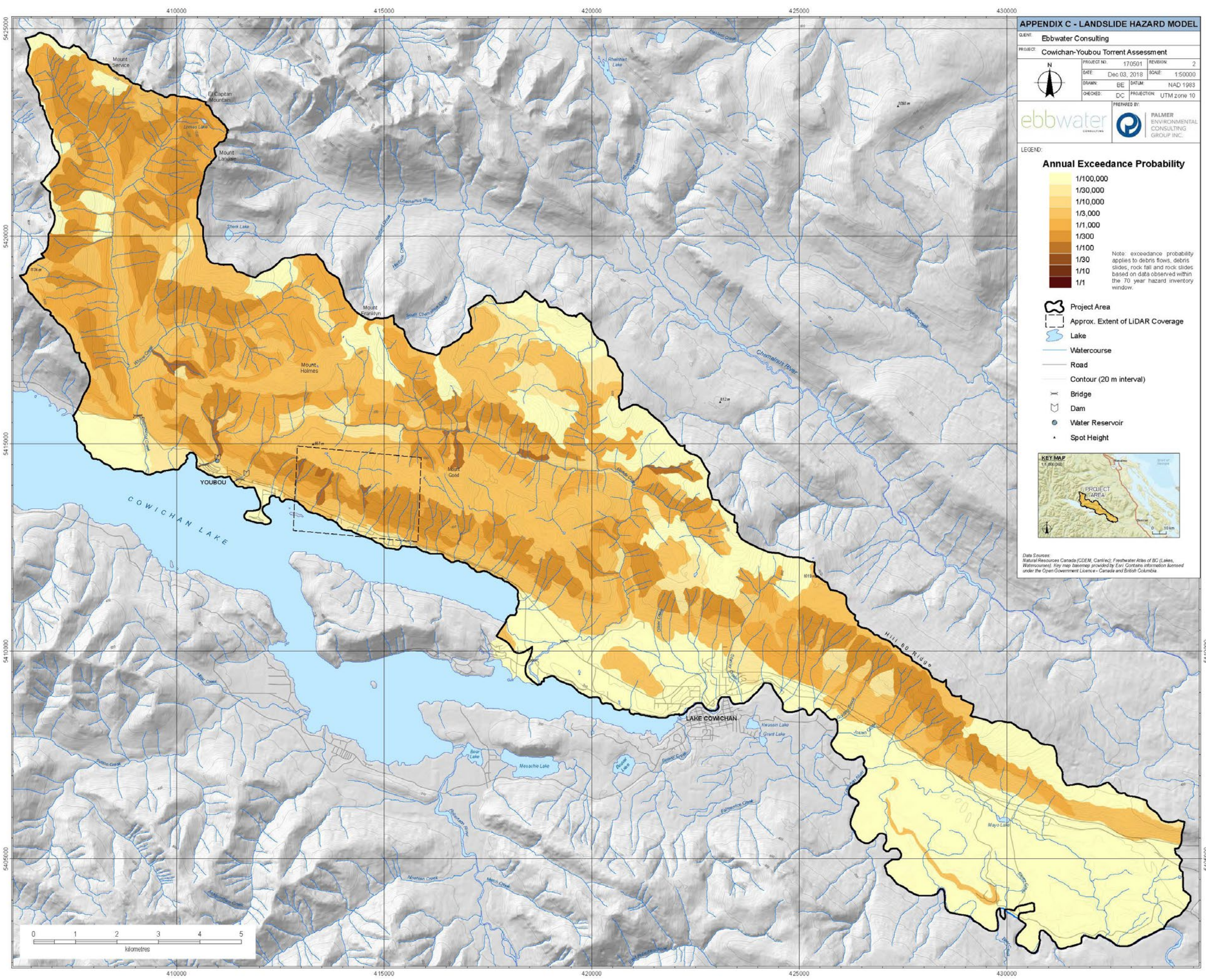


Figure 14: Landslide hazard model results (Palmer Consulting Environmental Group Inc., 2018).

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[7], 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[8] 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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[7] TimberWest, a forestry company, have tenure of lands within the project area. They participated in field work as a stakeholder of the project.

[8] Paraglacial describes the period after deglaciation, when unstable conditions can occur.

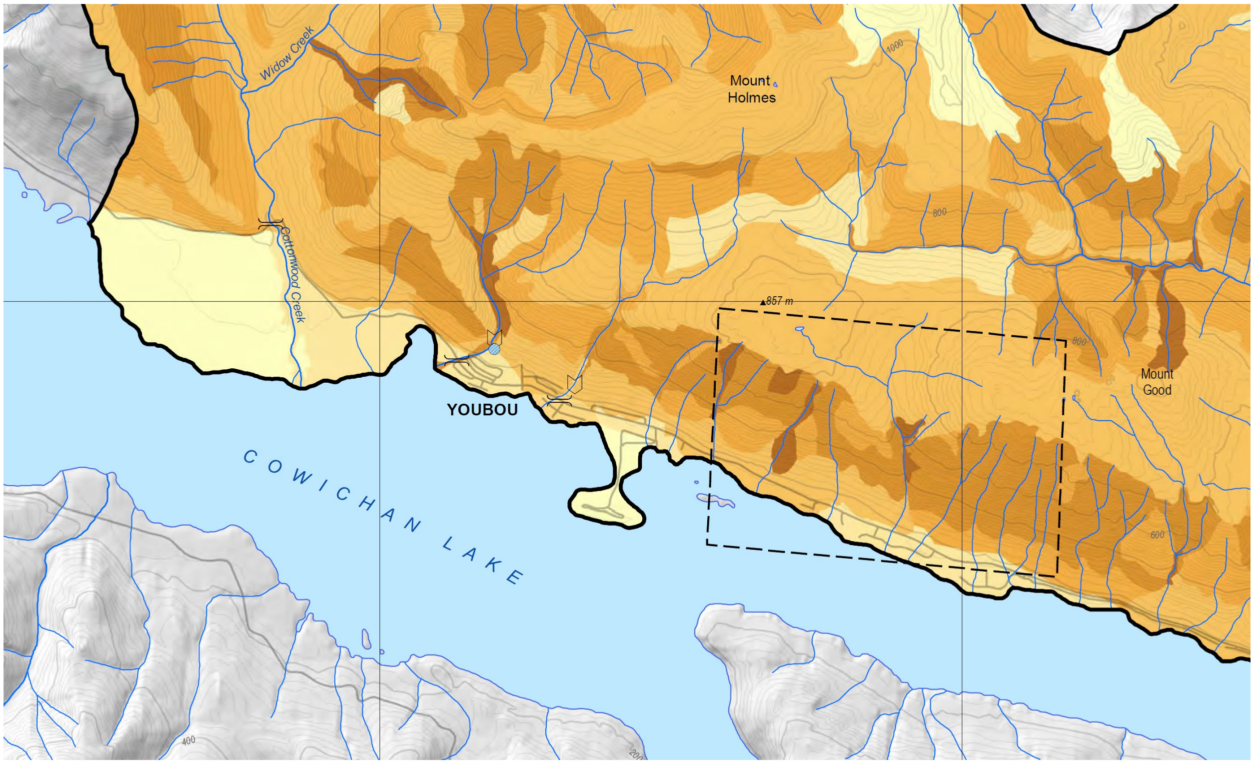

Figure 15: Hazard exceedance probability in Youbou Creek and unnamed creeks 7 to 11.

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 95th 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[9] 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

[9] 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.

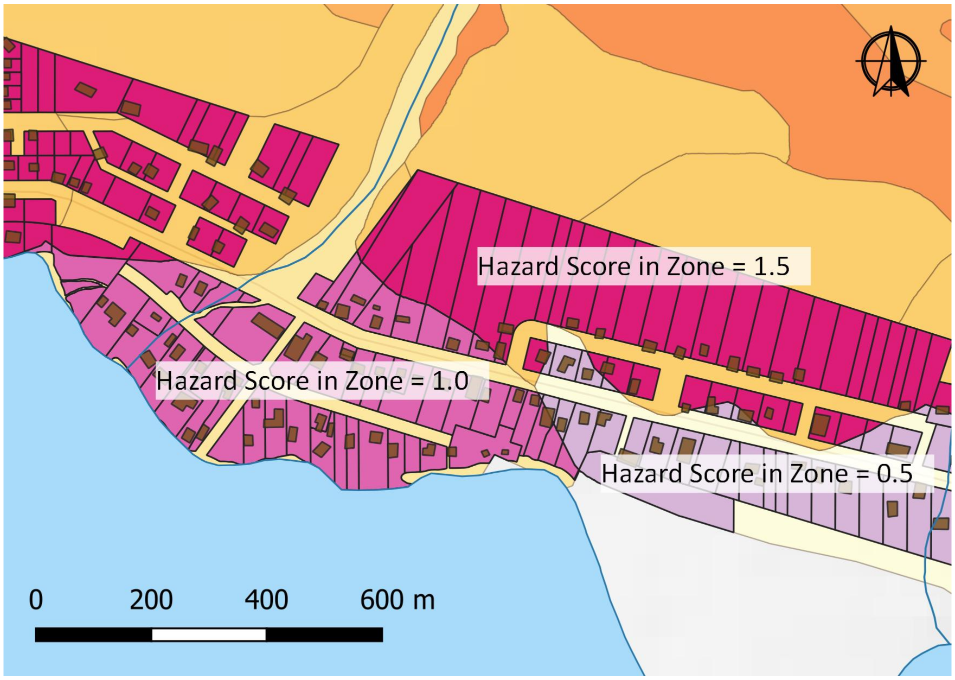

Figure 17: Quantitative exposure assessment process.

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 a 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

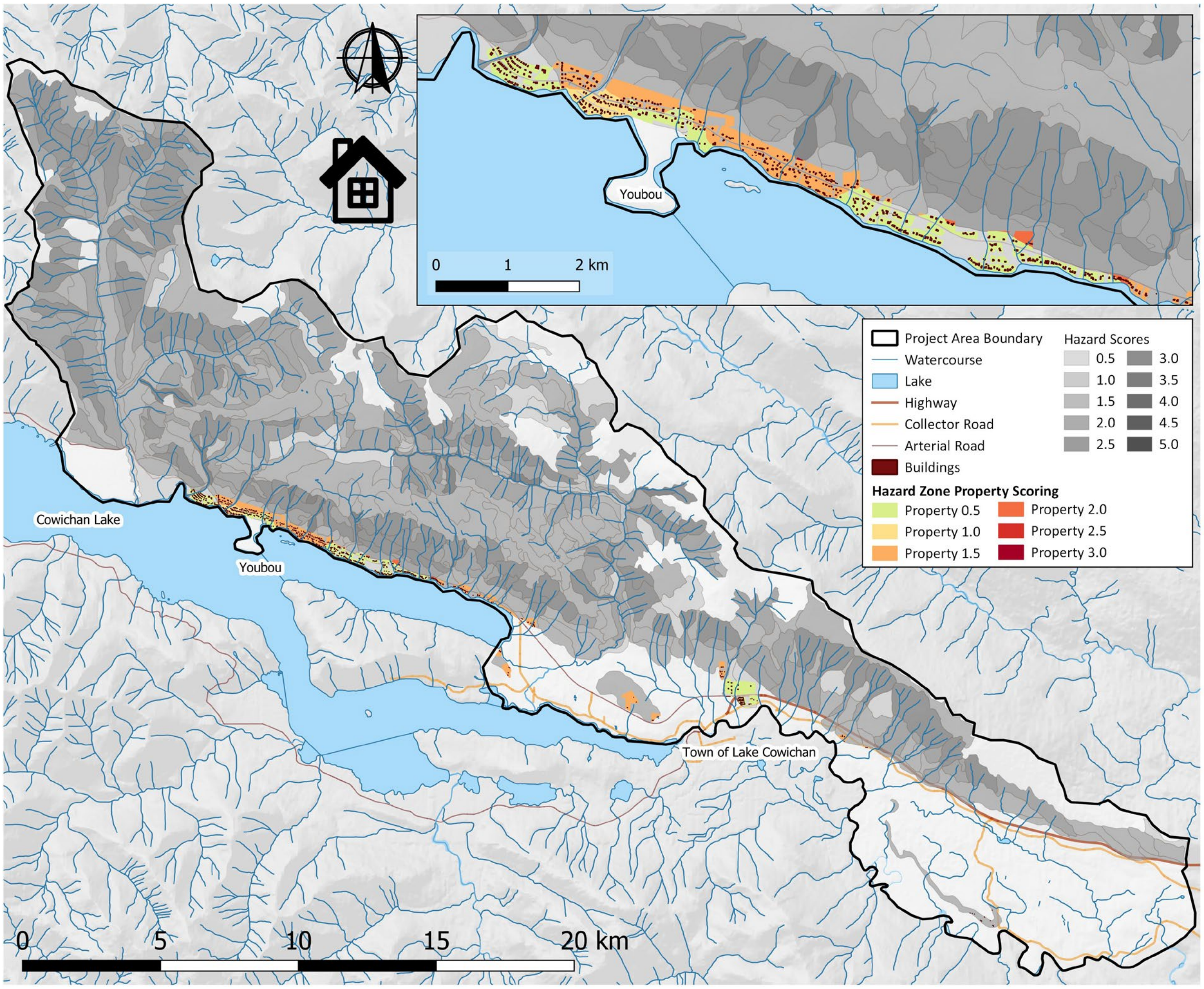

Figure 18: Exposed buildings in hazard zones within project area.

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.

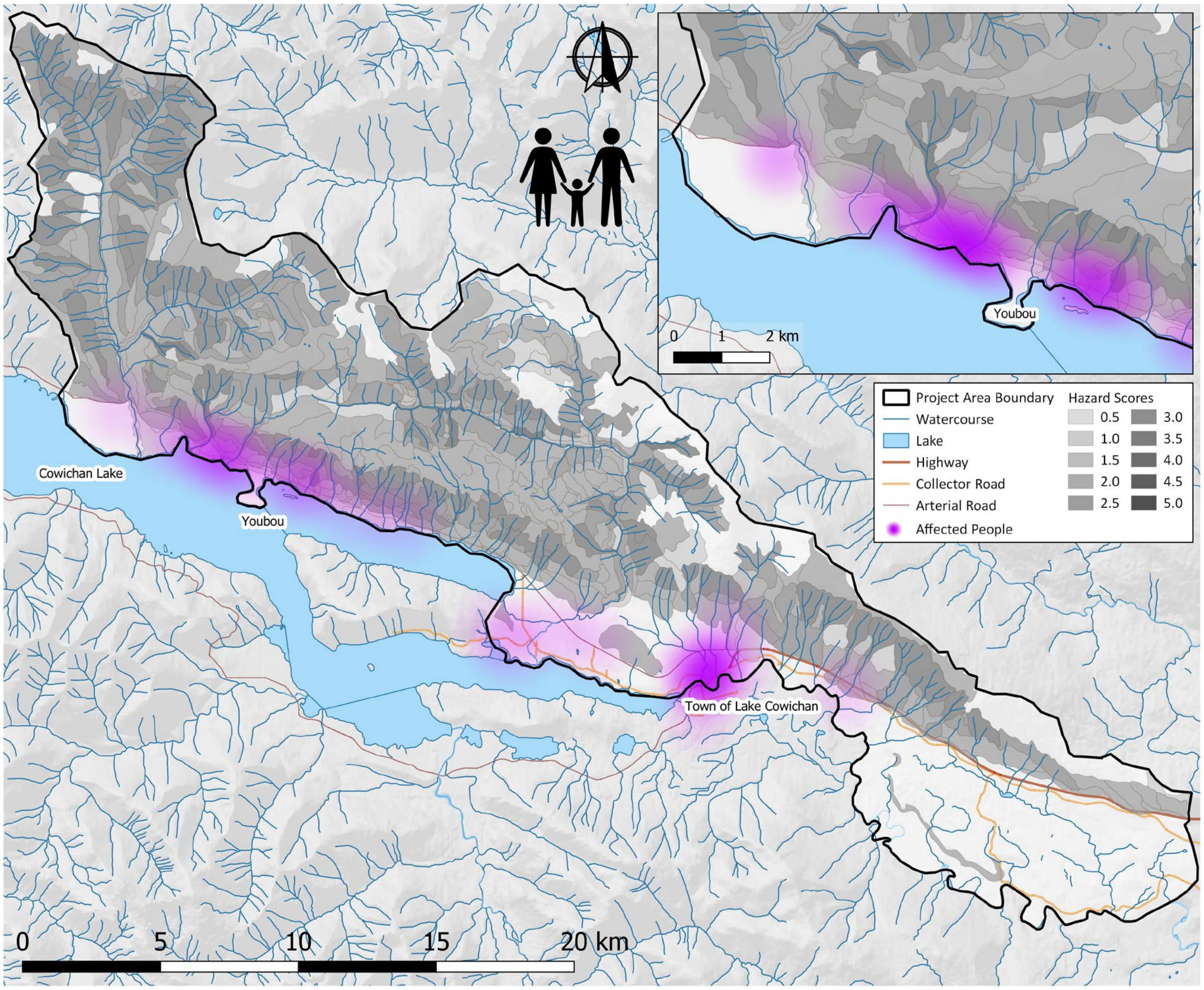

Figure 19: Hotspot map of affected people based on input from workshop 1.

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.

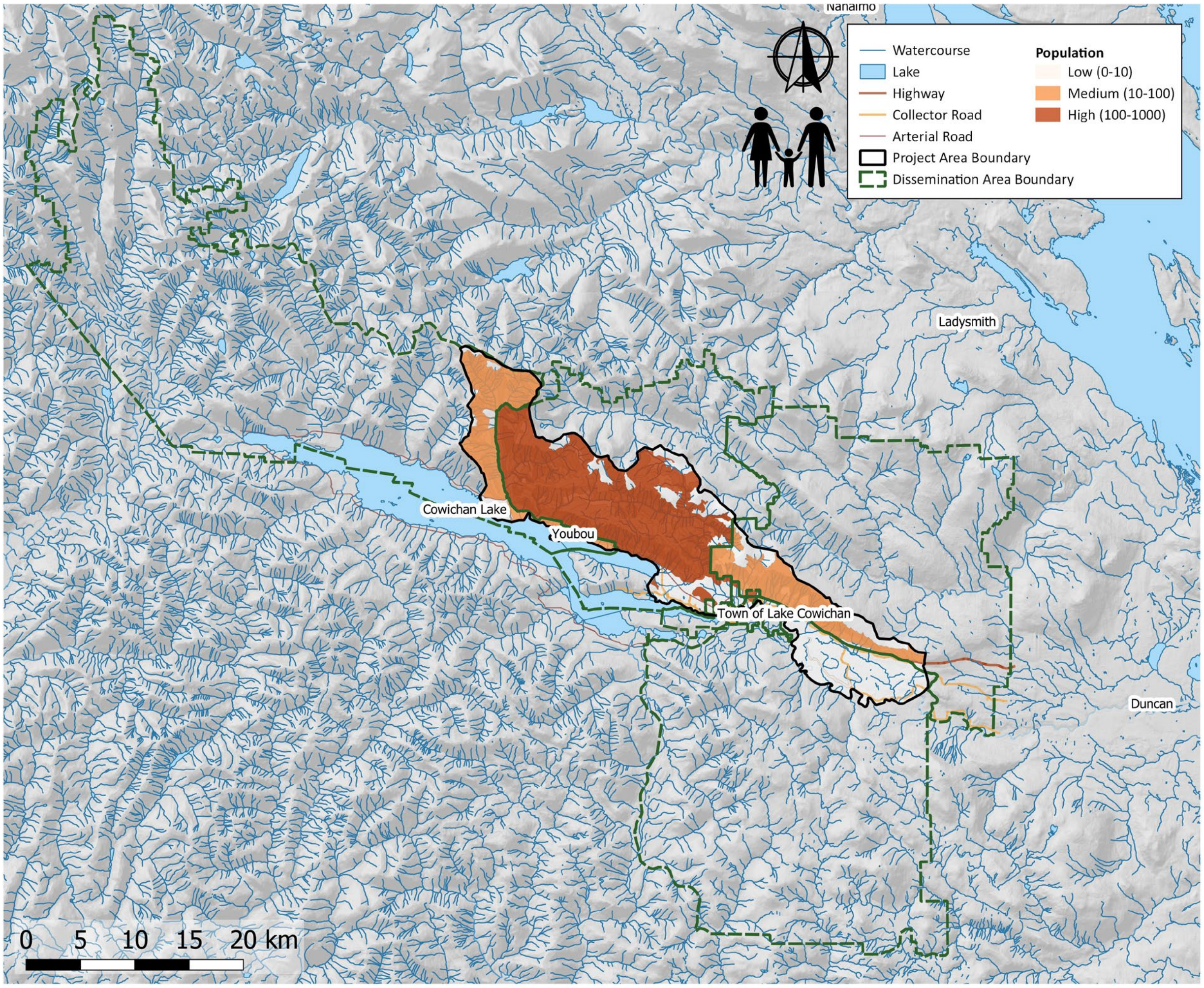

Figure 20: Population density in Lake Cowichan/Youbou by dissemination area within project area.

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[10].

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.

[10] Based on a total 2016 population of 6,802 from CVRD Electoral Areas I and F, Cowichan IR1, and Town of Lake Cowichan.

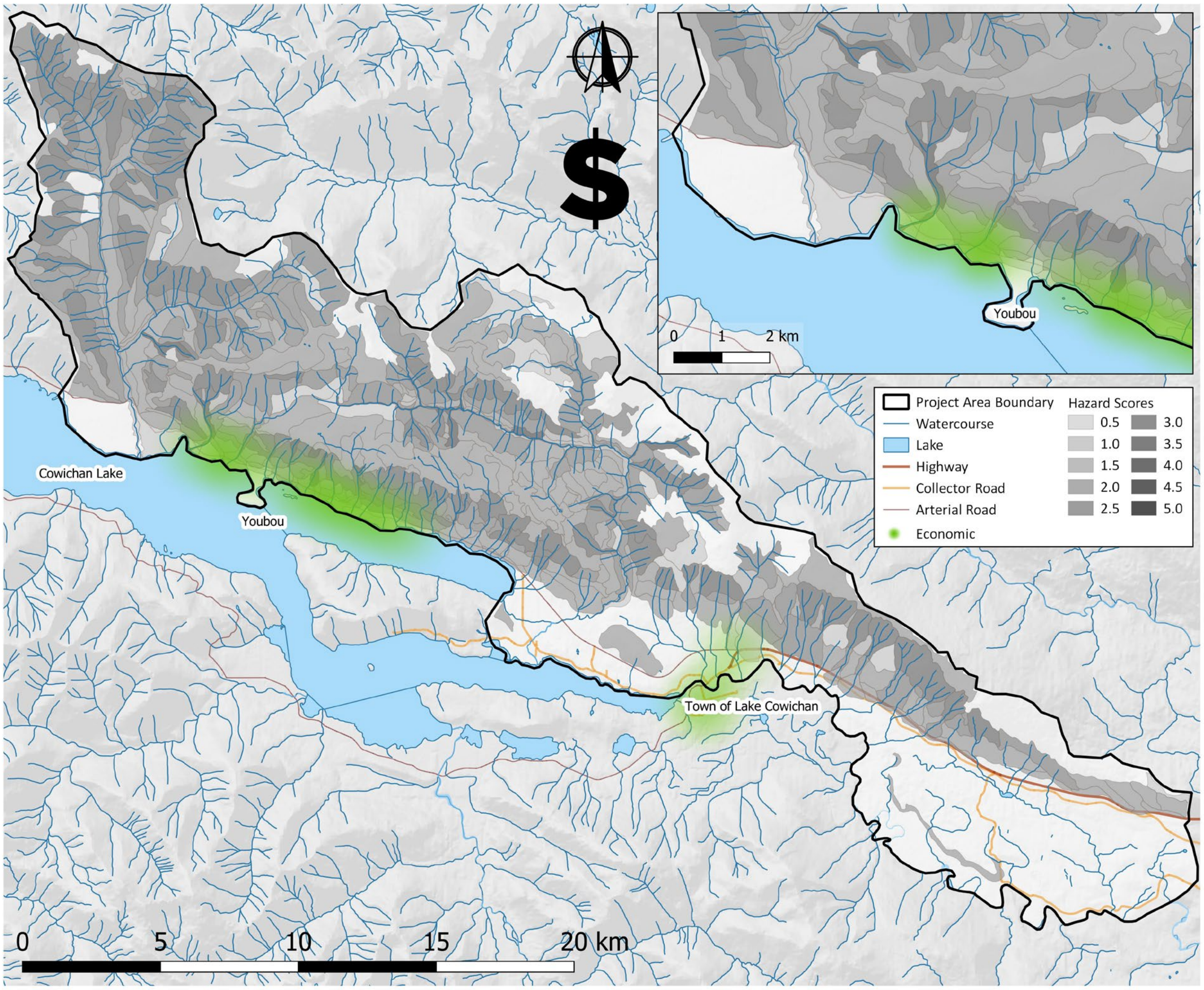

Figure 21: Hotspot map of economic impacts based on input from workshop 1.

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
Total	**262**	**143**	**405**

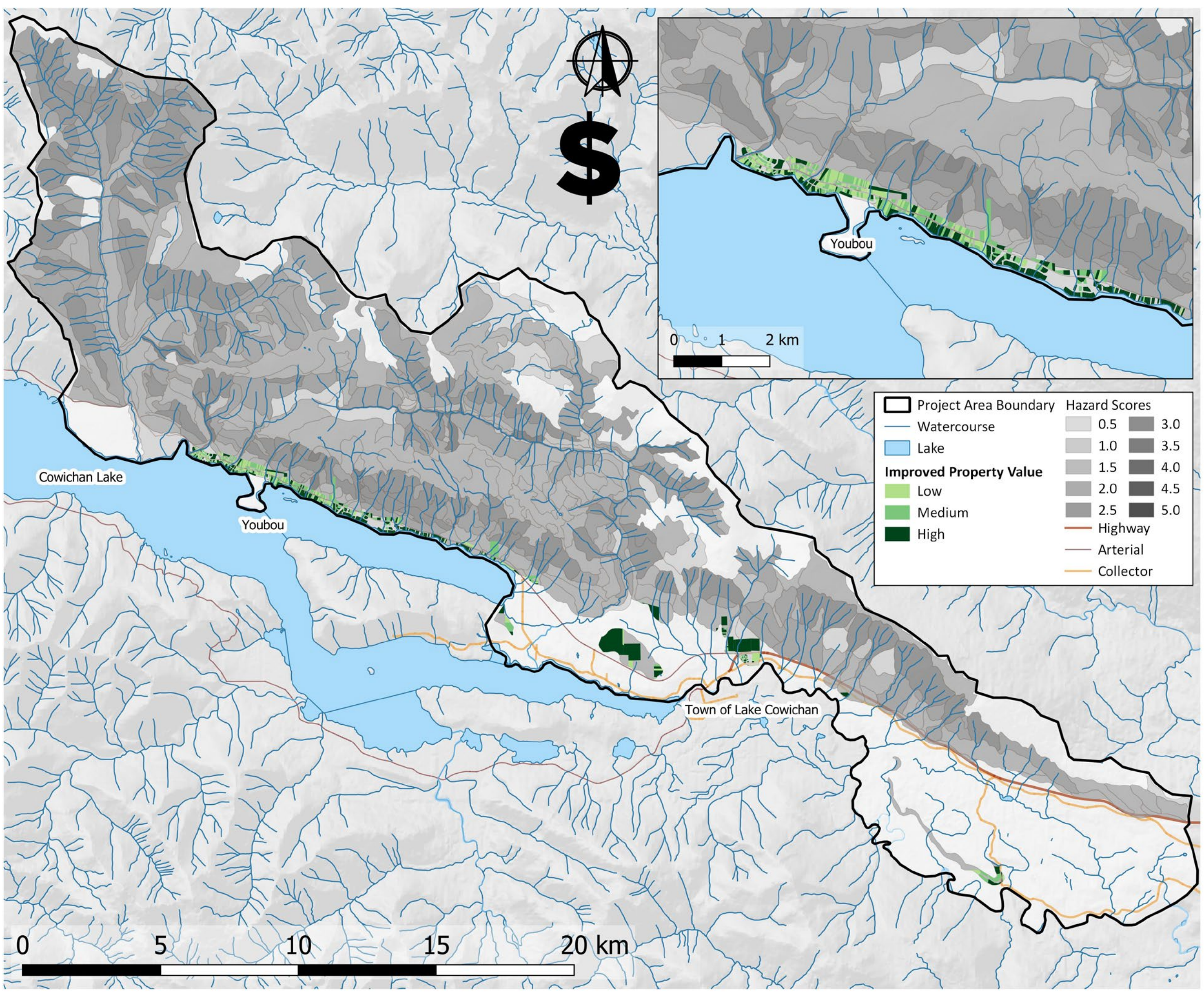

Figure 22: Economic impact of geohazard in project area using property values as a proxy.

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[11].

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.

[11] Assuming a 2018 Vancouver Island GDP of $39.5B (Economic Resources Vancouver Island, 2017)

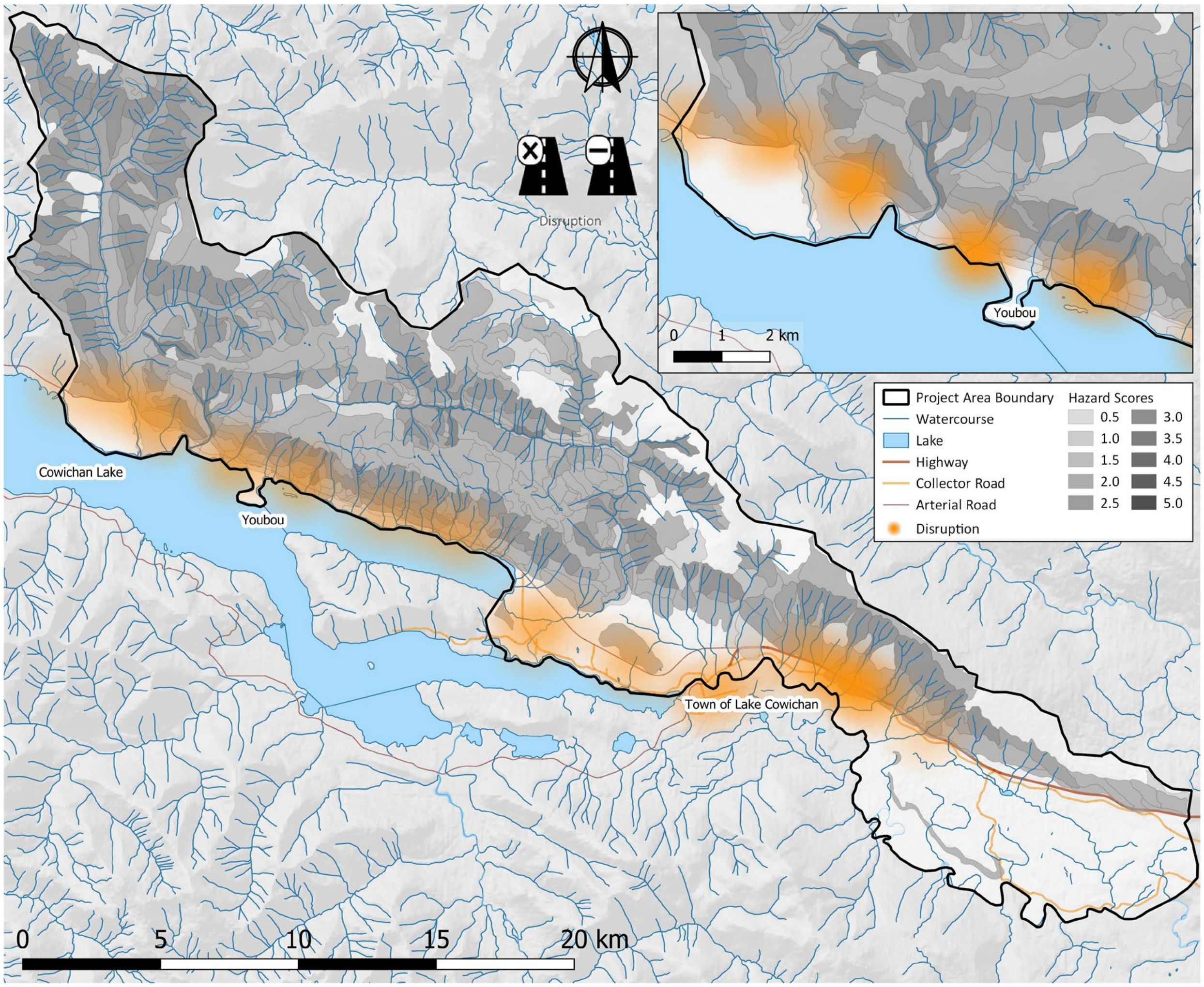

Figure 23: Hotspot map of disruption based on input from workshop 1.

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.

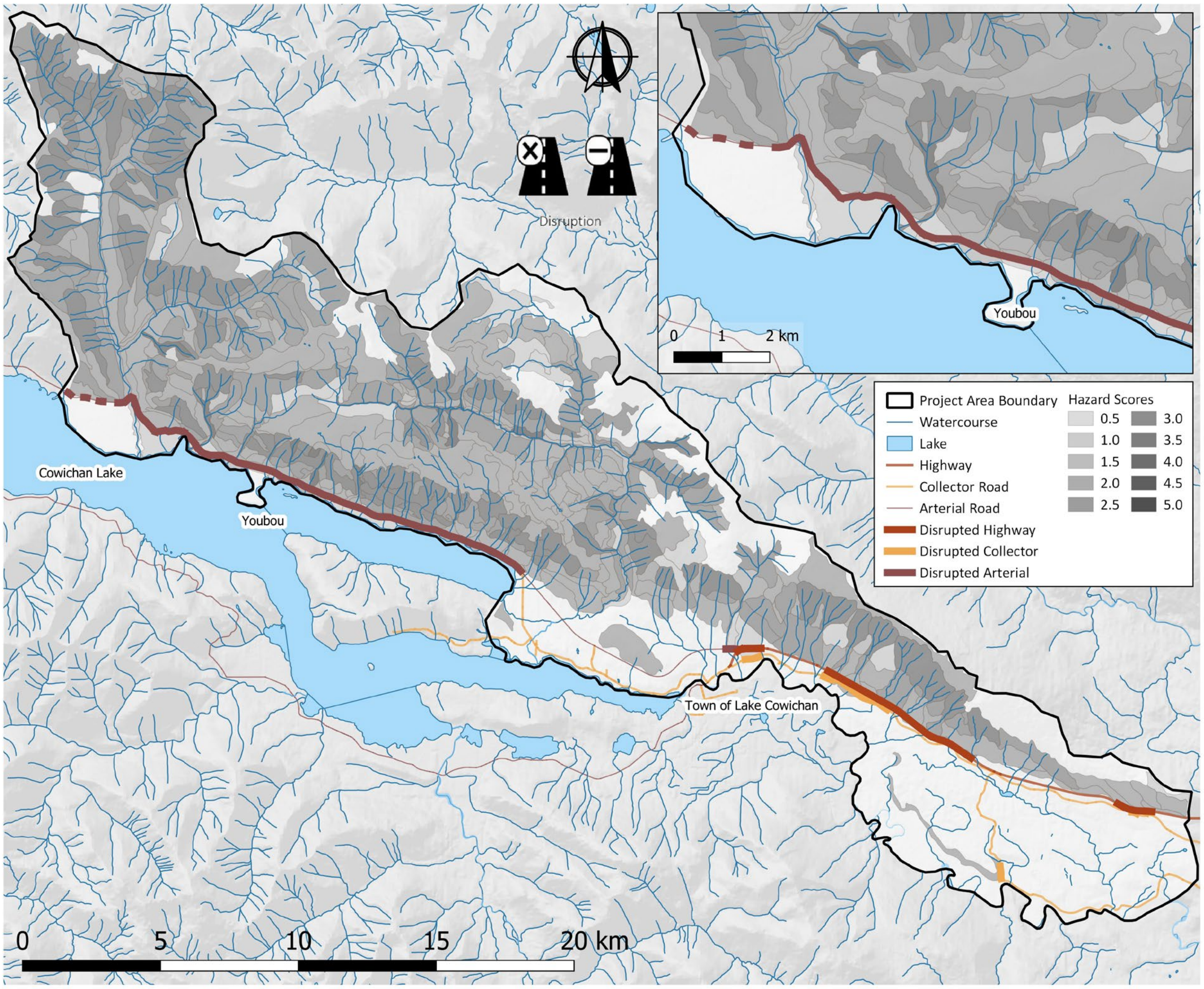

Figure 24: Disruption due to geohazard within the project area.

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%	-	-	-
Total points of disruption	**3**	**5**	**4**
Total length in zone (km)	**5.4**	**11.5**	**2.4**

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.

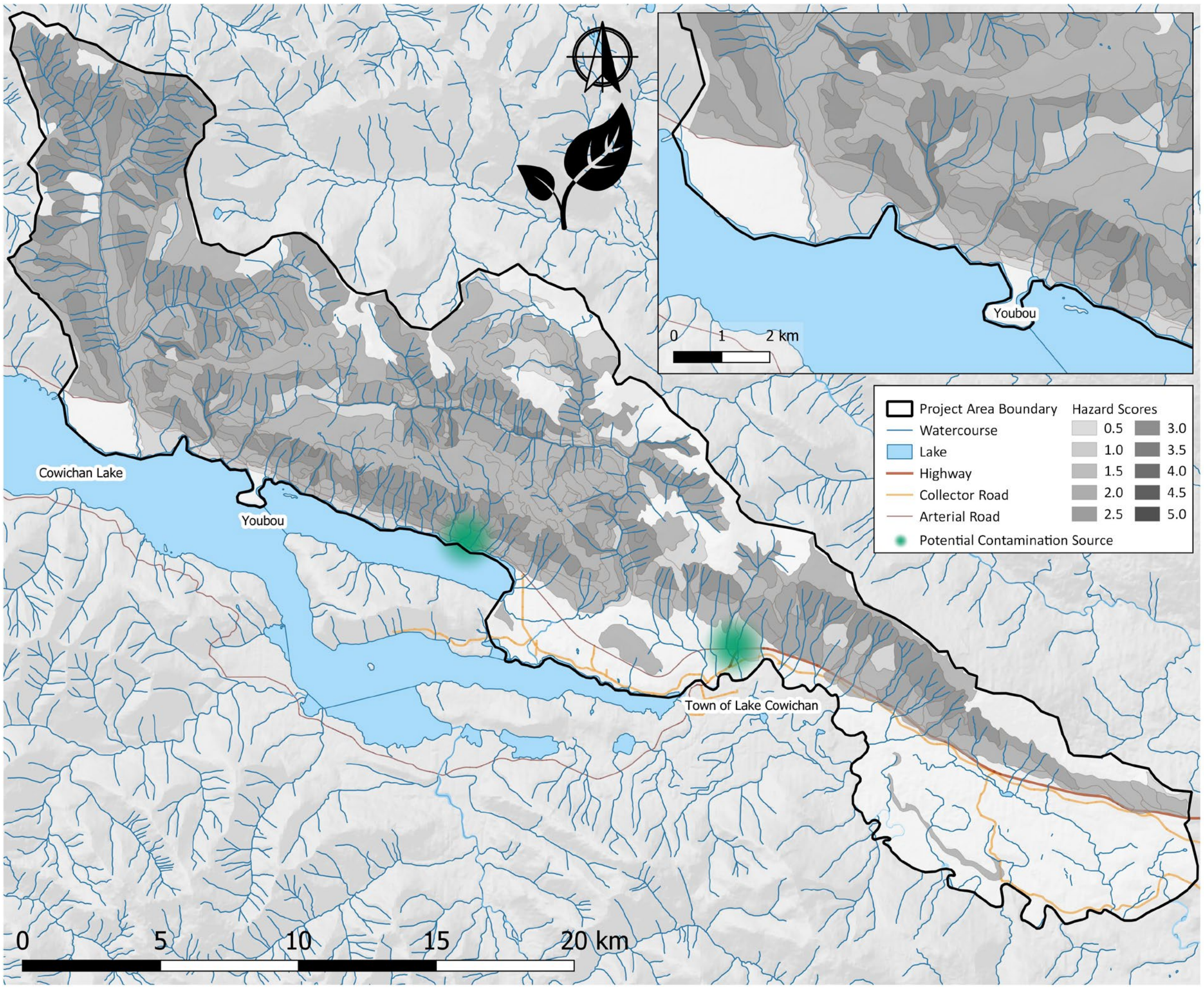

Figure 25: Environmental impacts due to geohazard within project area

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.

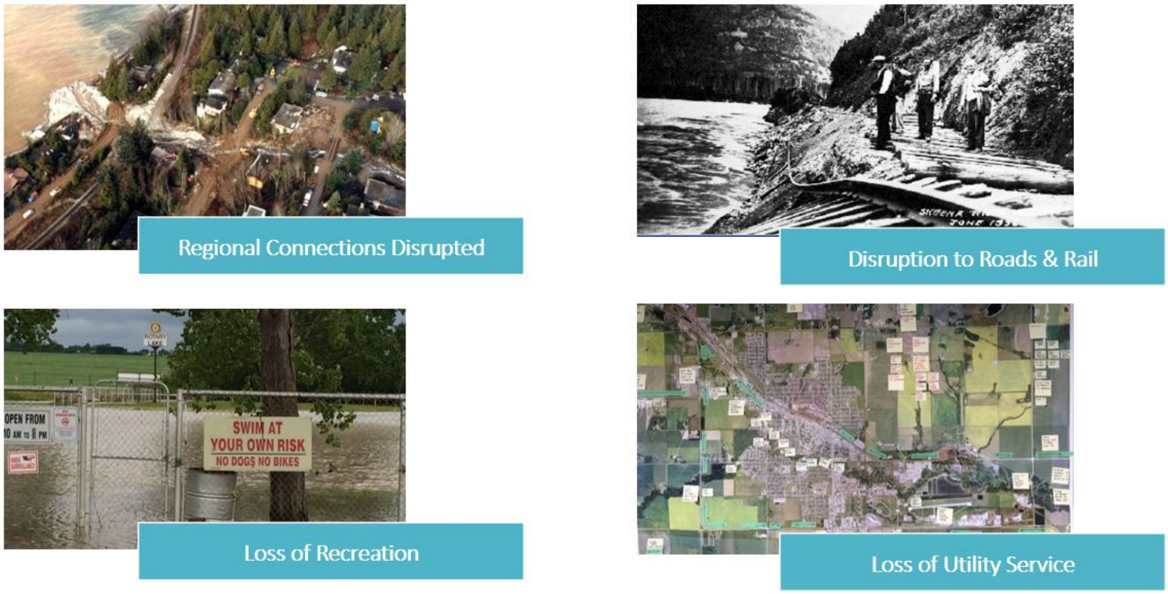

Figure 27: Examples of possible indirect impacts of debris flow in the CVRD (Photos from (Smith, 2004) and Ebbwater 2018).

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.

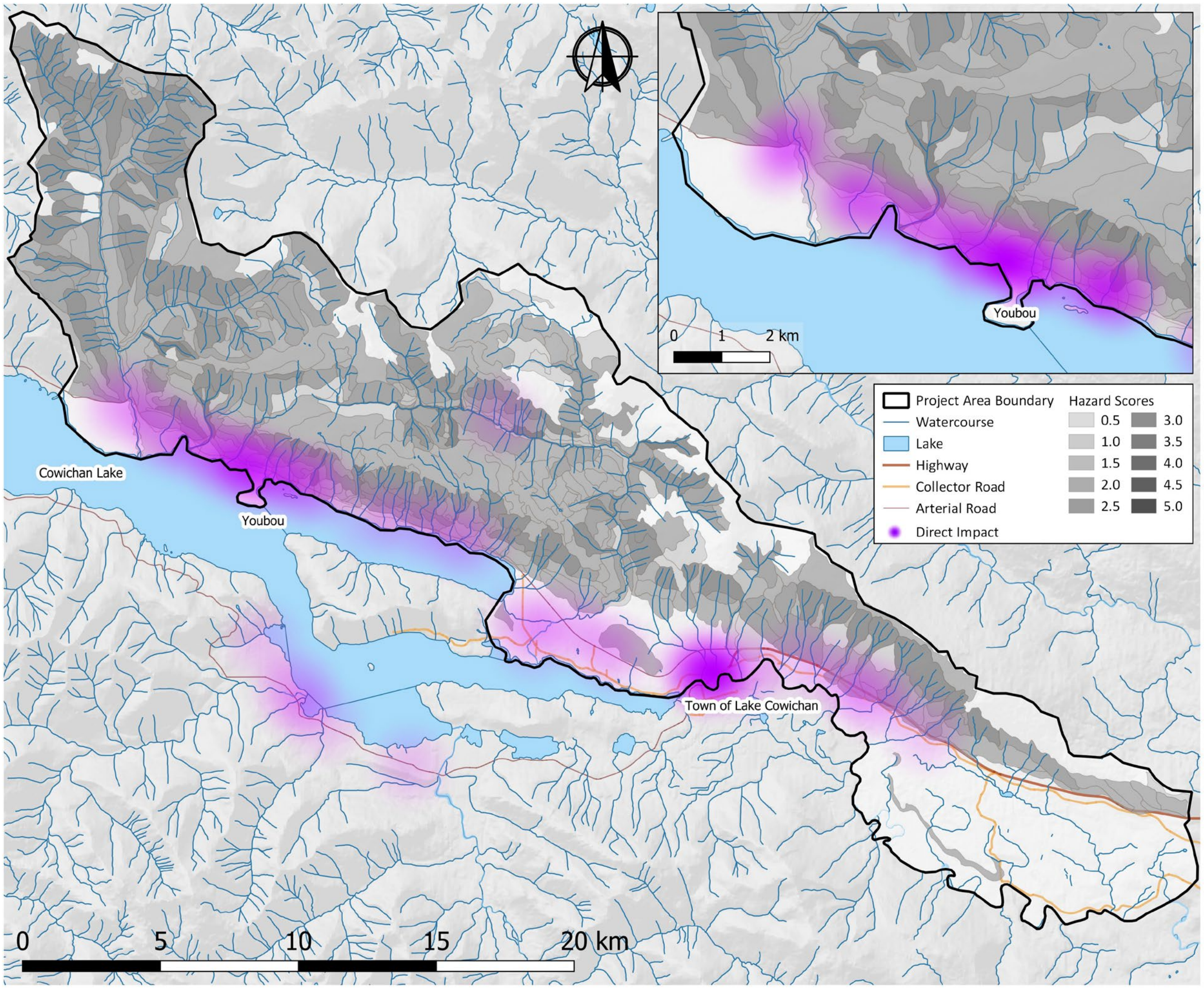

Figure 28: Direct impacts due to geohazard with input from stakeholders.

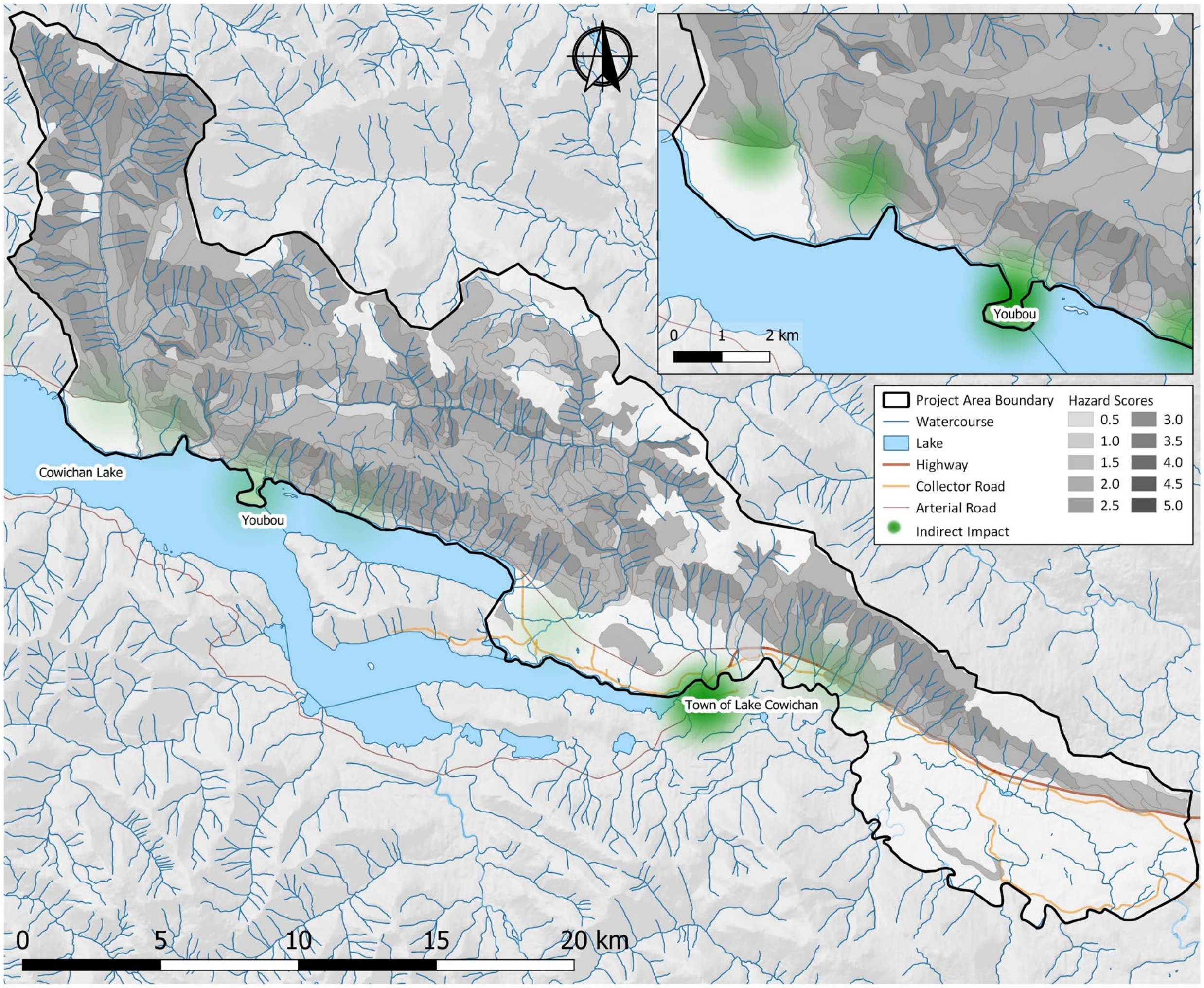

Figure 29: Indirect impacts due to geohazard with input from stakeholders.

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.

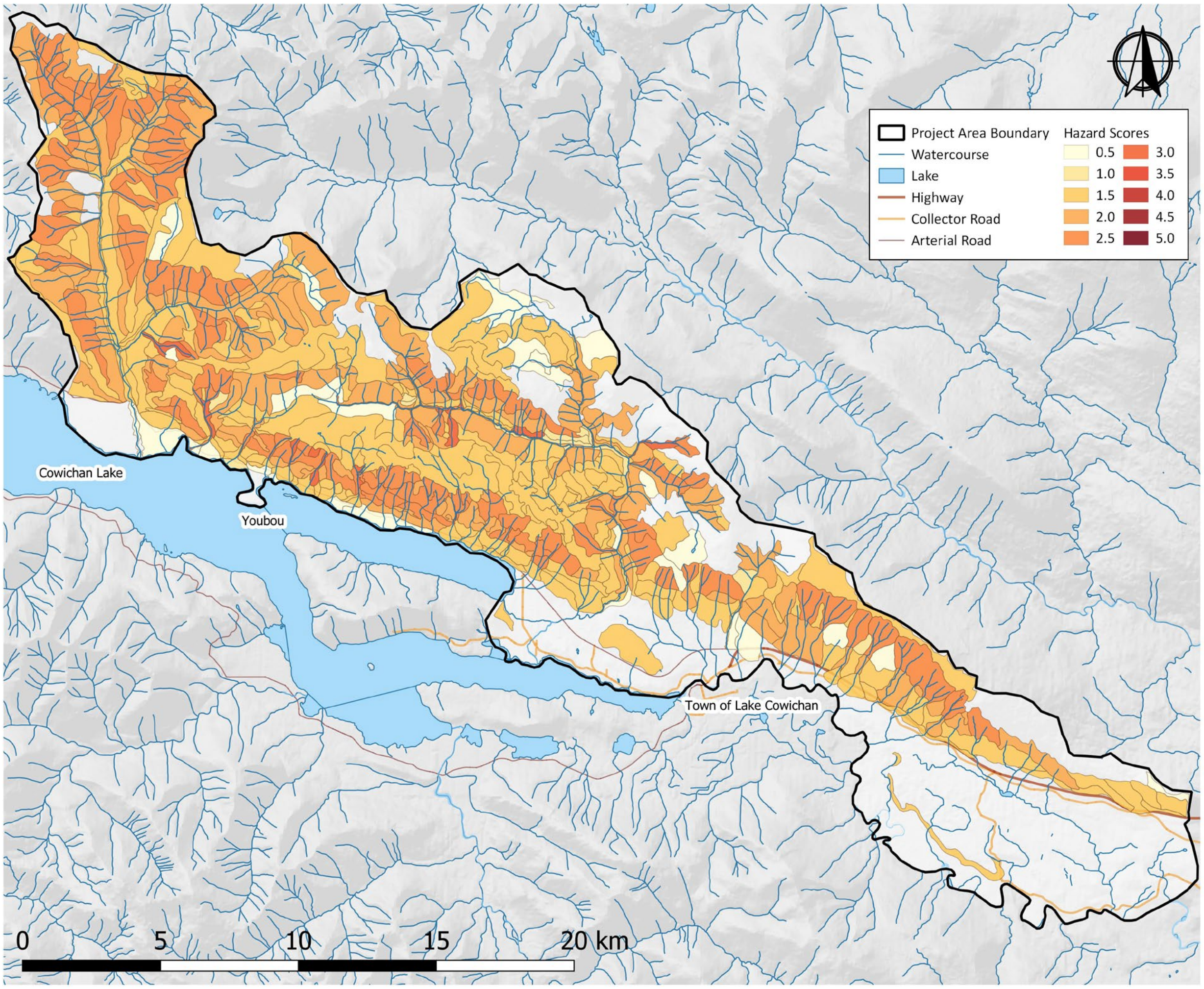

Figure 30: Hazard score map for project area.

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)[12]. 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 were no impact is calculated, then the scoring is set to 0; this approach has been taken specifically for

[12] 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
Mortality: Number of deaths and/or missing persons attributed to disasters		
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
Affected People: Number of directly affected people attributed to disasters*		
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
**Affected People Score based on ratio of the number of people directly affected compared to the population of Vancouver Island*		
Economic Consequences: Direct economic loss attributed to disasters in relation to approx. CVRD GDP		
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
***Economic Consequences Score based on Calculation of Score = Property Value in the hazard area/GDP of Vancouver Island * 100%*		
Critical Infrastructure and Disruption: Damage to critical infrastructure attributed to disasters		
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: • Energy and utilities • Information and communication technology • Water • Transportation • Safety		

Level	Score	Measure
• Finance • Health • Food • Government • Manufacturing Critical Infrastructure included here are bridges, sewers and roads		
Environmental: Damage to the environment		
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.
Cultural: Damage to cultural or heritage assets		
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[13] 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.

[13] 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

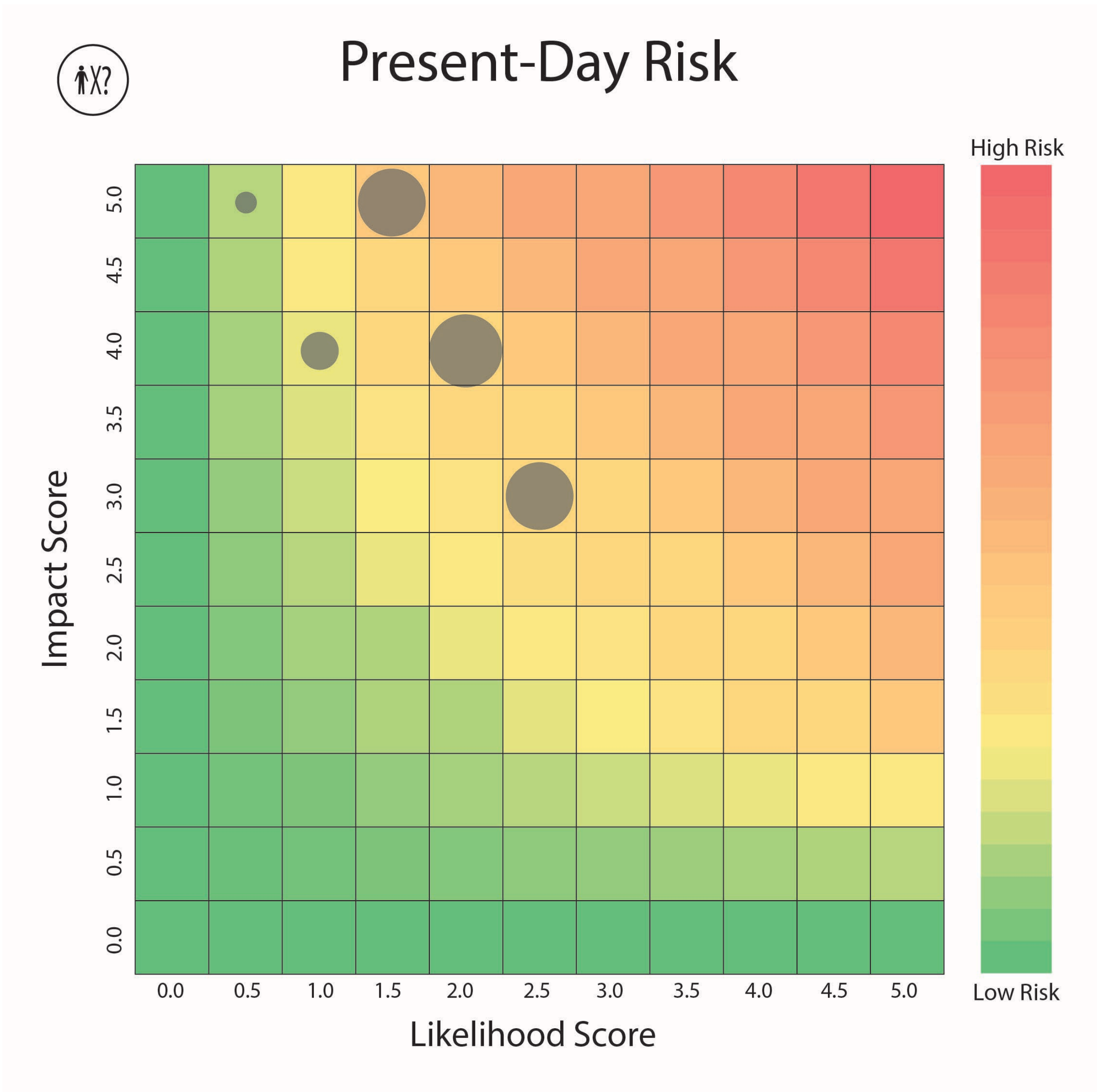

Figure 31: Risk figure – mortality and/or missing.

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

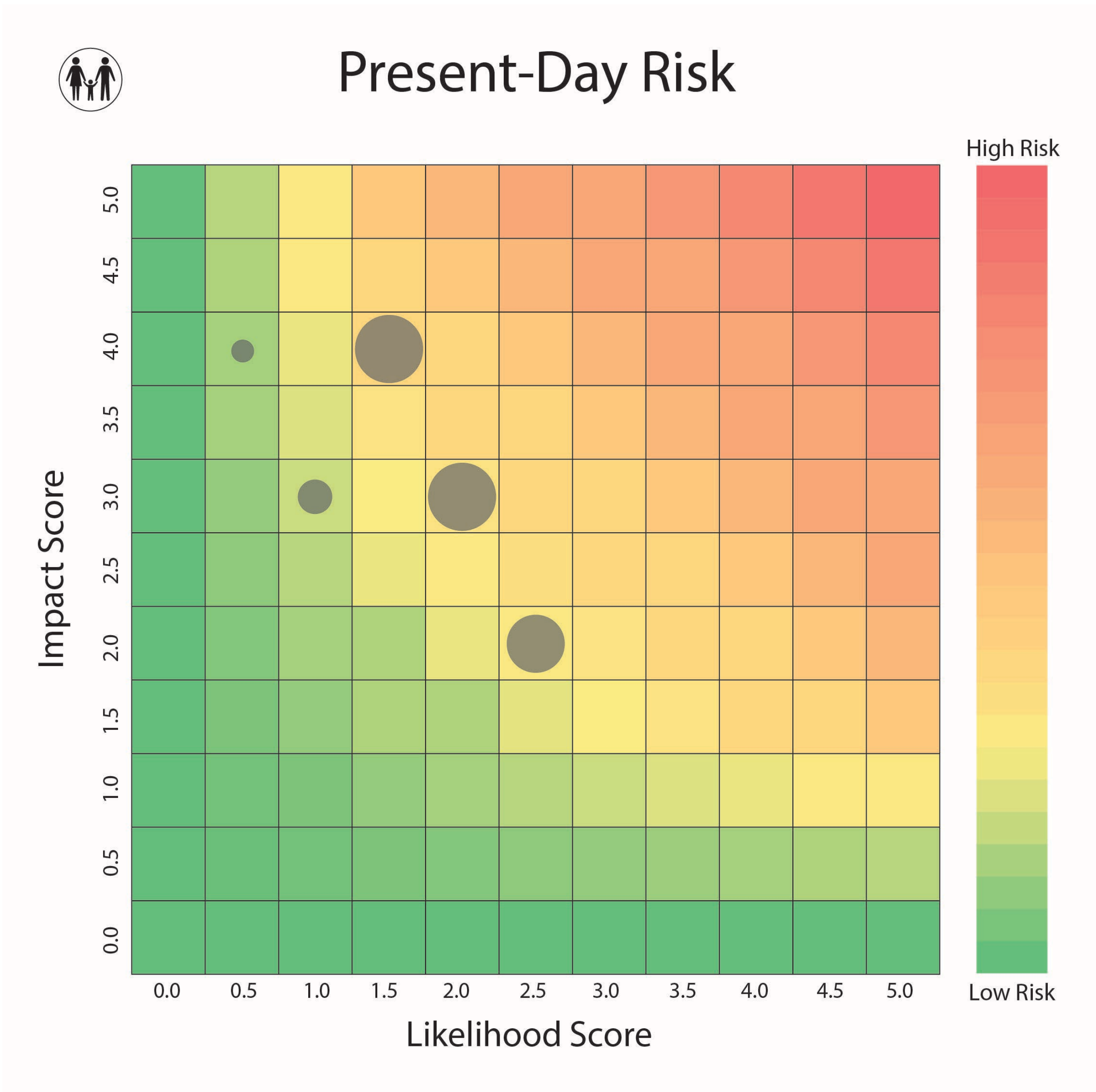

Figure 32: Risk figure – affected people.

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

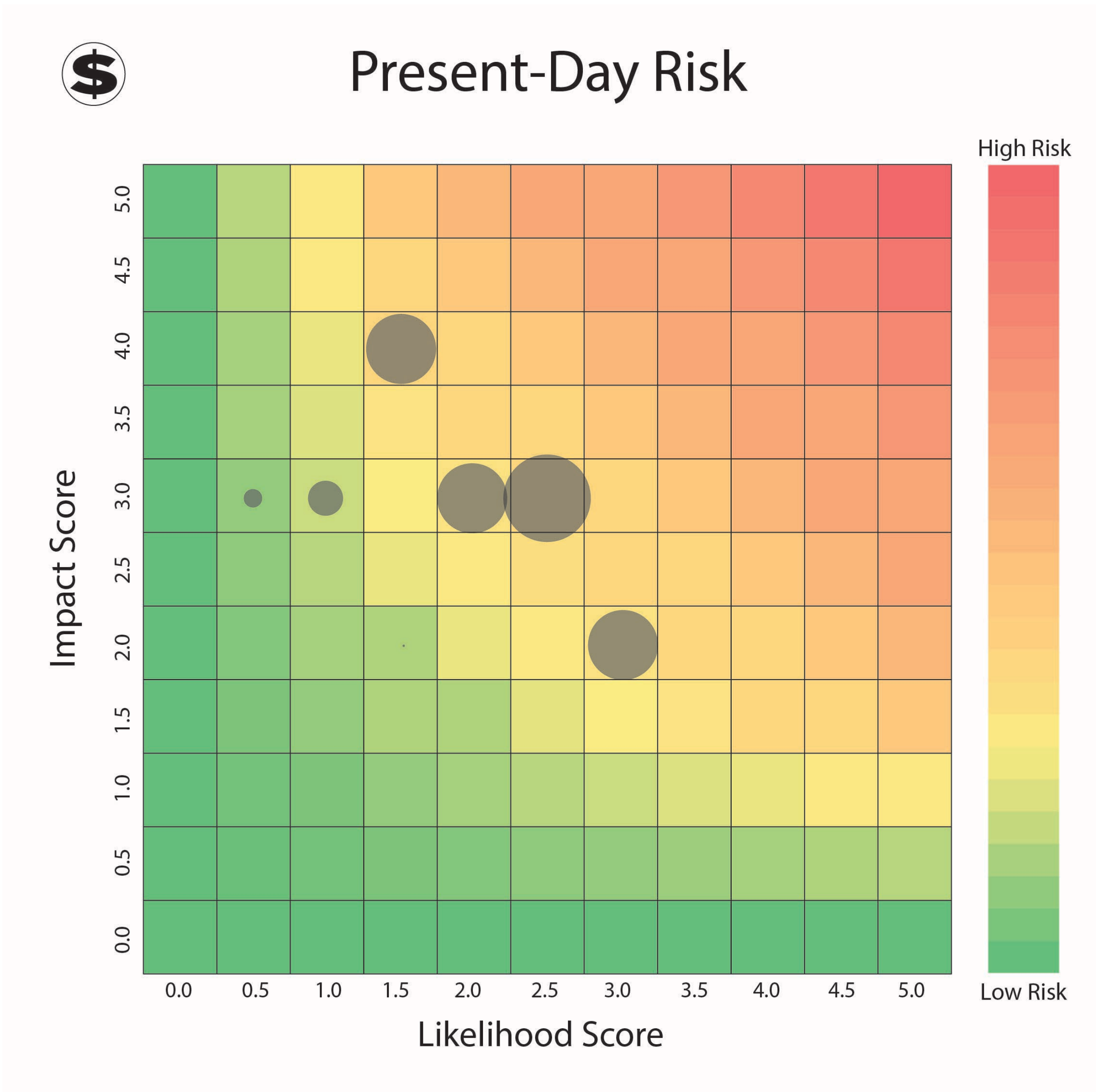

Figure 33: Risk figure – economic.

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.

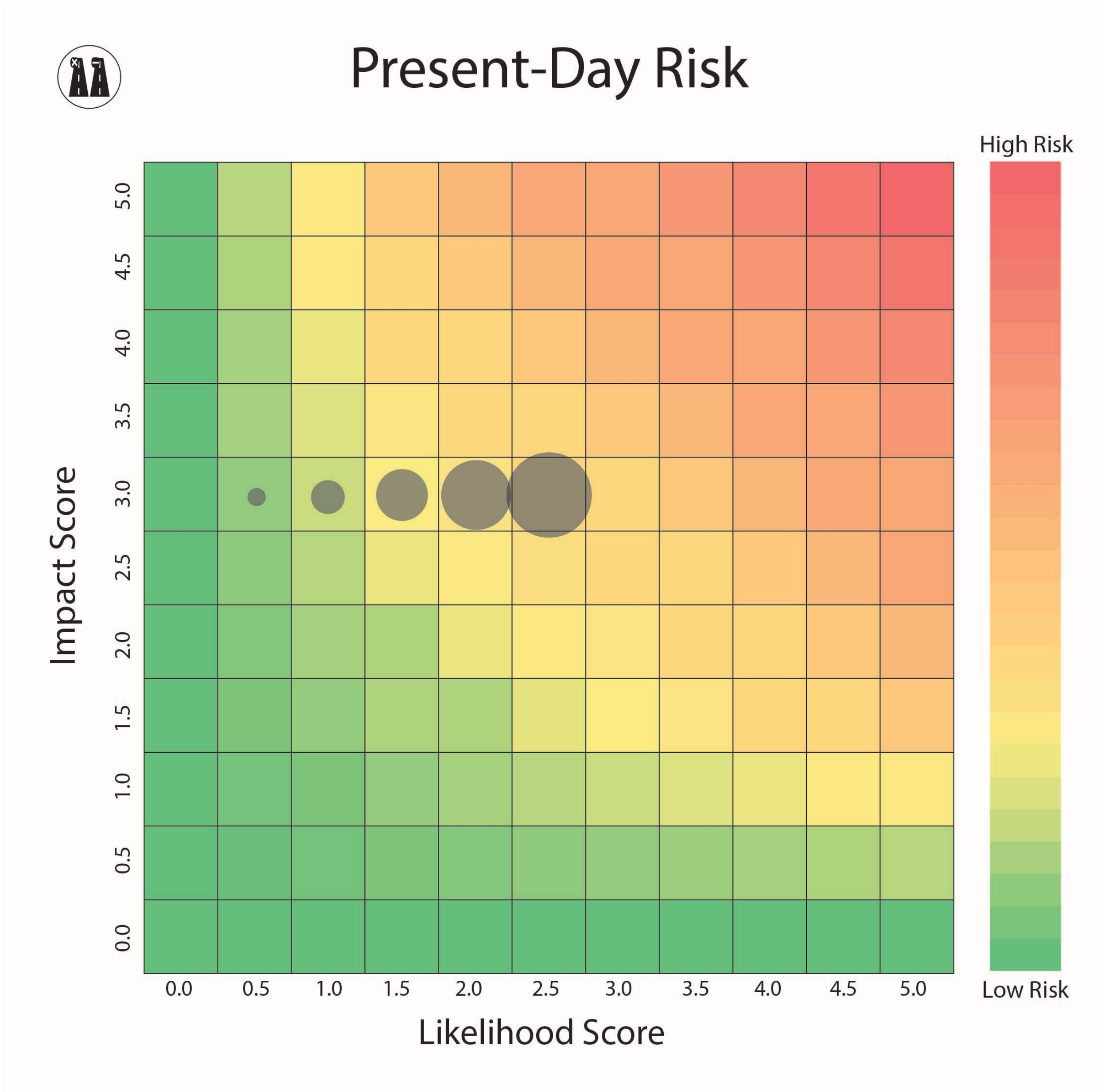

Figure 34: Risk figure – disruption.

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

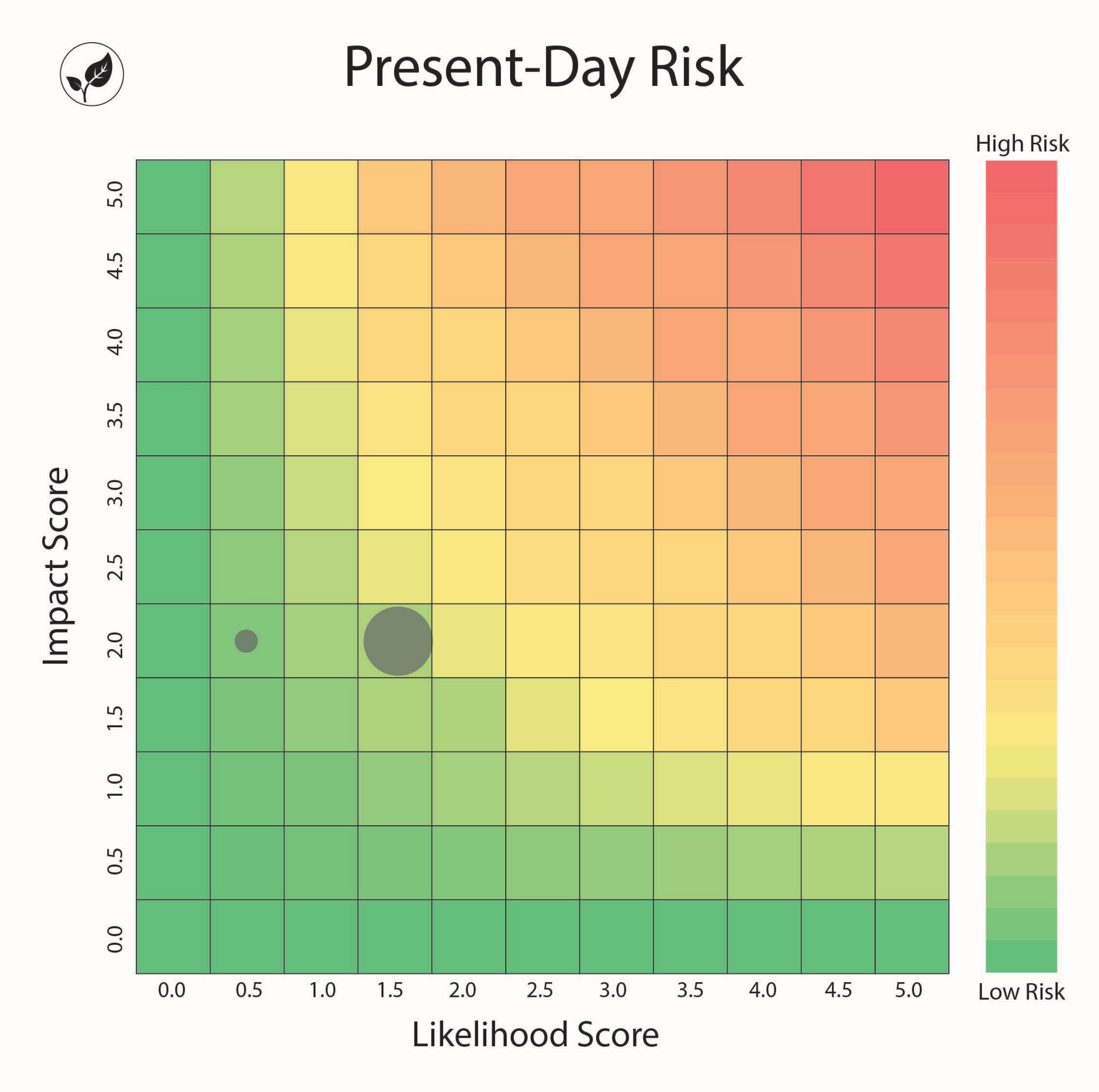

Figure 35: Risk figure – environment.

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 indictors. 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.

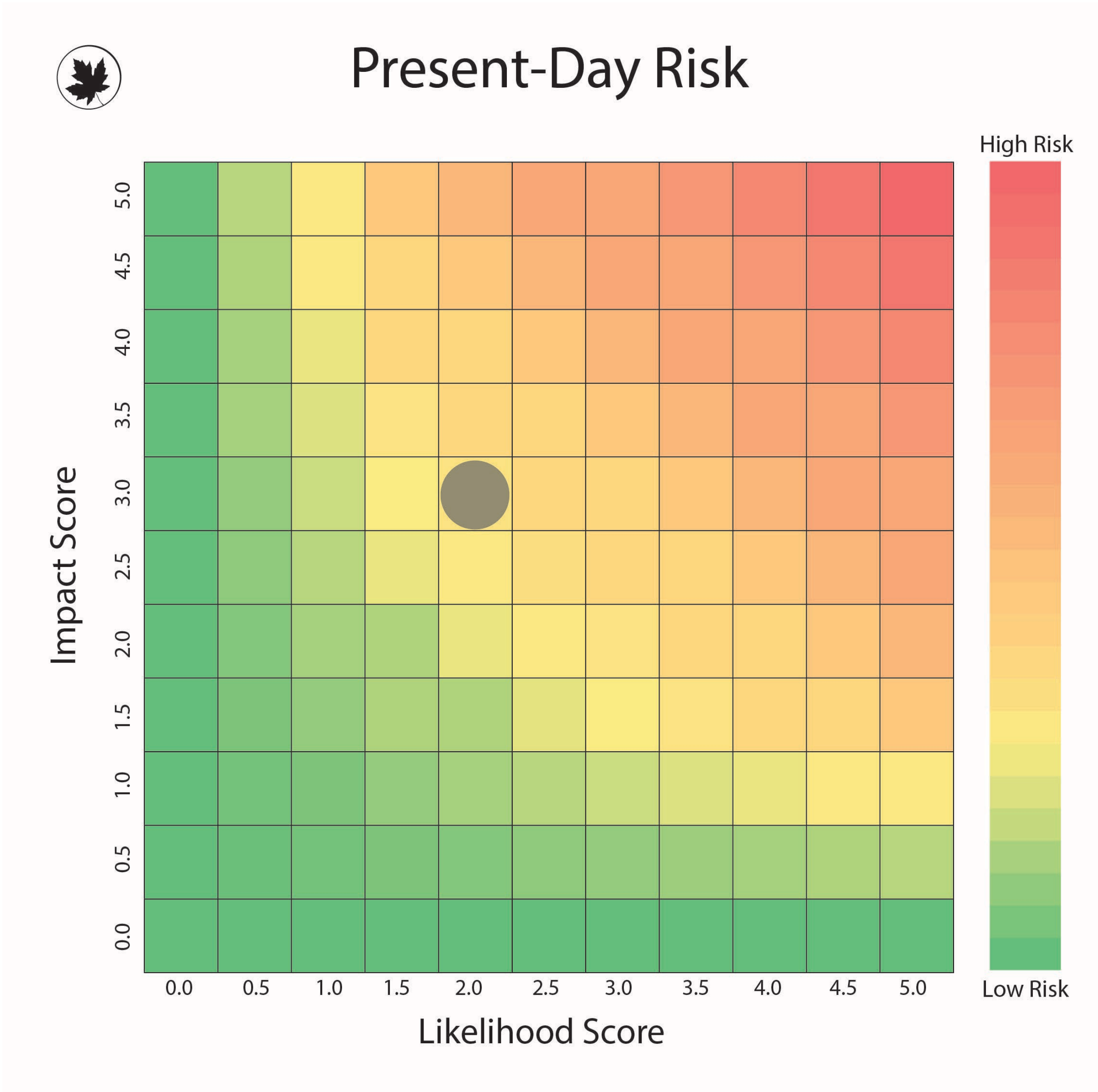

Figure 36: Risk figure – culture.

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
People (Mortality and/or Missing)	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.
Affected People	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.
Economic Consequences	$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.
Disruption	12 locations of overlap between hazard areas and road	Several disruption points were identified and weighted based on the importance of the asset.
Environment	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.
Culture	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

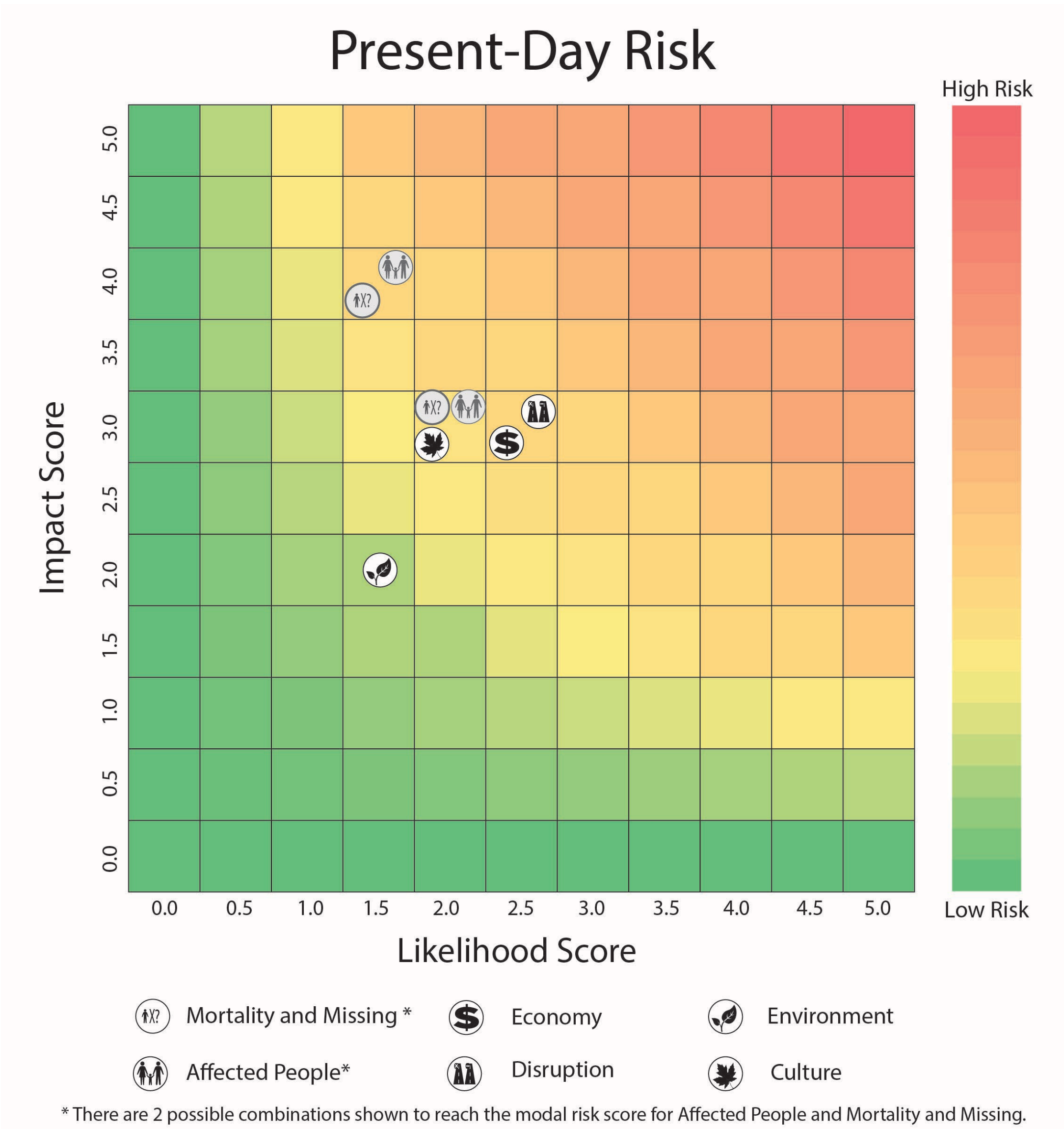

Figure 37: Geohazard risk assessment summary matrix (using modal risk scores).

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.

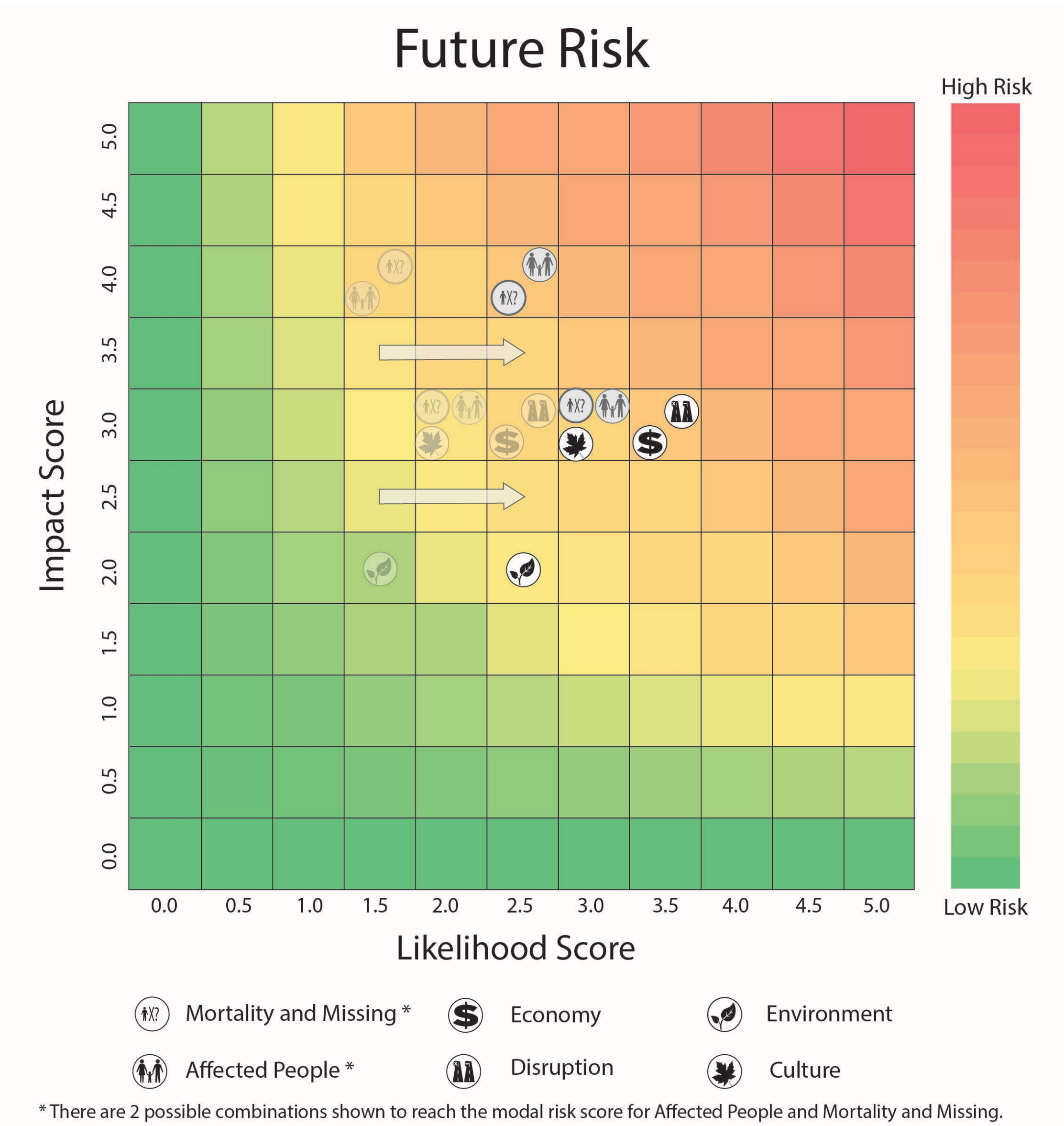

Figure 38: Future risk.

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 generally, 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.

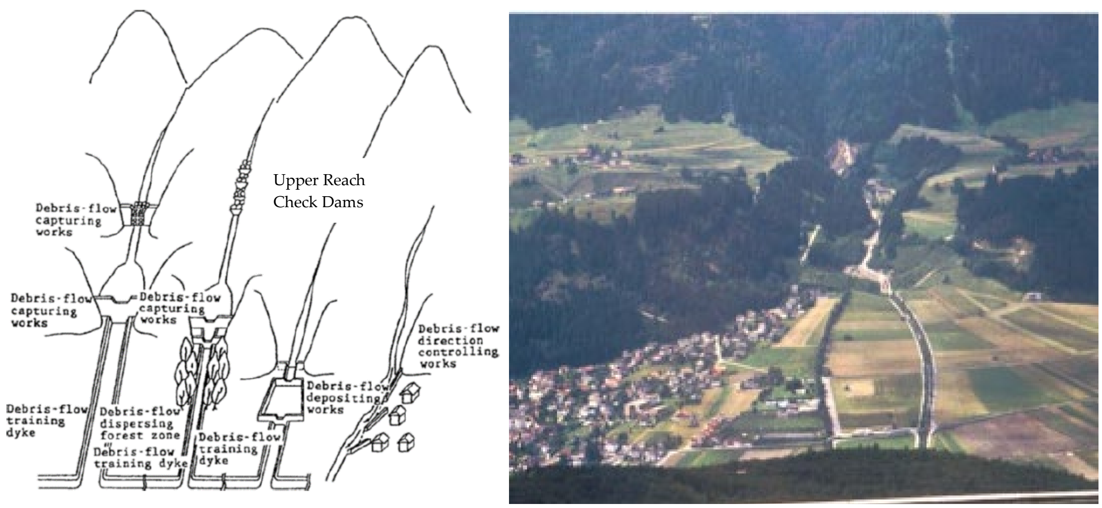

Figure 41: Examples of structural mitigation (left)(Okubo *et al.*, 1997) to reduce debris flow hazard, and an example of non-structural mitigation (right) in an area near Innsbruck, Austria, with spatial planning on an alluvial fan.

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
Non-Structural Mitigation – Category 1: Exposure reduction - spatial					
Update OCP/designate DPAs	• Planning documents could identify hazard zones spatially and implement a Designated Permit Area (DPA) for these zones (Porter and Dercole, 2011).	• Exposure and vulnerability reduced over time as new construction or renovations comply with the DPA.	• The OCP is produced by the CVRD for each electoral area. • 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	• 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. • 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).	• Affected People • Mortality and/or Missing • Disruption • Economic • Environment • Culture
Acquire exposed or repetitive loss properties	• Repetitive loss properties (if applicable) or properties in high hazard zones could be acquired (Porter *et al.*, 2007). • Reducing exposure by removing assets from harm's way is the surest means of reducing risk.	• Exposure reduction by removing people, structures, and assets of value from hazard areas.	• This has been done in other jurisdictions in BC. EMBC has recently expressed willingness to consider property acquisition for funding.	• Depending on property values, there can be significant financial obstacles. • Public support for this approach can also be a challenge.	• Affected People • Mortality and/or Missing

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Categories
Non-Structural Mitigation – Category 2: Exposure reduction – temporal					
Monitoring system	• Inspections of gullies and sidewalls can help to detect any signs of instability. • 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. • Regular slope inspections as part of monitoring system to evaluate the ongoing need for slide likelihood reduction measures (Porter and Dercole, 2011), (Porter *et al.*, 2017).	• A monitoring system provides timely slope condition information to support decision-making. • This can help with emergency management preparations and provide input to a warning system.	• This would be a new system/program for the CVRD. • On Private Managed Forest Lands, slope inspections and monitoring may be the responsibility of the landowner.	• Gully inspections would not require much in the way of equipment, etc. • Some level of monitoring and tracking could be a cost-effective option and significantly decrease risk to life. • It would likely be cost prohibitive to instrument all possible source slopes.	• Affected People • Mortality and/or Missing

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

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Categories
Bedroom relocation	• Vulnerability reduction measure for homes. • 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 *et al.*, 2007).	• This reduces risk as it reduces the exposure of people during the night. • This is effective if only a portion of the house is affected by a landslide event. • Limited effectiveness for higher hazard levels.	• This is something that has been considered by the DNV. • This could be integrated into planning documents.	• This would be a new approach and would require public support. • It would be applied over time.	• Mortality and/or Missing
Non-Structural Mitigation – Category 4: Improved response and/or recovery					
Emergency management planning	• Emergency management planning should be based on the best available information of hazards and likely consequences. • New information from risk assessment should be integrated into emergency management plans (Porter and Dercole, 2011).	• Reducing vulnerability over time with better response planning. • Improve life safety with effective evacuations.	• Integrated with current Emergency Management Plans and relevant supporting authorities.	• Some capacity-building effort will be needed to integrate new information from risk assessment. • Likely a low-regrets option. • Would perform better with a warning system in place.	• Affected People • Mortality and/or Missing

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Categories
Establish risk tolerances (to support public education and implementation of other measures)	• Engage stakeholders and possibly members of the public to establish risk tolerances. • This can be applied to asset management, land development divisions, and life safety measures. • 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 *et al.*, 2007).	• Establishing risk tolerances will help to set a threshold for "acceptable risk". • With this determined, areas of "unacceptable risk" can be identified.	• CVRD has expressed interest in establishing risk tolerances across the region. • This will help to support risk mitigation and strategic planning around hazards.	• The process of eliciting risk tolerances is challenging, requiring sufficient background information and consideration for process. • This can help to address other hazards.	• Affected People • Mortality and/or Missing • Disruption • Economic • Environment • Cultural
Risk communication strategy	• Communication with stakeholders and public as appropriate related to understanding geohazard risk (Porter and Dercole, 2011).	• Helps to improve public understanding of problem. • Can build local capacity and resilience.	• CVRD has already developed excellent communication plans on climate and risk. This could build on previous work.	• This can be integrated into the ongoing climate communications work by the CVRD.	• Mortality and/or Missing

Table 21: Structural landslide mitigation measures.

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Category
Structural Mitigation – Category 1: Surface protection – erosion control					
Restoration of Vegetation or Geosynthetics	• Restoration of vegetation to promote interception of precipitation, attenuate runoff, and promote stronger root networks OR addition of geosynthetics to achieve soil stabilization.	• Effective for some small areas but not large debris flow zones.	• Appropriate for site-level application in some zones.	• Not appropriate for large-scale application across the project area.	• Affected People • Mortality and/or Missing • Disruption • Environment (if restoration)
Structural Mitigation – Category 2: Deviating the path of landslide debris					
Increase conveyance capacity of channel and crossing (culvert/bridge)	• Increases to channel/crossing capacity to make space for debris flow conveyance (Porter *et al.*, 2017). • Possible for some zones where there is space to increase capacity. • This is a common option for debris flow management.	• This reduces the hazard by inhibiting the build-up of material behind crossings. • Sudden failure of crossings can be avoided.	• Modifications to road at creek crossings.	• Road ownership to be addressed. • Could be expensive and should be combined with other road works.	• Affected People • Mortality and/or Missing • Disruption
Diversion channel away from development	• Construction of diversion channel to transport debris away from exposed elements (Porter *et al.*, 2017). • This is considered to be a reasonable option for debris flow management.	• This reduces the hazard by providing an alternative pathway for material away from vulnerable areas.	• Modifications to land where new channel would be needed.	• Land would need to be acquired.	• Affected People • Mortality and/or Missing • Disruption

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Category
Deflection berms	• Earth or structural berms to deflect potential debris flow away from exposed elements. • These tend to require a large footprint and be constructed on relatively gentle slopes (Porter *et al.*, 2007), (BGC Engineering Inc., 2010). • This is a common option for debris flow management.	• This reduces the hazard by deflecting material away from vulnerable areas.	• Modification to land where berm would be placed.	• Land would need to be acquired.	• Affected People • Mortality and/or Missing
Structural Mitigation – Category 3: Dissipating the energy of debris flows					
Debris-restraining structure	• Physical nets/geo-grids/stakes can be used to restrain movement of source material. • Large diameter for larger debris.	• Reduces the severity of the hazard by trapping large debris.	• Installed in the channel.	• Sufficient space and access for installation required.	• Affected People • Mortality and/or Missing
Structural Mitigation – Category 4: Arresting and detaining landslide debris or rock fall					
Debris-resisting barrier	• Barrier installed to block the flow of debris.	• Reduces hazard by providing a barrier to downslope flow of material.	• Barrier constructed upstream of vulnerable area.	• Sufficient space and access for installation required.	• Affected People • Mortality and/or Missing
Debris-flow detention basins	• Construction of a debris-flow trap (detention basin) could be considered to contain material flowing down the slope (Porter and Dercole, 2011),(Porter *et al.*, 2017).	• Reduces the hazard by providing space for the flow material to accumulate.	• Detention basin constructed upstream of vulnerable area. • This option has recently been selected for Cougar Creek, Canmore, at a cost of $43M.	• Good option for debris flow hazard reduction but can be costly. • Sufficient space and access for construction required.	• Affected People • Mortality and/or Missing

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.

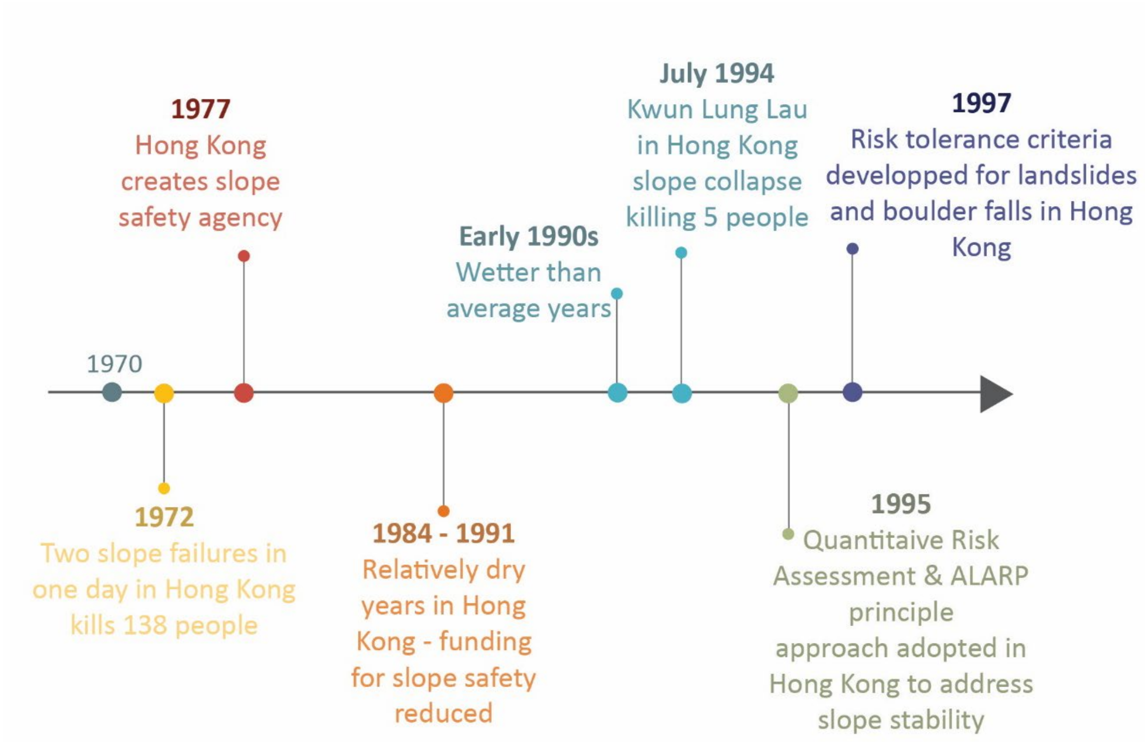

Figure 43: Timeline of policy development for landslide hazard in Hong Kong (Adapted from (Malone, 2005)).

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.

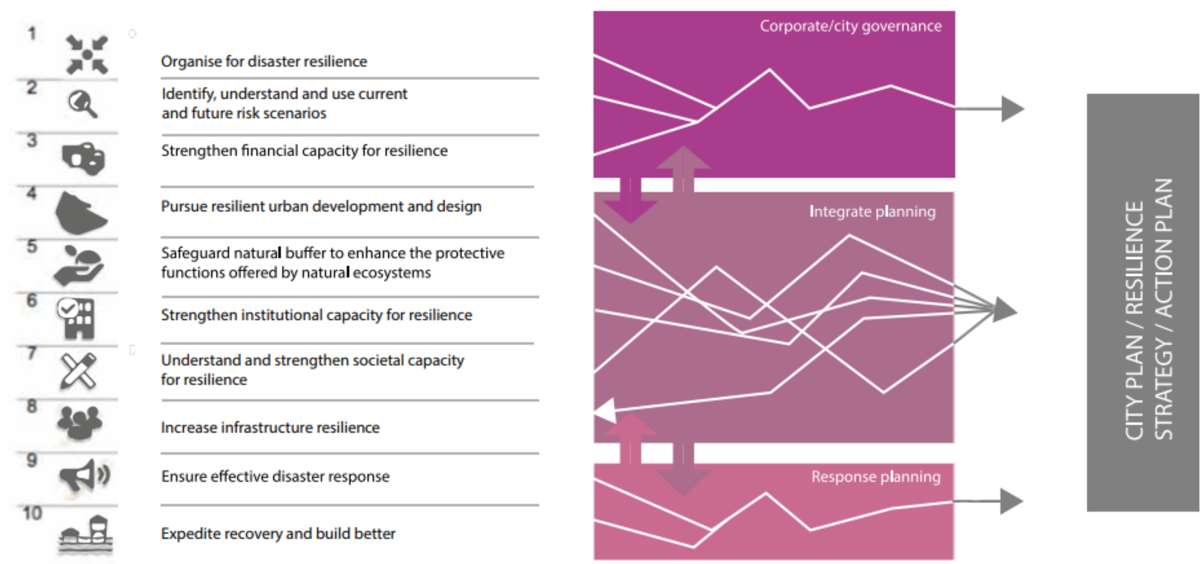

Figure 44: Ten essentials for making cities disaster resilient (United Nations Office for Disaster Risk Reduction, 2017).

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."

Progress	The CVRD has recognized that natural hazard risk is an important issue. This may support buy-in for the development of a resilience strategy.
Next Steps	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. 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. 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.

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."

Progress	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.
Next Steps	Currently, the CVRD is working on several case studies to inform regional policy on climate adaptation and mitigation and natural hazard risk reduction. 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

	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. 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. 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.

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."

Progress	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.
Next Steps	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.

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."

Progress	For geohazard, this has not yet explicitly been considered in CVRD land use and planning policy, nor in corporate decision-making documents.
Next Steps	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.

	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). 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.

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."

Progress	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.
Next Steps	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 *Private Managed Forest Land Act* [2003] to include natural hazards. It may also be possible to leverage the *Water Sustainability Act* [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. 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.

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."

Progress	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.
Next Steps	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. 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.

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."

Progress	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.
Next Steps	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. Consider interdisciplinary approaches to community-based risk tolerance and reduction activities.

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."

Progress	This project considered the impacts of geohazards on roads, creek crossings, power infrastructure, and water infrastructure. The CVRD has also recently completed climate-based risk assessments of its assets, as a component of its integrated asset management strategy.
Next Steps	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. 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). 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.

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."

Progress	This project engaged local stakeholders responsible for disaster response through workshops 1 and 2. This included members of the RCMP and Ambulance Services.
Next Steps	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. Updated and well-conceived emergency preparedness and response plans will help to lessen the impacts of hazards on local communities. Activities may include regularly updating plans, communicating the plan to all stakeholders, and guidelines or regulations regarding preparedness. Early warning systems can help in this endeavour as they provide information that can tie in with activating different aspects of a response plan.

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."

Progress	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).
Next Steps	Expediting recovery and building back better presents an opportunity when a hazard event does occur. 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. 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.

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 difference 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 it 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 adaption, 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.	MODFIED 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 *likelihood.*	PSC
Quantitative Risk Assessment	A *risk assessment* 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	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. 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.	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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Appendix A Risk Assessment (Generic)

The following provides information that could be included in a risk assessment. It is based on the expected future form of the NMDP RAIT. Elements that should be included in the form are highlighted in green.

Appendix A Risk Assessment (Generic)

The following provides information to inform the completion of risk assessments templates or forms. It is based on the expected future form of the National Disaster Mitigation Program (NMDP) Risk Assessment Information Template (RAIT), which could be used if the NDMP is renewed or reconfigured. It also includes relevant information for the completion of the natural hazard risk components of the Disaster Mitigation Adaptation Fund (DMAF). Further, this provides a summary of risk information for the project area, which will be used by the CVRD to build a case study. Details on the methods and meaning of the risk assessment is presented in the main body of the report. This section merely provides hazard, exposure, and risk scores that can be input directly into forms for the various funding agencies or score summaries.

1 Geohazard Risk Assessment

These scores are calculated using the geohazard encounter probability scores and exposure information within the exposed area. Details on the hazard and exposure are found elsewhere in the report. The selected score is highlighted in green.

Likelihood

Table 1: Likelihood rating for generic risk assessment for geohazard in project area.

Likelihood Score	AEP	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
**Note: These hazard scores represent the range of probabilities in areas where there is exposure.		

Impacts

Table 2: Proposed impacts ratings for debris flow.

Level	Score	Measure
Mortality: Number of deaths and missing persons attributed to disasters, per 100,000 population		
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

Level	Score	Measure
Limited	1	Deaths less than 0.1 per 100,000
Affected People: Number of directly affected people attributed to disasters, per 100,000 population*		
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
**Affected People Score based on Calculation of Score = Affected People/Population of Cowichan Valley Regional District * 100,000*		
Economic Consequences: Direct economic loss attributed to disasters in relation to Vancouver Island GDP**		
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
***Economic Consequences Score based on Calculation of Score = Property Value in Flood Hazard Area/GDP of Cowichan Valley Regional District * 100%*		
Critical Infrastructure and Disruption: Damage to critical infrastructure (CI) attributed to disasters***		
Catastrophic	5	>100 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 (<6 hours) disrupted
CI facilities are represented by the CI sectors in the National Strategy for Critical Infrastructure (Government of Canada) and include: • Energy and utilities • Information and communication technology • Finance • Health • Food • Water • Transportation • Safety • Government • Manufacturing ***Critical Infrastructure included here are bridges, sewers, and roads		
Environmental: Damage to the environment.		
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

Level	Score	Measure
Cultural: Damage to cultural or heritage assets.		
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

Risk Summary – Geohazard in the Project Area

Table 3: Summary of geohazard likelihood scores and exposure scores in the project area.

Element	Hazard Likelihood Score	Exposure Score
People (Mortality & Missing)	2.0	3.0
Affected People	2.0	3.0
Economic	2.5	3.0
Disruption	2.5	3.0
Environment	1.5	2.0
Cultural	2.0	3.0

Appendix B Completed RAIT Form

Provided separately due to protection settings on RAIT form.

Appendix C Workshop Outputs

Two workshops were conducted with local stakeholders in the Town of Lake Cowichan to gather input for the risk assessment, communicate results, and build local capacity:

- Workshop 1 – July 13, 2018
- Workshop 2 – October 2, 2018

This Appendix includes the following materials related to these workshops:

- Workshop 1 Report
- Workshop 1 Presentation Slides (included in Workshop 1 Report Appendix)
- Workshop 2 Map Package (included in Workshop 1 Report Appendix)
- Workshop 2 Presentation Slides

Cowichan Valley Regional District
Geohazard Risk Assessment: North Slope of Cowichan Lake
Workshop 1 Summary Report: Setting the Stage

July 13, 2018

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

ebbwater CONSULTING

Cover Photo: Photo from Stakeholder Workshop in Lake Cowichan, April 24, 2018

(own photo)

ebbwater CONSULTING

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Contents

Figures

Tables

1 Introduction to the Project

The project area is home to a stunning landscape of mountains and water, which makes it a desirable place to live and visit. However, these features also expose the community to several types of natural hazards. This includes geohazards, such as debris flow, debris slide, rock fall, and rock slide. Some areas on the north slope of Cowichan Lake are located in a high hazard area, meaning that people, buildings, economic assets, and infrastructure may be exposed. From the hazards included in the this project, the main hazard for these areas is debris flow, resulting from saturated material along creeks, mobilizing and flowing downhill.

The Cowichan Valley Regional District (CVRD) and its partners were successful Stream 1 applicants to the National Disaster Mitigation Program (NDMP), and now have the opportunity to explore the natural hazards, impacts, risk, and resilience strategies for the project area. The **objective of this project is to understand the risk from geohazards, specifically debris torrents, in the area**, which can then inform risk reduction and resiliency planning for the future. The CVRD has engaged Ebbwater Consulting (Ebbwater) and Palmer Environmental Consulting Group (Palmer) to support them in this endeavour. The location of the project area is presented in Figure 1.

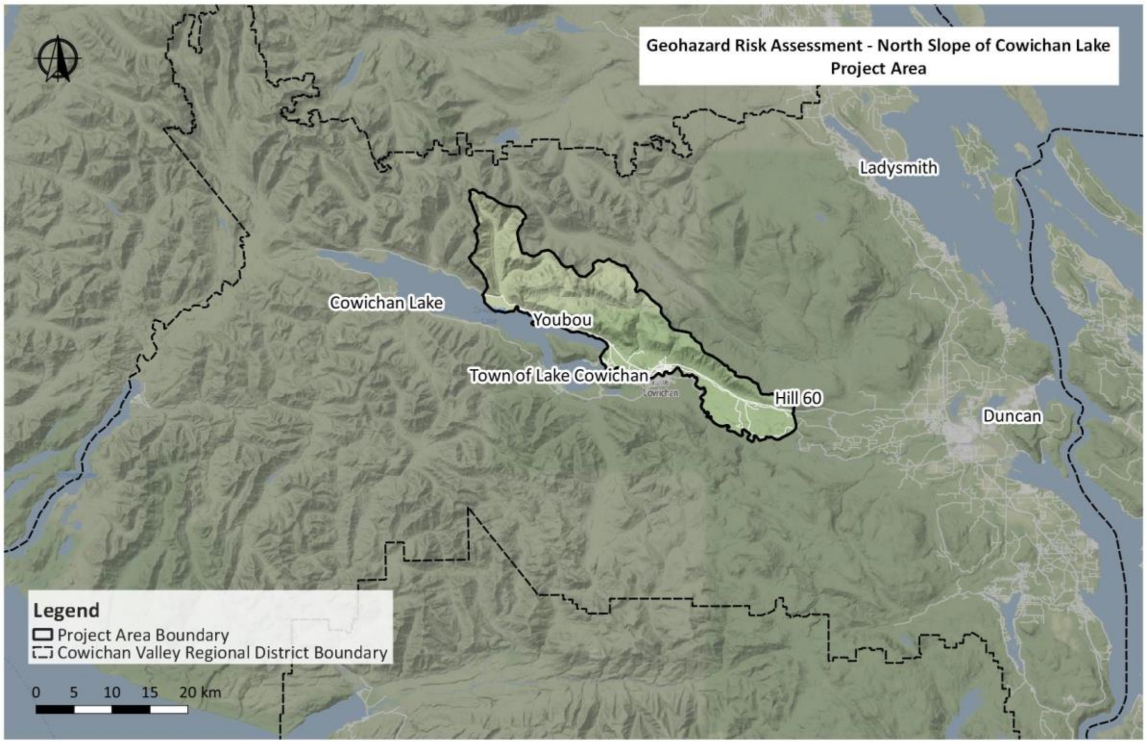

Figure 1: CVRD geohazard risk assessment project area map.

At this stage, the consulting team has begun to characterize the hazards in the area. Ebbwater and Palmer facilitated a workshop in the Town of Lake Cowichan to learn from the community about the potential impacts and consequences of these hazards. This information will inform the development of a risk assessment for geohazards and enable the CVRD and its partners to apply for funding from senior levels of government for future phases of work. The phases of this project are outlined at a high level in Table 1.

Table 1: Project timeline.

Stage	Timing	Status	Objectives
Setting the stage	January 2018	Complete	• To build a shared understanding of risk assessment, and project goals and objectives. • To establish if there are opportunities for data sharing to support the risk assessment.
Desktop hazard mapping	Winter 2017/2018	Complete	• To establish a preliminary understanding of geohazards in the project area.
Understanding exposure by learning about community values and impacts (reported on in this document)	April 2018	Complete	• To gather relevant local information about potential direct and indirect impacts of geohazards.
Further analysis of hazard (field visits), exposure, and risk	Spring/Summer 2018	In progress	• To ground-truth and validate the desktop hazard study. • To improve and refine exposure and risk calculations.
Stakeholder ground-truthing and resilience-building workshop	Fall 2018	Upcoming	• To ground-truth and validate findings from the risk analysis.
Reporting and grant applications	Fall/Winter 2018	Upcoming	• Provide useful information and deliverables for future work.

It should be noted that this study is **limited to geohazards** and does not include other hazards that the project area could be exposed to. In other words, this is **not a full multi-hazard assessment;** as noted above, there may be other un-identified hazards. It should be noted, however, that there is concurrent work being done on flood hazards related to Cowichan Lake. The purpose of this document is to summarize the preliminary findings of a geohazard desktop study and the consultation with local stakeholders. This report provides a summary of the workshop (Section 2) and a description of next steps (Section 3). The appendices include the workshop agenda (Appendix A), list of workshop participants (Appendix B), background on risk assessment and geohazards (Appendix C), the workshop presentation slides (Appendix D), and full-page workshop maps (Appendix E).

2 Workshop Summary

Ebbwater Consulting and Palmer Environmental Consulting Group hosted a workshop with the CVRD on April 24, 2018 in Lake Cowichan. The objectives of this workshop were to:

- Develop a shared understanding of natural hazard risk (hazard, exposure, vulnerability) and principles of best practice for disaster risk reduction.
- Record impacts and vulnerabilities to natural hazards in the project area.
- Better understand stakeholder and community values and vulnerabilities as they relate to risk management.

Information was provided to the participants on what the project aims to achieve and where that fits into the longer process of disaster risk reduction for the area. The workshop agenda included the following activities:

- Welcome and introductions.
- Principles of best practice.
- Natural hazards risk in the project area.
- Managing natural hazard risk.
- Recording impacts of geohazards in the project area.
- Closing.

Background materials on the project and geohazards were also provided, and it was explained that the information collected would be used as part of a risk assessment for the area. This section presents what we heard from workshop participants.

2.1 Introductions and Best Practice

As part of the introductions, participants were asked to pair up with somebody at their table to introduce themselves and discuss which phase of the disaster management cycle they work in. The results of this exercise are presented in Figure 2. The placement of each gray dot represents a stakeholder and the location indicates the phase of the disaster management cycle that they work in.

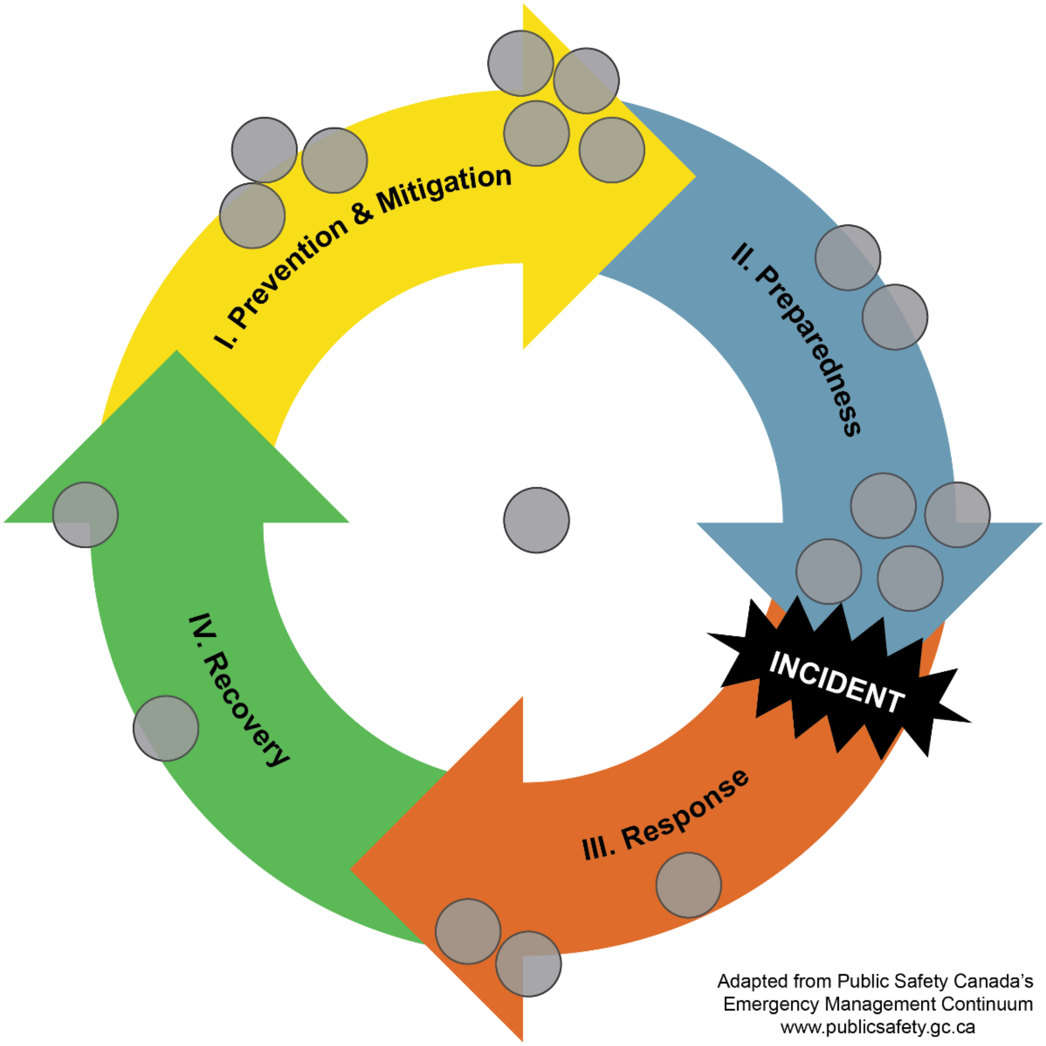

Figure 2: Disaster management cycle with dots showing the phase that stakeholders are working in.

It was found that many people in the workshop are focused on the first two phases of prevention and mitigation (Phase I) and preparedness (Phase II). Also, many of the participants are focused on more than one phase. Overall, the roles of stakeholders in the workshop cover all phases of the disaster management cycle. This suggests that input from stakeholders would draw from experiences across the cycle. This is good as challenges and potential solutions can be drawn from participants who have different knowledge bases. A summary of workshop participants is presented in Table 2 with the organization represented and the number of participants.

Table 2: Summary of workshop participants.

Organization	Number of Participants
BC Ministry of Transportation and Infrastructure	2
BC Emergency Health Services	1
CVRD	8
Emergency Management BC	2
Hancock Timber Resource Group	1
Lake Cowichan Fire Department	2
RCMP	1
Timber West	2
Town of Lake Cowichan	1

It should be noted that while stakeholders from all phases of the disaster management cycle were present, there was no participation of First Nations representatives in this session. However, input is being collected in separate meetings, and engagement of First Nations should continue through the project.

Following the disaster management cycle exercise, a discussion of best practices in natural hazard management was facilitated. Best practice dictates that it is best to manage for risk and enable resilience. Managing risk first requires a foundation of understanding risk, which must include its multiple components. This includes hazard and vulnerability, as well as the consequences and the likelihood of those consequences, as highlighted in Figure 3. More information on risk assessment can be found in Appendix C.

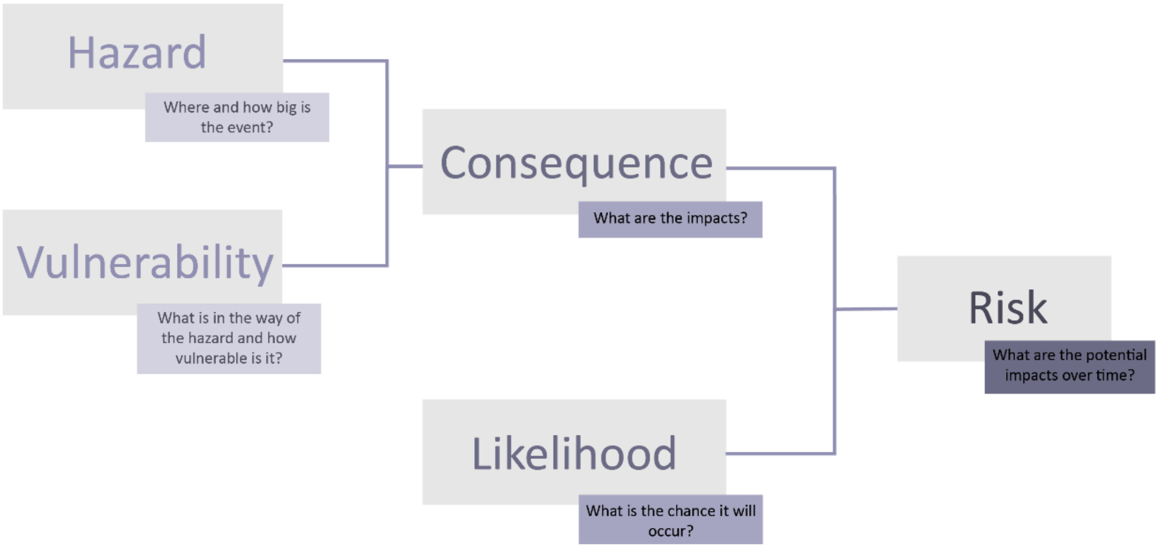

Figure 3: Risk as a function of hazard, likelihood, and vulnerability.

Given that the goal of this project is to help communities in the project area build resilience to natural hazards, stakeholders were next asked to state what they feel makes a safe, prosperous, and resilient community. The themes reported are presented as a word cloud in Figure 4.

Figure 4: Keywords from stakeholders on what makes a safe, prosperous, and resilient community.

The word cloud highlights what is important to enable resilience in the local community. Words that were reported more often appear larger in the cloud. In this case, many people felt that **community** and **emergency management** were important, as well as maintaining **communication**, **connection** within the community, and **planning**.

2.2 Managing Natural Hazards

Natural hazard management is a classic "wicked problem". Wicked problems are 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.

Furthermore, many players and perspectives are involved. Workshop participants were asked to think about how they had experienced natural hazard as a wicked problem. These were recorded during the workshop and are summarized as a word cloud in Figure 5.

Figure 5: Natural hazard as a wicked problem.

The issues reported by the workshop participants highlight some key trends. First, establishing risk tolerance is a major challenge for natural hazard management, as there will always be a spectrum of tolerance to risk within a community. For example, while some voices may advocate for development in risky areas, others may wish to put more restrictions on this. Other challenges are related to coordination between jurisdictions, as occasionally a hazard will originate in one area but affect another. Issues such as **insurance**, **seasonal variation** within the population, **cost**, and **uncertainty** were also highlighted several times.

2.3 Reporting Impacts

To manage natural hazard, it is important to know not only where the hazards are, but also what might be affected. In line with the Sendai framework for disaster risk reduction, the six categories presented in Figure 6 were used to frame the discussion of impacts.

Figure 6: Impact categories for disaster risk reduction (DRR).

Participants were asked to think about what could be directly or indirectly impacted by a hazard in the project area. As shown in Figure 7, direct impacts occur when the hazard interacts directly with elements at risk.

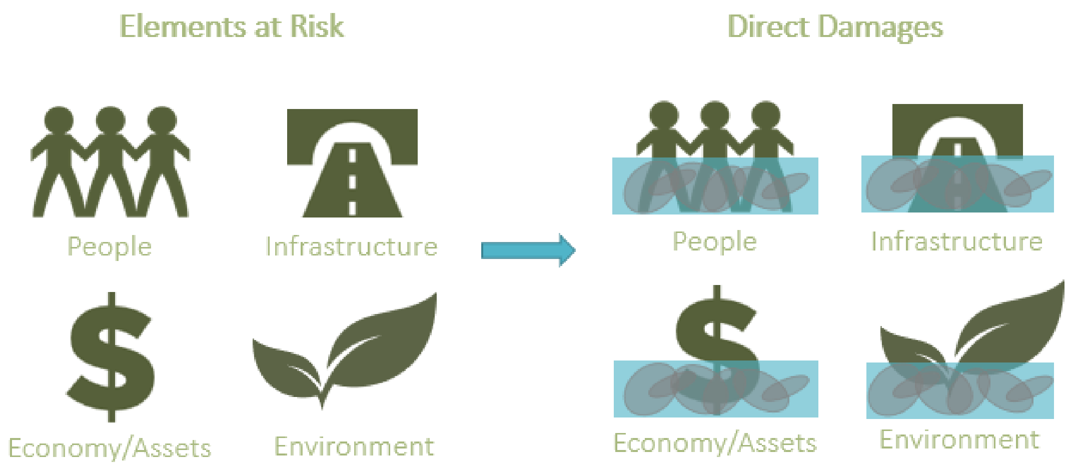

Figure 7: Understanding direct impacts of natural hazards.

It is important to also think about indirect impacts, which can be somewhat more complex. Indirect impacts will increase the spatial and temporal extent of the impact, meaning that an area larger than where the hazard occurs can experience disruption in some form. As shown in Figure 8, when road access is affected by a natural hazard, schools or other buildings may become inaccessible and emergency services may not be able to reach certain areas or may need to travel longer distances.

Figure 8: Understanding indirect impacts of natural hazards.

Workshop participants were asked to identify these kinds of impacts in the project area and then label them on the map. Direct impacts were noted on the maps with purple or pink labels and indirect impacts were labeled with green or yellow ones. Below are some photos of participants at the workshop mapping these impacts in the project area.

Figure 9: Workshop participants in Lake Cowichan, April 24, 2018.

The impacts mapped in the workshop by local stakeholders were recorded and input into a GIS database. These are presented in Figure 10 and Figure 11 in the form of hotspot mapping. Full-size maps are presented in Appendix E. Hotspot mapping shows zones with many reported impacts at a high level with a larger area of colour. These maps help to identify the preliminary zones within the project area that could be affected during a geohazard event based on stakeholder input. More detailed impact mapping will be developed at a later stage, once more detailed hazard and vulnerability information is available and additional quantitative assessments are conducted.

The draft hazard inventory and encounter probability scores were produced using the completed desktop hazard study. The hazard categories and locations were identified using terrain elevation information. The encounter probabilities are calculated based on historical hazard events in terms of geological time. The encounter probability scores were assigned based on the proposed national risk assessment methodology with probabilities ranked according to a logarithmic scale.

Table 3: Likelihood score ranked by probability.

Likelihood Score	Annual Exceedance Probability (AEP)	Estimated Frequency (once every X years) (Indicative)
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

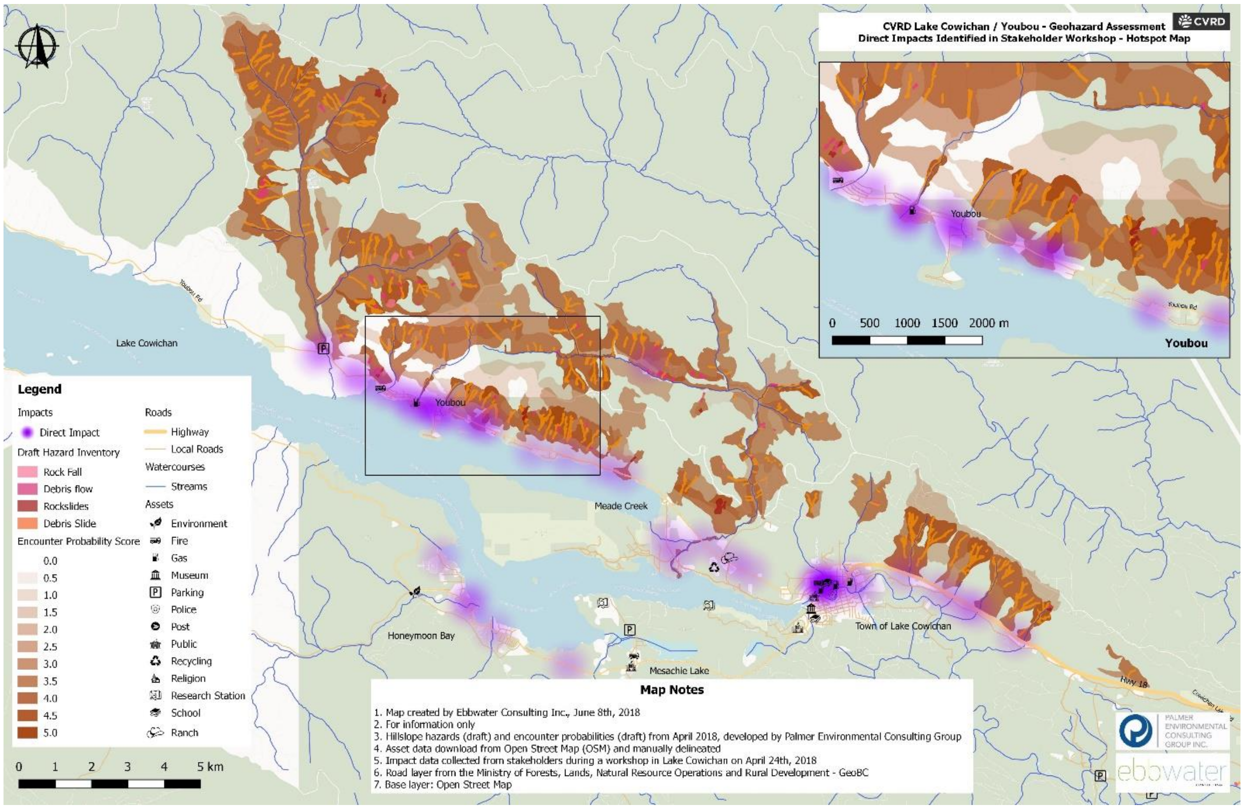

Figure 10: Direct impacts map created from stakeholder input.

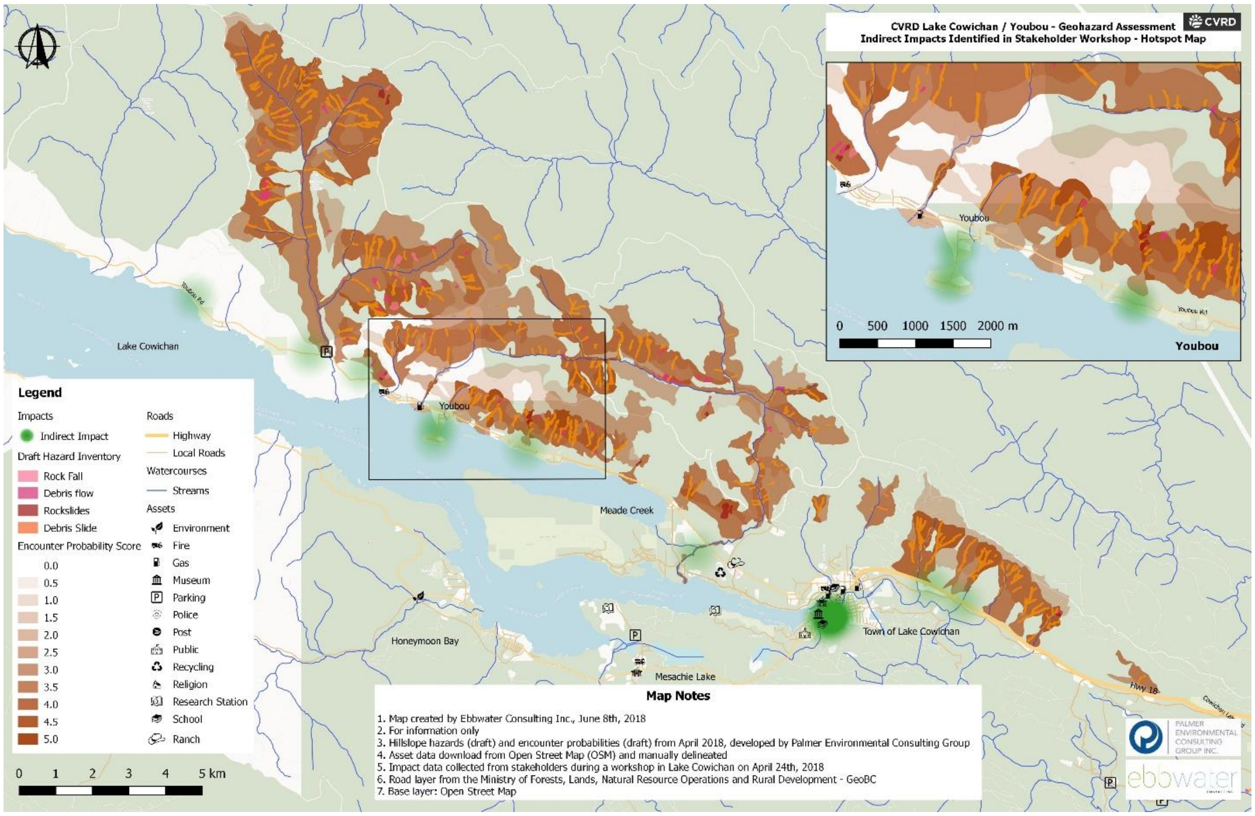

Figure 11: Indirect impacts map created from stakeholder input.

The hotspot mapping of direct and indirect impacts highlights a few trends to consider. First, direct impacts were identified across the project area. They include things like damage to homes, roads, and bridges after a failure. It was mentioned several times that the community would be quite vulnerable to road closures, as there is only one main road to access the Town of Lake Cowichan. Furthermore, since there is a just single road providing access to the areas around the lake, communities such as Youbou are also particularly vulnerable to any road obstructions or damage to other linear infrastructure. In general, linear infrastructure in this area, such as roads, power lines, and telecom lines are mostly non-redundant. This means that disruption in one part of the network would likely have consequences for several areas of the community. Furthermore, these features are spread along large distances and often at the bottom of a slope where material would fall or flow. Direct impacts could also include drinking-water wells or affected community buildings.

While the direct impacts reported by stakeholders are well distributed across the project area, the indirect impacts are mostly concentrated in settlements. This means that when the road is blocked, or the power is out, people in residential areas are without access or power. This makes sense, as indirect impacts are experienced by the people who would normally be using those services. A list of the direct and indirect impacts reported in the workshop is provided in Table 4.

Table 4: Direct and indirect impacts recorded during the workshop.

Direct Impacts	Indirect Impacts
Residential Properties - Permanent residents - Seasonal residents - First Nations lands - Mobile homes	**Residential Properties** - Loss of food access - Loss of access to emergency services - People displaced
Infrastructure Affected - Bridge washout/damage - Highway blocked - Power lines damaged - Water/wastewater treatment facilities - Telecom line - Drinking-water wells	**Infrastructure Affected** - Access to community disrupted - Loss of water and wastewater treatment with power outage greater than 24 hours (length of time that back-up power is available)
Emergency Management - RCMP building - Lake Cowichan fire department - Volunteer fire department building - Ambulance building	**Emergency Management** - RCMP access - Lake Cowichan fire department access - Volunteer fire department access - Ambulance service access
Community Properties - Community hall - Schools	**Community Properties** - Access to Heather campground
Commercial Properties - Lake Cowichan ranch event space - Forest assets	**Commercial Properties** - Loss of economic opportunity - Loss of tourism money - Grocery store without power if power outage is greater than 24 hours (length of time that back-up power is available)
Environmental Impacts - Gordon Bay provincial park	**Environmental Impacts** - Impact on riparian and benthic communities - Listed species at risk around the lake - Impact on water quality
Cultural Sites - Cultural sites directly affected	**Cultural Sites** - Loss of access to cultural sites

All impacts listed in Table 4 have been recorded in GIS as part of the hotspot mapping for direct and indirect impacts. These will be used to support next steps, including a spatial analysis of impacts. Vulnerable elements in exposed areas will be identified and risk for each category quantified where possible. This will be used to conduct a risk assessment of the project area.

3 Next Steps

In the coming months, additional data on vulnerability and hazard in the study area will be collected and compiled. Vulnerability information will come from public data sources, such as the recently completed Natural Resources Canada exposure database for BC, as well as Open Street Map. Vulnerability data will also be provided by the CVRD and partners in this project. Palmer will conduct field work within the project area during the summer of 2018 to ground-truth the geohazard mapping; preliminary maps were produced for the April workshop based on a desktop study.

This additional vulnerability and hazard information will enable the completion of a risk assessment for the project area, which will support planning, as well as applications for future funding from senior levels of government for the CVRD and its partners.

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Appendix A Workshop Agenda

Meeting Agenda
CVRD Lake Cowichan / Youbou – Geohazard Assessment

April 24th 2018, 10:30am – 2:30pm (PST)

Cowichan Lake Sports Arena Curling Facility - 311 South Shore Rd., Lake Cowichan, BC

Meeting Objectives

- Develop shared understanding of natural hazard risk (hazard, exposure, vulnerability) and principles of best practice for disaster risk reduction
- Record impacts and vulnerabilities to natural hazards in the study area
- Better understand stakeholder and community values & vulnerabilities as they relate to risk management

10:30	**Welcome and Introductions**
11:05	**Principles of Best Practice**
11:35	**Natural Hazard Risk in the Study Area**
12:15	**LUNCH**
1:00	**Managing Natural Hazard Risk**
1:25	**Recording Impacts of Geohazards in the Study Area (Hands-on mapping activity)**
2:25	**Closing**

Appendix B Workshop Participants

Meeting Registration List
CVRD Lake Cowichan / Youbou – Geohazard Assessment

April 24th 2018, 10:30am – 2:30pm (PST)

Cowichan Lake Sports Arena Curling Facility - 311 South Shore Rd., Lake Cowichan, BC

Organization	Number of Participants
BC Ministry of Transportation and Infrastructure	2
BC Emergency Health Services	1
CVRD	8
Emergency Management BC	2
Hancock Timber Resource Group	1
Lake Cowichan Fire Department	2
RCMP	1
Timber West	2
Town of Lake Cowichan	1

Appendix C Background on Risk Assessment and Geohazards

1 Risk Assessment for Natural Hazards

It is well-documented that preparation and planning ahead for a disaster will greatly reduce cost and suffering during and after a disaster event (Public Safety Canda, 2008). Understanding and assessing the hazards and risk posed by natural disasters is the first step in any mitigation plan (Figure 1). This is confirmed by the recent Sendai Framework, which has **understanding disaster risk** as Priority 1 (UNISDR, 2015). You cannot manage or reduce risk without first identifying and assessing it.

Figure 1: Natural hazard risk planning process

1.1 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 (Figure 2). C*onsequence* 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?).

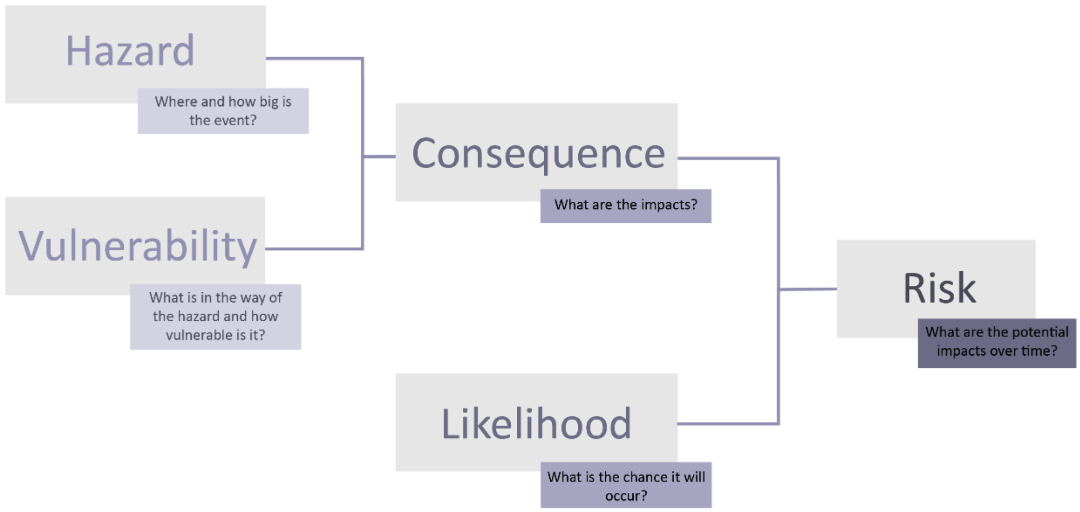

Figure 2: Risk as a function of hazard, likelihood, and vulnerability

Figure 3 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 flood that occurs annually over several decades may in fact be more impactful than a catastrophic flood that occurs just once (Figure 3). 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.

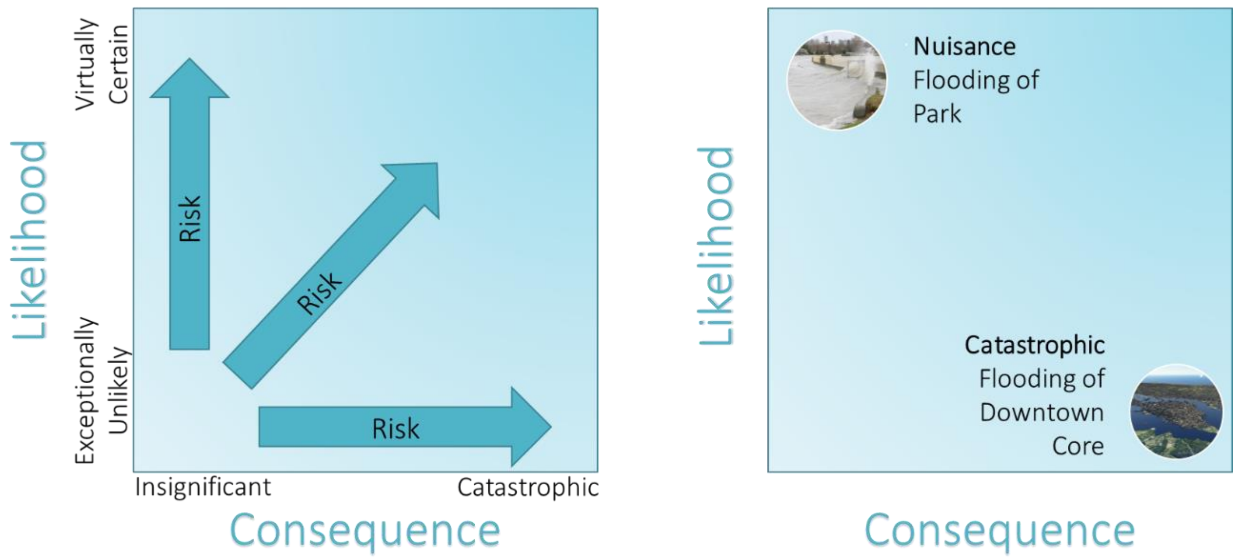

Figure 3: Risk as a function of likelihood and consequence – nuisance and catastrophic flooding

1.2 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 meet the needs of **Sendai Priority 2: investing in disaster risk reduction resilience,** in particular through the use of land-use policy, requires a more robust methodology—ideally a fine-scale quantitative risk assessment. 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.

1.3 Summary

In summary, a true *risk assessment*, one that looks *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.

2 Geohazards in the Study Area

The area to the northeast of Cowichan Lake is a beautiful place to live and visit, however, it is also home to several Geohazards. These include Debris Flow, Debris Slides, Rock Falls, and Rock Slides and they are described below.

2.1 Debris Flows

Debris flows are rapid mass movements of saturated surficial material and organic debris. 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.

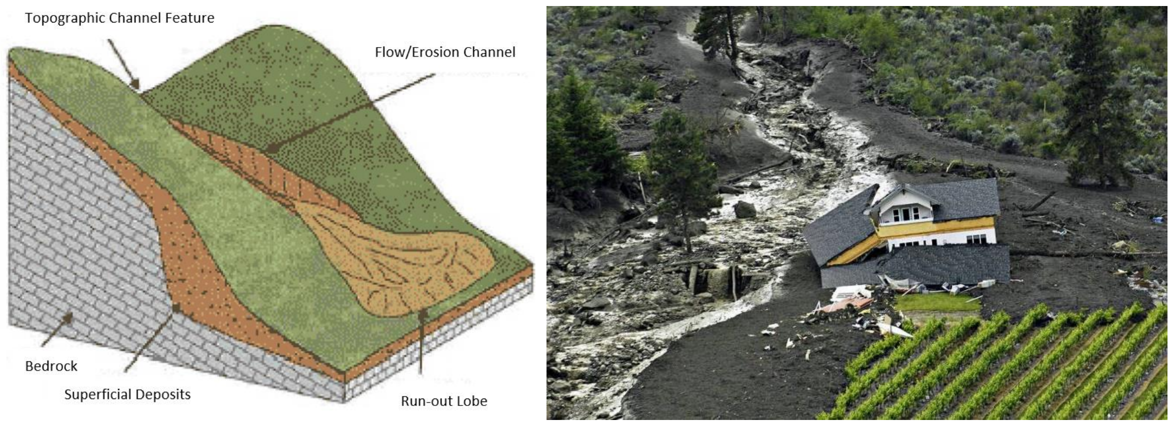

Figure 4: Channelized Debris Flows

Debris flows can initiate from other movement styles, such as rockslides, 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 Youbou/Cowichan Lake study area.

2.2 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.

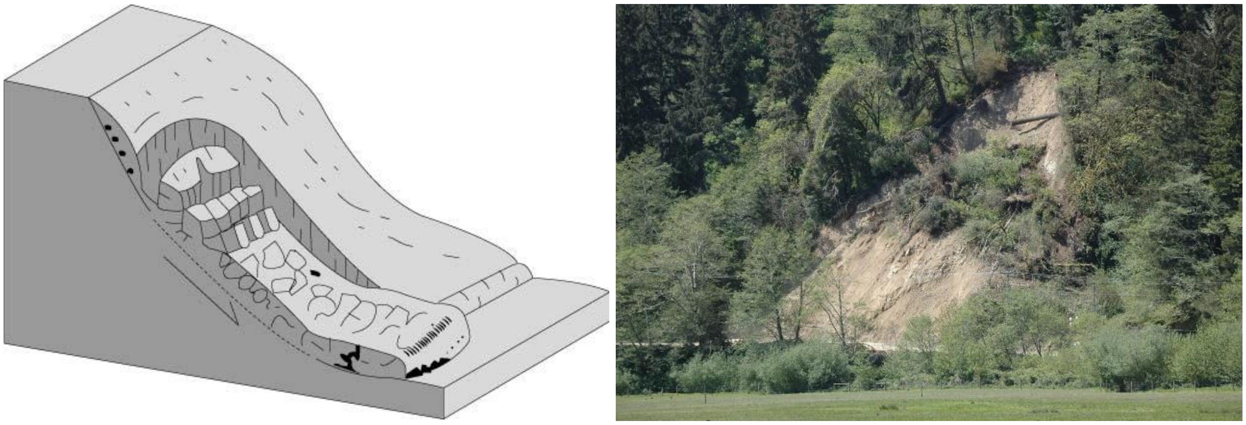

Figure 5: Debris Slides

2.3 Rock Falls

Rock Falls occur when detached masses of bedrock moving 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 6: Rock Falls

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.

2.4 Rock Slides

Rock Slides are large disintegrating masses of bedrock moving downslope by sliding. Rockslide volumes can vary greatly. The largest landslides in Canada are rockslides (eg. Frank slide, pictured).

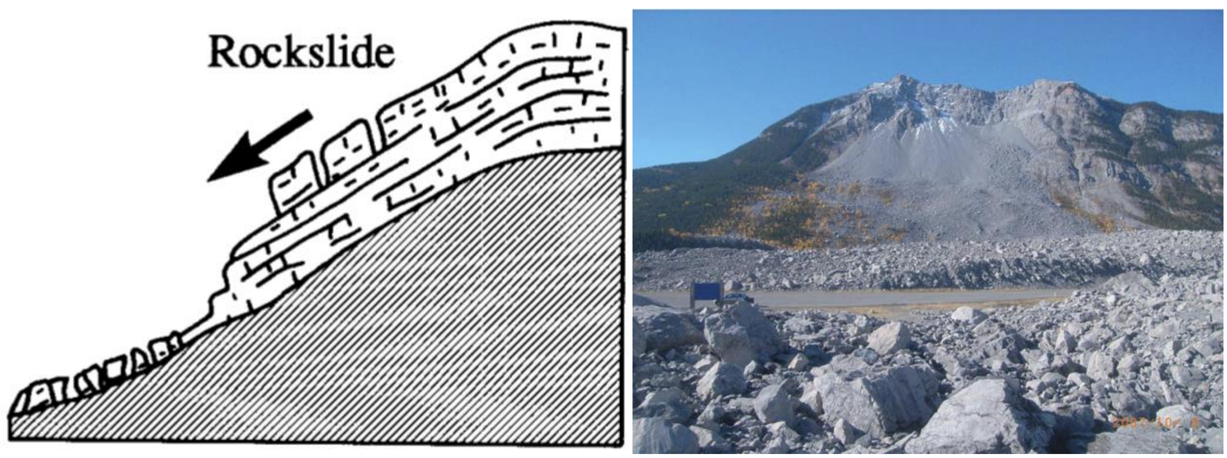

Figure 7: Rock Slides

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

2.5 Geohazard summary

There are many types of geohazards present on the north shore of Lake Cowichan. Preliminary mapping of these has been completed and was presented at the workshop with some further detail on the triggers for these processes and relevant case studies.

3 Works Cited

Public Safety Canada. (2012). *All Hazards Risk Assessment Methodology Guidelines 2012-2013*. Retrieved from http://www.publicsafety.gc.ca/cnt/rsrcs/pblctns/ll-hzrds-ssssmnt/index-eng.aspx

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Appendix D Workshop Presentation Slides

Lake Cowichan/Youbou Geohazards

Risk Assessment

Tuesday – April 24th, 2018

Stakeholder Meeting – 10:30 am to 2:30 pm

Tamsin Lyle, P.Eng | Principal | Ebbwater Consulting

Heather Murdock, P.Eng | Project Engineer | Ebbwater Consulting

David Sacco, P.Geo | Surficial Mapping Specialist| Palmer Environmental

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Agenda

10:30	Welcome and Introductions
11:05	Principles of Best Practice
11:35	Natural Hazard Risk in the Study Area
12:15	LUNCH
1:00	Managing Natural Hazard Risk
1:25	Recording Impacts of Geohazards in the Study Area (Hands-on mapping activity)
2:25	Closing

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Meeting Objectives

- Develop shared understanding of natural hazard risk (hazard, exposure, vulnerability) and principles of best practice for disaster risk reduction
- Record impacts and vulnerabilities to natural hazards in the study area
- Better understand stakeholder and community values & vulnerabilities as they relate to risk management

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Introduction

Kate Miller, M.Sc | Manager Environmental Services | CVRD

Tamsin Lyle, P.Eng | Principal | Ebbwater Consulting

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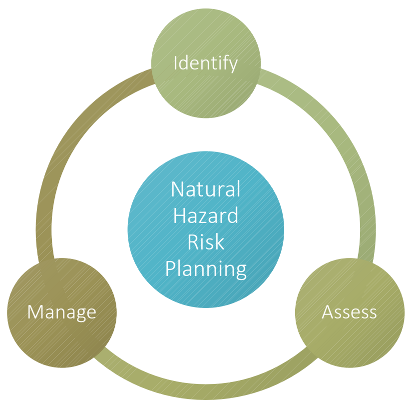
Once we understand risk, we can mitigate and improve community resilience



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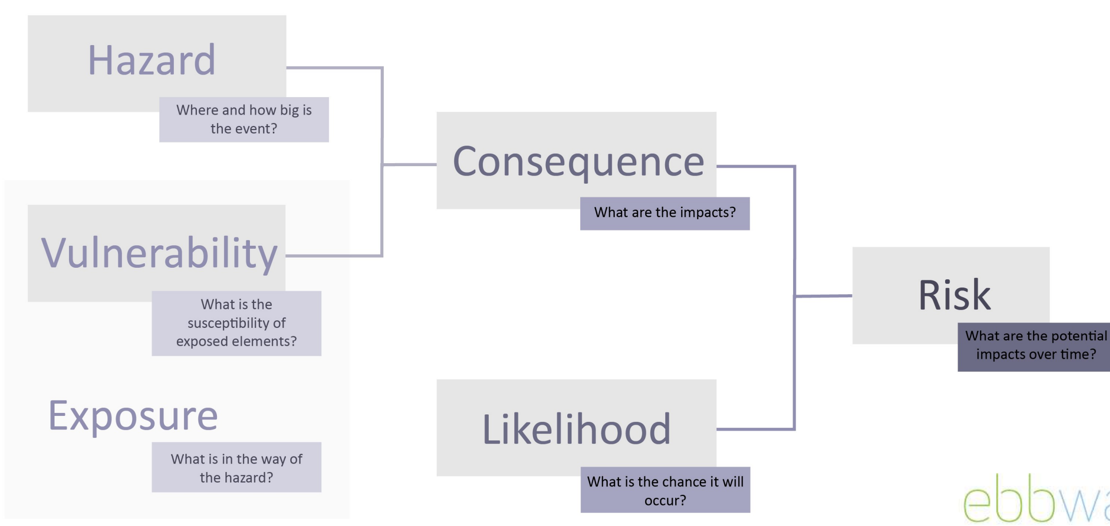
Risk 101 – Terminology is Important



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Tool Scale		Data Requirements	Uses
Highly-Spatial		H: Local-level detailed hazard mapping V: Parcel-level GIS attributed with vulnerability information C: Relevant, up-to-date damage/fragility curves	▪ Local government planning ▪ Risk mitigation decision-making and design ▪ Emergency response ▪ Public engagement ▪ Input to insurance models
		H: High-level hazard mapping V: Neighbourhood-level (census tract) GIS attributed with generic vulnerability information C: Generic or synthetic damage/fragility curves	▪ Regional/Provincial/Territorial planning and prioritisation ▪ Emergency planning and management ▪ Public engagement
Aspatial		H: High-level hazard identification (quantitative or qualitative) V: Regional scale vulnerability information (quantitative or qualitative) C: High-level empirical loss methods (Probable Maximum Loss) or qualitative matrices	▪ National-scale planning and prioritisation ▪ Input to re-insurance models

H Hazard V Vulnerability C Consequence

CartoDB Map Attribution (Positron Map)

What the community needs for planning → this project is developing tools for future disaster risk reduction planning

What the funder needs for planning → this project will have a deliverable of a RAIT.

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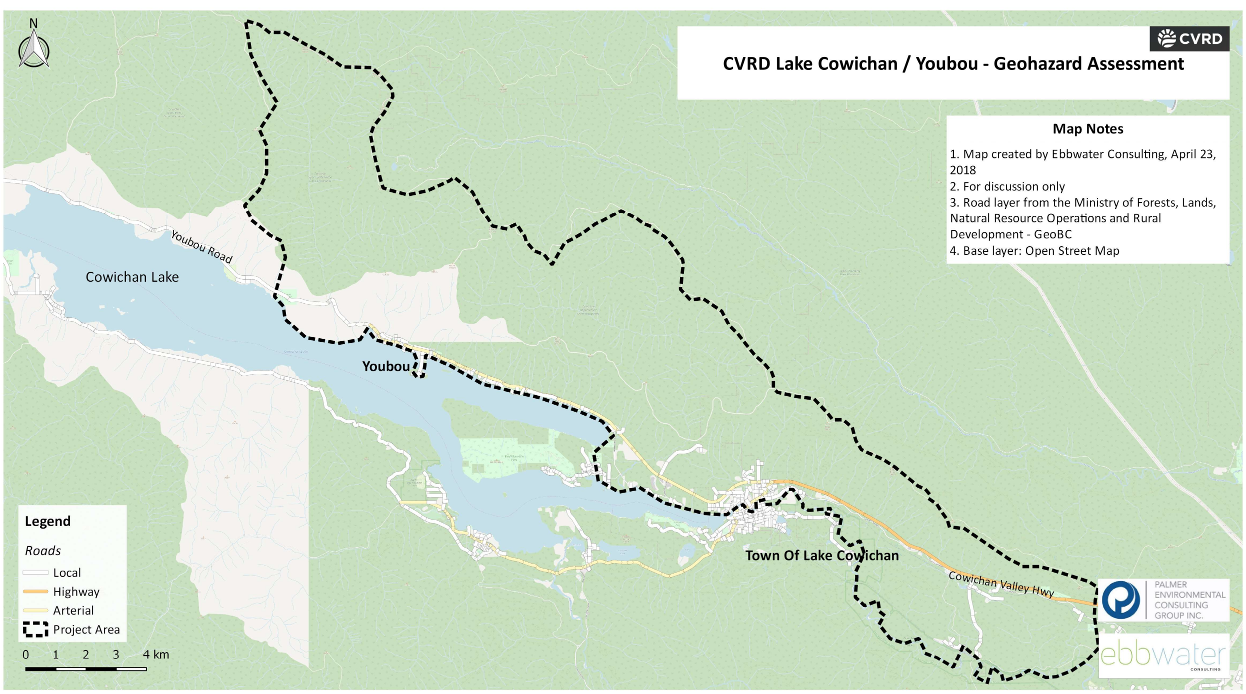

Timelines

January 2018	Winter 2017/2018	April 2018	Spring/ Summer 2018	Fall 2018	Fall 2018
Kick-off presentation (some of you were there)	Desktop hazard mapping (you'll get to see this today!)	Understanding exposure by learning about community values and impacts (**this event)**	Further analysis of hazard (field visits), exposure and risk	Stakeholder ground-truthing and resilience building workshop	Reporting (written and verbal)

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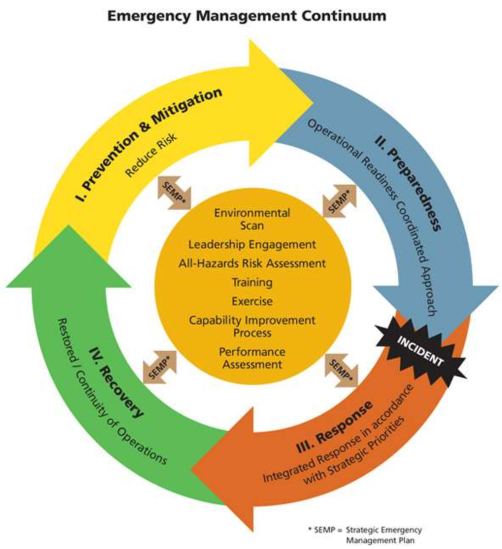
Introduce your partner:
Name, organization & one thing you would both put in your emergency kit

Disaster Management Cycle
Where do you fit?



Source: publicsafety.gc.ca

Best Practice in Natural Hazard Management

Tamsin Lyle, P.Eng | Principal | Ebbwater Consulting

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With a partner:
Identify what makes for a SAFE, PROSPEROUS and RESILIENT community?

*Community resilience is the sustained ability of a **community** to utilize available resources (energy, communication, transportation, food, etc.) to respond to, withstand, and recover from adverse situations (e.g. economic collapse to global catastrophic risks).*

Why?

It's the right thing (and might be the prudent thing)

No deaths as mudslide tears through B.C.'s wine country

Debris from a landslide is shown from the air near Testalinden Creek, just south of Oliver, B.C. on Sunday June 13, 2010. As rescuers made their way through the debris of a landslide that struck several homes in southern British Columbia on Sunday, it began to appear that most area residents had made it out in time.

DANIEL HAYDUK/THE CANADIAN PRESS

ELIZABETH CHURCH AND REBECCA LINDELL
TORONTO, VANCOUVER
GLOBE AND MAIL UPDATE
PUBLISHED JUNE 13, 2010
UPDATED MARCH 26, 2017

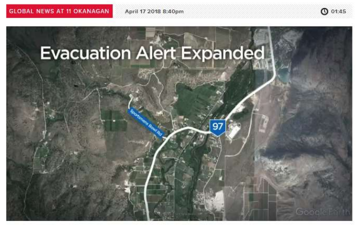
A wall of mud, water and rocks roared down a mountain in southern British

Global NEWS | BC Change Location | News & Radio Programs Newscasts, Radio, and Videos

World | Canada | Local | Politics | Smart Living | Money | Entertainment | Health | Commentary | Trending

BREAKING 3 mins ago 9 dead, 16 injured after pedestrians struck by van in Toronto

GLOBAL NEWS AT 11 OKANAGAN | April 17 2018 8:40pm | 01:45



Efforts to prevent debris flow in Oliver area as evacuation alert expands

The flooding situation in rural Oliver is becoming so serious that crews are now trying to prevent a potential disaster.
Shelby Thom reports.

- Efforts to prevent debris flow in Oliver area as evacuation alert expands

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French mayor Rene Marratier jailed for role in deadly flood

12 December 2014 | Europe | Share

Rene Marratier said he would appeal against the verdict

The former mayor of a French seaside town has been sentenced to jail for four years for ignoring flood risks before a storm that killed 29 people.

Rene Marratier hid the risks to La Faute-sur-Mer to avoid putting off property developers, the court said.

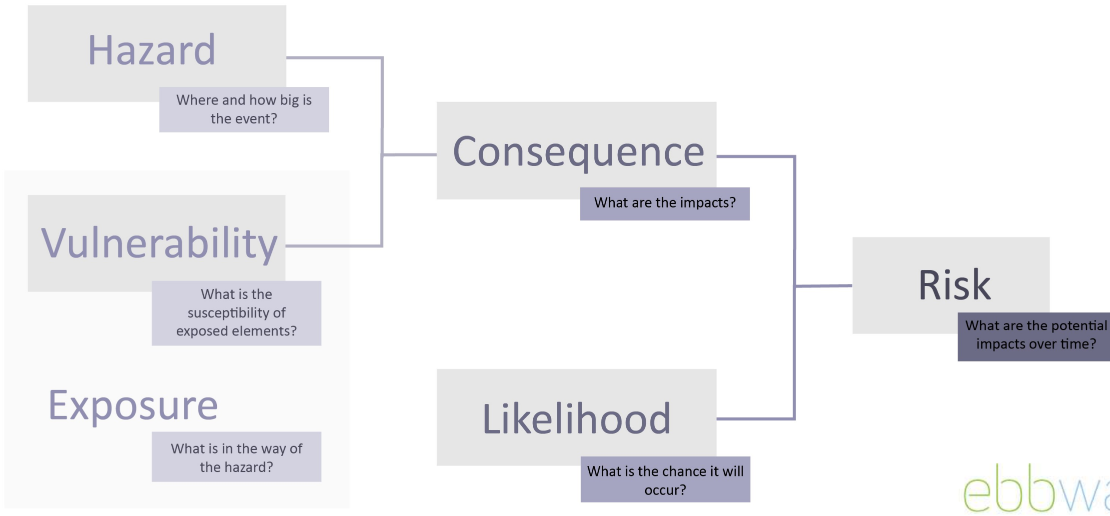
The storm Xynthia hit western Europe in early 2010. The storm knocked down seawalls in La Faute-sur-Mer, leading to severe flooding.

Marratier called the verdict "unjust" and said he would appeal.

On Friday, the court said that Marratier knew La Faute-sur-Mer, a west coast resort in the Pays de la Loire region, was at risk of flooding.

However, he "deliberately hid" the risk so that he could benefit from the "cash-cow"

What: Plan for Risk not Hazard



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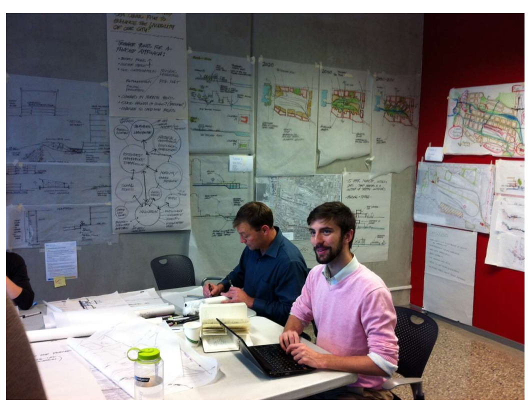
What: Listen to People and Consider Values (…And stop thinking like engineers)



Talk to people; not just those you like

Image sources: West Coast Environmental Law

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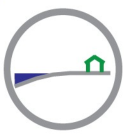
What: Enable Resilience

Reduce the Hazard
Block the water

Reduce Exposure
Stop things/people you care about getting wet



Reduce Sensitivity
Reduce impact of getting wet

- We can't fight nature
- We can't sterilise our hazard areas

- We can reduce sensitivity to our built environment
- We can speed up our recovery
- We can safely fail instead of striving for the fail-safe solution

What: Make Good Decisions
Look Beyond Dollars and Cents

PEOPLE	
People Displaced	# of people displaced from flood events
People Displaced	# people displaced permanently
'at risk' people impacted	Social Vulnerability Index (SVI) weighted displacement
Park and Recreational Amenity Value	Value-weighted area affected per event
Loss of critical services	# of pieces of infrastructure impacted
Aesthetics	-2 to 2
ENVIRONMENT	
Risk of Contaminant Release	# of sites with potential contaminants
Environmental Benefits	-2 to +2
ECONOMY	
Damage to Infrastructure	Value-weighted km of roads impacted
Damage to buildings	$M
Business disruption	# of employees working in impacted businesses
Loss of Inventory	$M
Emergency Response costs	Estimated cost per event
IMPLEMENTATION	
Capital Costs	$M
Maintenance costs	$M
Adaptability	1 to 4
Ease Of Implementation	1 to 5

Example measures for City of Vancouver, 2015. Developed with Compass Resource Management.

What: Embrace Uncertainty

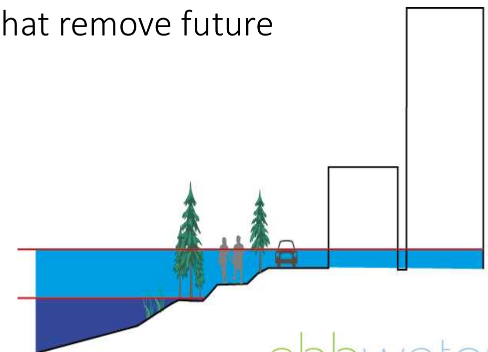
- Don’t rush in; preserve our options
- Strive for adaptive solutions that will work under many climate and development futures
- Avoid solutions that are single-minded or that remove future options

High end of range:

Overinvestment in protection

Low end of range:

Potential catastrophic impacts



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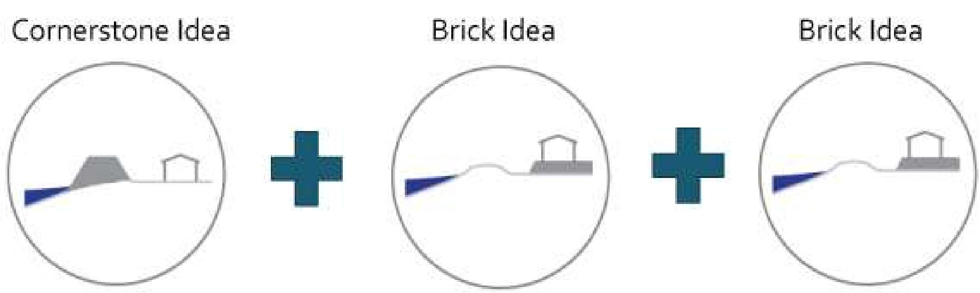
What: Have a Back-Up Plan

Complementary Design with Co-Benefits



e.g. A dike

complemented with property-level-protection

improved with habitat enhancement and a bike path

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Anything to Add?:
Identify what makes for a SAFE, PROSPEROUS and RESILIENT community?

*Community resilience is the sustained ability of a **community** to utilize available resources (energy, communication, transportation, food, etc.) to respond to, withstand, and recover from adverse situations (e.g. economic collapse to global catastrophic risks).*

Geohazards in Lake Cowichan / Youbou

David Sacco, P.Geo | Palmer Environmental

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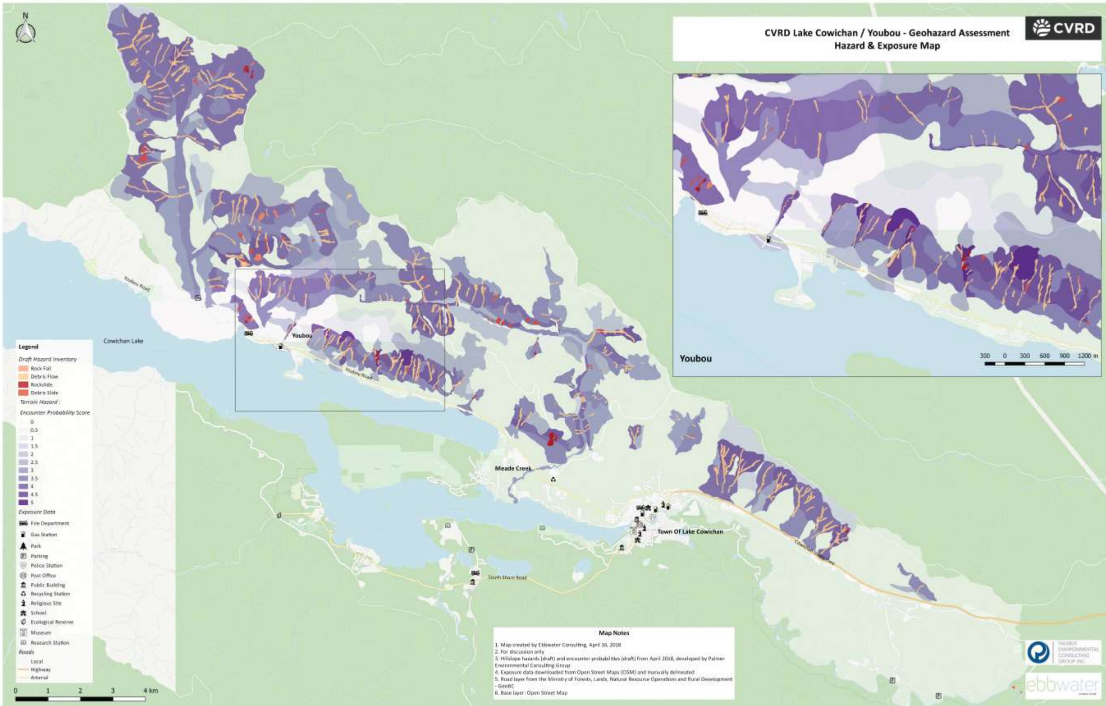

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Youbou Hazard Assessment

April 24, 2018

Lake Cowichan, BC

Presented by: Dave Sacco, M.Sc.

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

- Hazards Team
- Cowichan Valley and hazards
- Objectives of hazards assessment
- Terrain mapping and hazard inventory
- Progress to date

Hazards Team

PECG:

Robin McKillop, M.Sc. P.Geo – *Senior Geomorphologist*
Derek Cronmiller, P.Geo – *Hazard Specialist*
Sarah Ellis, B.Sc. – *Mapping and field work support*
Dave Sacco, M.Sc. – *Geomorphologist; project support*

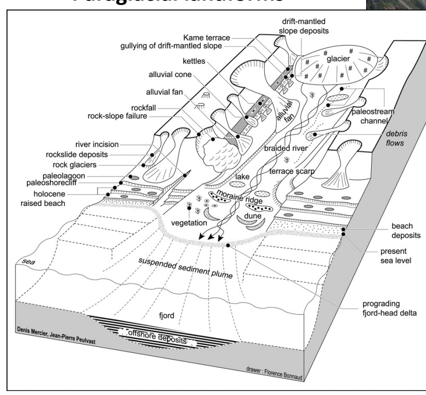
Westrek:

Tim Smith, P.Geo. – *Engineering Geologist; External Review*

Why is Cowichan Valley susceptible to hazards?

- Mountainous landscape
  - Steep slopes
- Glacially conditioned landscape
  - Large volumes of sediment
  - Over-steepened slopes
  - Period of rapid post-glacial sedimentation
    - Frequent mass movements
    - Formation of deep gully systems
    - Development of paraglacial fans (e.g. Meade Creek fan)
  - Followed by period or reduced event frequency
- Climate
  - Precipitation patterns

Paraglacial landforms



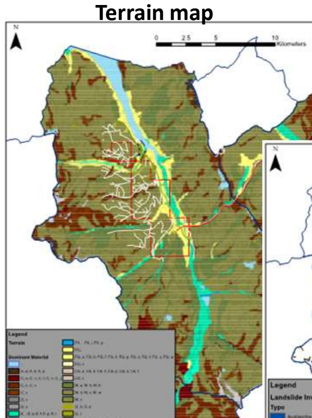
Mercier, 2008

Objectives

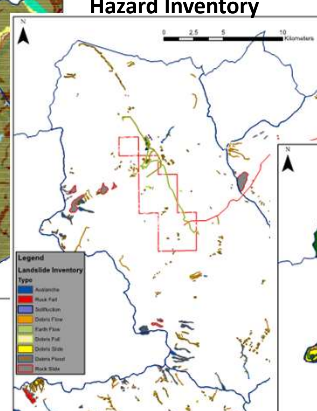
Hazards assessment:

- Terrain Map
- Hazard Inventory
- Hazard Potential Map
  - Predictive; extrapolate hazard ratings based on terrain characteristics for polygons where hazards have not yet occurred
  - considers changes in climate

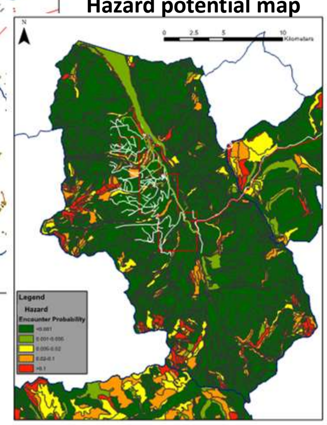
Terrain map



Hazard Inventory



Hazard potential map



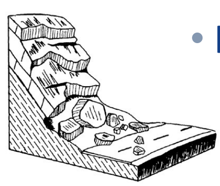
Methods: Terrain Mapping and Hazard Inventory

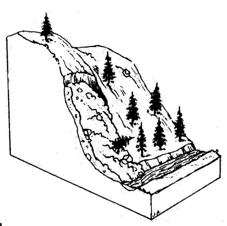
- Preliminary Desk-top interpretations
  - Uses standardized, BC Terrain Classification System
    - surficial material
    - material texture
    - Surface expression/landform
    - Geomorphic process
      - activity state (active, inactive)
  - Data Sources
    - Aerial photography (1972)
    - Pseudo-stereo orthophotography (2007, 2014)
    - Elevation Data

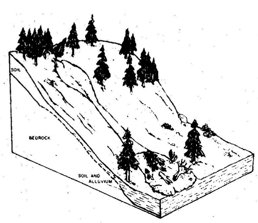
- Field work
  - Ground truth terrain interpretations
  - Characterize hazards

Hazard Inventory

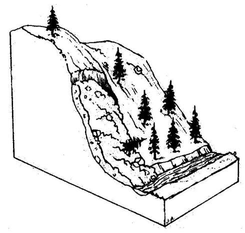
- Interpretations from imagery and elevation data
- Hazard classification
  - movement style
  - material
  - triggers







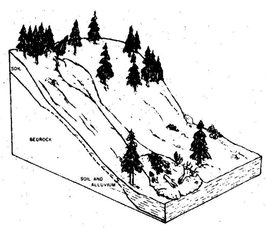
- Included hazards:
  - Debris slides
  - Debris flows
  - Rockslides
  - Rock fall
- Hazards not inventoried:
  - Flooding
  - Forest fires
  - Avalanches
  - Earthquake



Debris Slides

Rapid mass movement of surficial material

- Generally moves as coherent mass down planar surface
- Relatively short run-out
- Commonly associated with fluvial processes (undercutting) and roads (sidecast)
- Can transform into debris flow if saturates upon entering gully

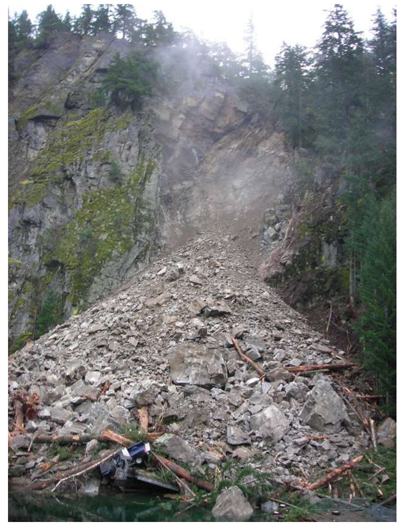


Debris Flows

Rapid mass movement of surficial material

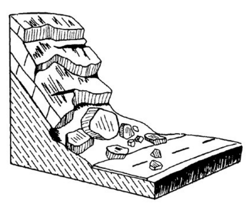
- More water than debris slide
- Moves in a slurry resembling wet concrete
- Relatively long run-out, generally channelized
- Commonly grow in size through material entrainment
- May be referred to as “debris torrent”
- Commonly triggered by intense/prolonged precipitation events

Rockslides



Large, disintegrating masses of bedrock sliding downslope

- Rockslides are typically largest mass movements
- Occurrence influenced heavily by bedrock structure
- Commonly triggered by earthquakes, freeze-thaw cycles or intense/prolonged precipitation



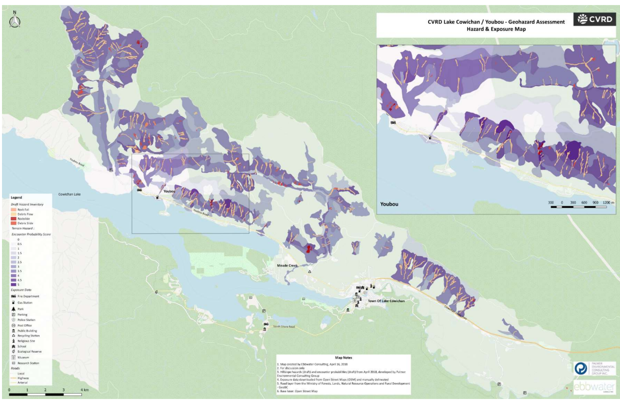
Rock Fall

Detached masses of bedrock moving by falling, bouncing and/or rolling

- Relatively small volumes
- Commonly persistent hazard (low magnitude / high frequency)
- Limited to the steepest bedrock slopes
- May form talus cones at base of bluff
- Commonly initiated by freeze-thaw cycles

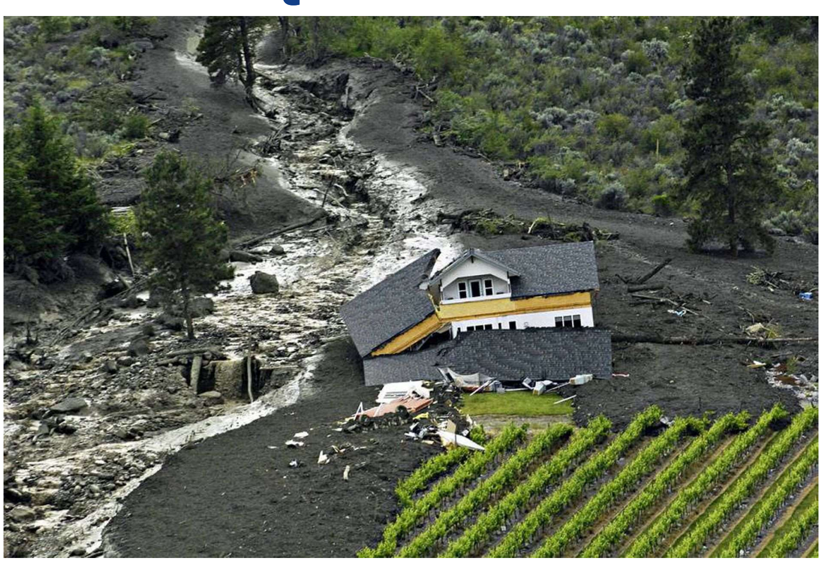
Progress to date

- Completed:
  - Desk-top terrain mapping
  - Desk-top hazard inventory
  - Preliminary hazard map



- Future tasks:
  - Incorporate local knowledge
  - Field work
    - Ground truth desktop assessments
    - Classifying fans
      - Incision, avulsion, evidence of recent activity
  - Finalize hazard map
    - Incorporate climate change
      - Changing weather patterns
    - Predict hazard potential in terrain where events haven't occurred

Questions?



Testalinden Creek, south of Oliver, BC

LUNCH BREAK

Back to work at 12:45

What is a "wicked problem"?

- Won't stay solved
- Tangle of interconnected influences
- No single solution
- Answer depends on how and who you ask
- Many players and perspectives
- Moving target

Painting by Ani Magai

Natural hazard management is a wicked problem

- High degree of technical complexity
- Multiple dimensions of uncertainty
- Multiple objectives
- High stakes, high emotions
- Intense political scrutiny
- High expectations for quality and transparency
- Limited resources in terms of time, money and personnel.

Natural Hazards in BC (www.empr.gov.bc.ca)

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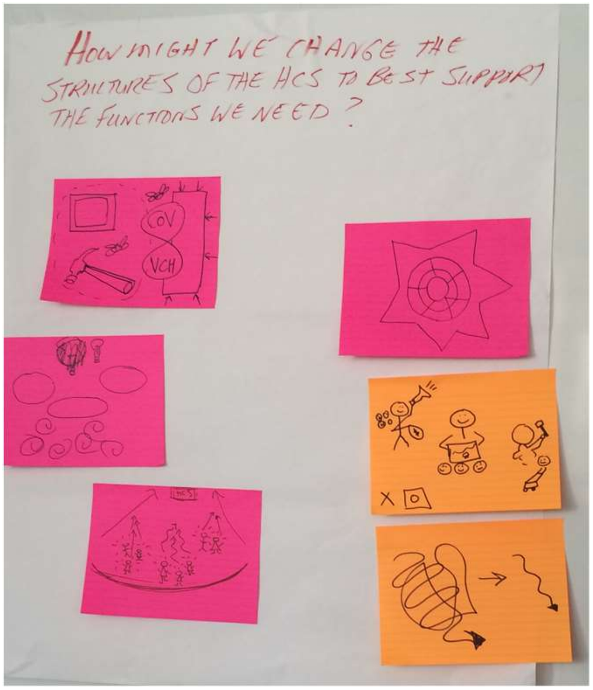
1983 Debris Flow in Lion's Bay, BC (VIU image)

How have you experienced natural hazard and/or management as a "wicked problem"?

Can you imagine how it is a "wicked problem"



Report Back:
How would you draw it?

Think about:

- Connected elements
- Different points of view
- Uncertainty today
- Uncertain future

Pop Quiz

We warned you terminology was going to be important….

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Plan for Risk not only Hazard!

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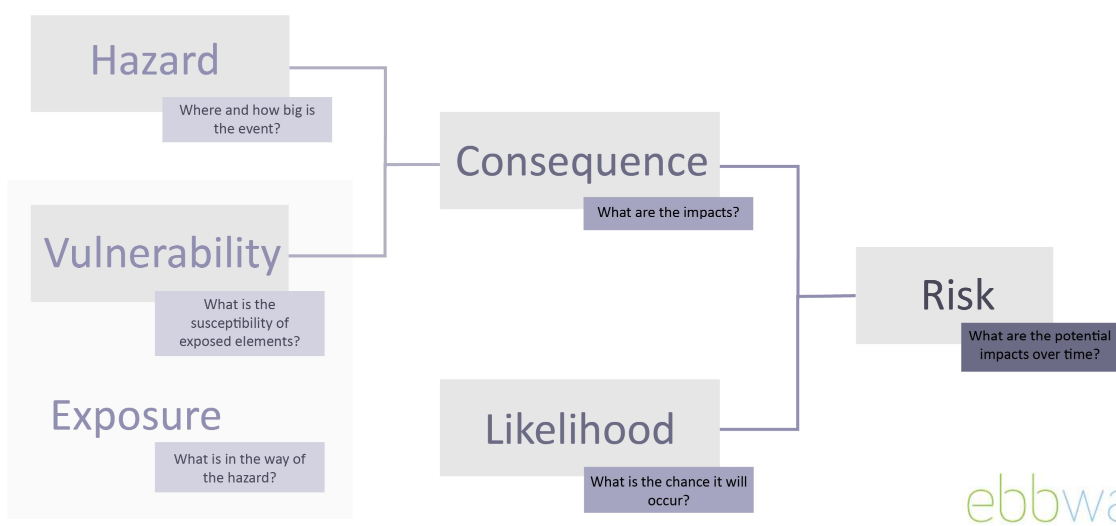
Did you remember?



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Impacts

Heather Murdock, P.Eng | Project Engineer | Ebbwater Consulting

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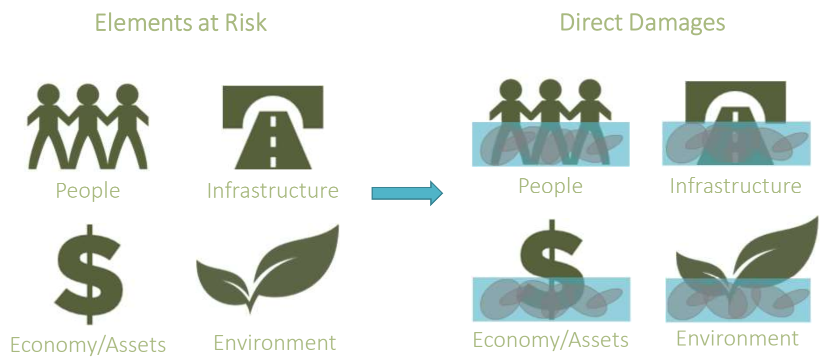
High-level impact categories

National Risk Profile

Risk Assessment
A Multi-Disciplinary Task



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Geohazard Impacts – Direct


Blocked Roads

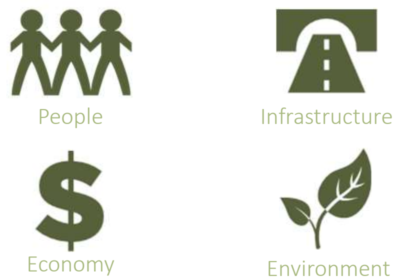

Damaged Houses


Damaged Property

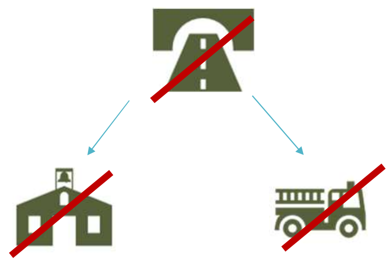

Damaged Infrastructure

What happens when the road is blocked?
The Tricky(ier) Part

Direct Impacts



Indirect Impacts
(Cascading Effects)



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Impacts - Indirect

Regional Connections Disrupted

Disruption to Roads & Rail

Loss of Recreation

Loss of Utility Service

Narratives from Geohazard Events

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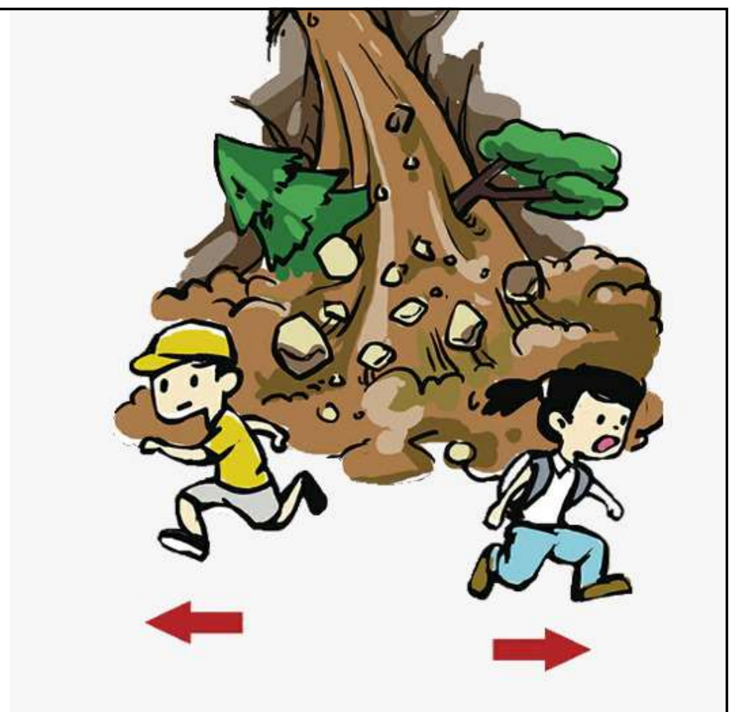
So What?... Examples of Hazard Impacts

April 24, 2018

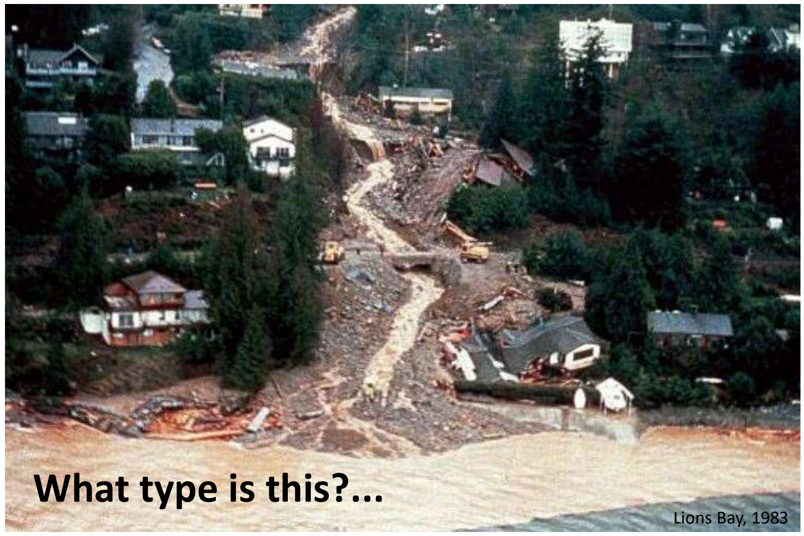
Lake Cowichan, BC

Presented by: Dave Sacco, M.Sc.



Reminder of hazard types

- Debris flow
- Debris slide
- Rockfall
- Rockslide

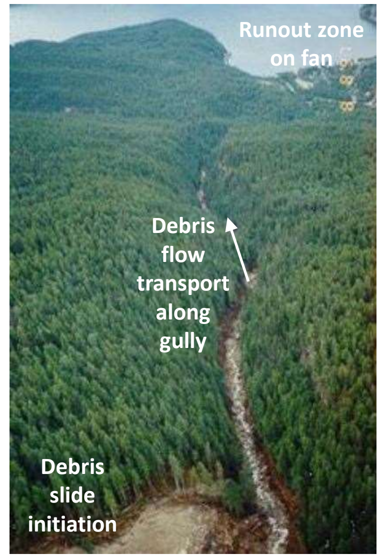


When considering impact potential

- Size
  - Volume
- Speed
  - Rapid or slow
  - Position in path – transport or runout zone
- Transported material
  - Organic-rich
  - Soil vs. rock
- Vulnerability or resilience of element at risk

Debris flow: Hummingbird Creek, Mara Lake, BC

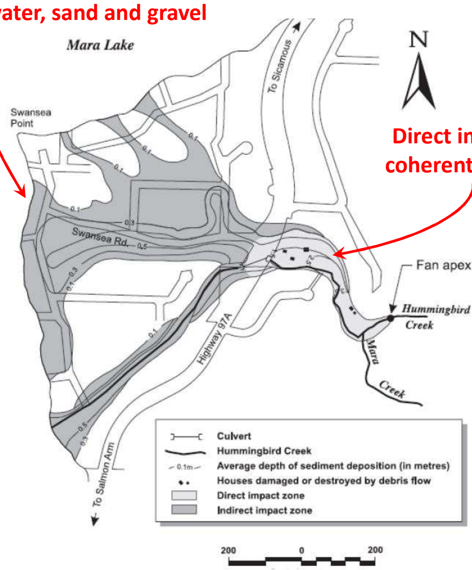
- July 11, 1997
- 92,000 m^3 of mud, boulders and organic debris
- Peak discharge 50 times greater than 200-yr flood!
- Impact to Highway 97A
- Extensive damage to homes and cabins in community of Swansea Point, which is built on fan



Debris flow: Hummingbird Creek, Mara Lake, BC

Debris flow:
Hummingbird Creek, Mara Lake, BC

Indirect impacts from subsequent inundation by water, sand and gravel



Direct impacts from coherent debris front

Incised fan channel, after event

Cabins swept off foundations

Debris slide:
Anstey River, Sushwap region, BC

- 1990
- Large debris slide into Anstey River

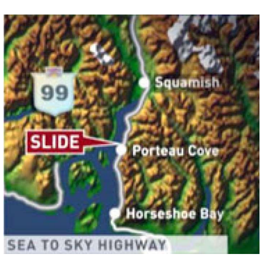
Debris slide runout onto river bottom

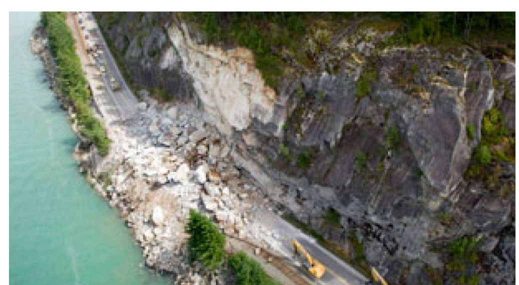
Rockfall:
Remote location, coastal BC

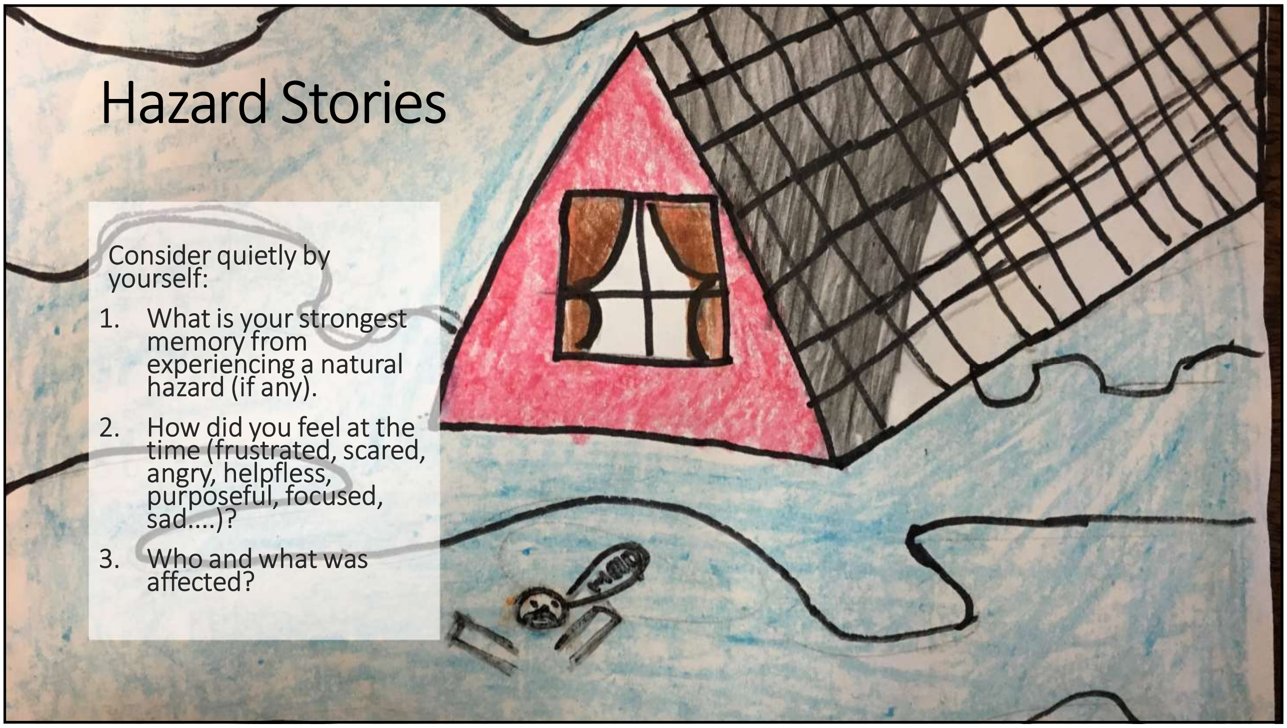
- Small event, between 2008 and 2011
- First ‘test’ of rockfall protection barrier fence
- 2 m-diameter boulders

Rockslide:
Porteau Cove, Sea to Sky Highway, BC

- July 29, 2008
- 16,000 m^3 of car-sized rock masses crossed highway
- 5-day highway closure

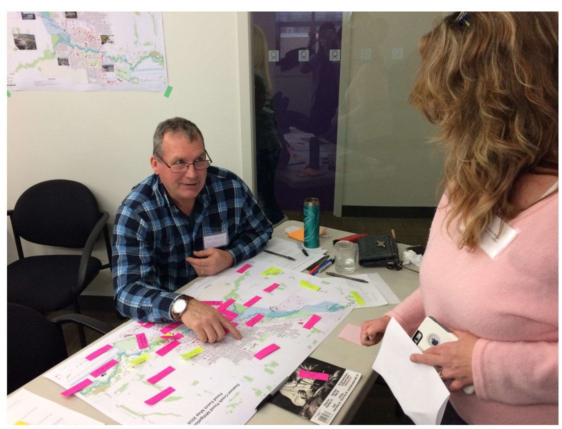






Map Exercise:

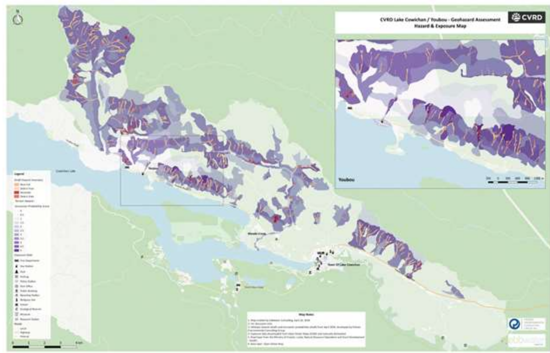
Sharpen your pencils

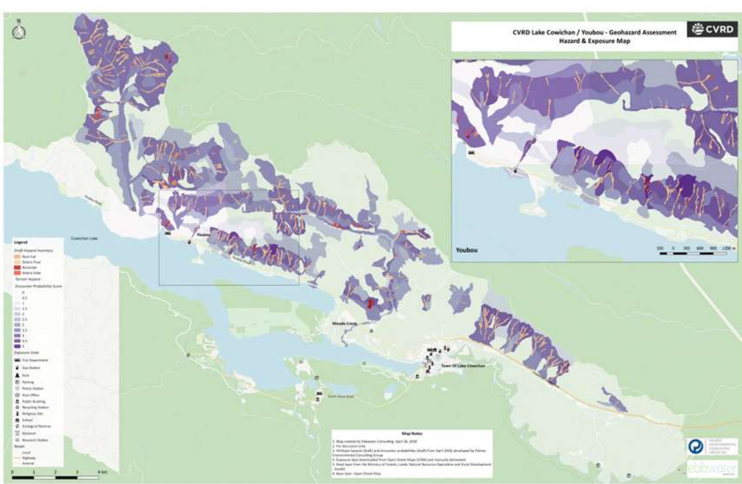


Mapping Direct & Indirect Impacts

1. Write impacts on sticky notes (1 per sheet) & place on map:
   Direct Impacts – PINK/PURPLE
   Indirect impacts –YELLOW/GREEN

2. Group discussion at your table (20 min):
   What matters, and why?
   What connections do you notice with what matters to others?
   Any upstream/downstream connections?
   What is missing? What questions do you have?





What stood out?

What matters the most?

What do we (consultants) need to know?

Next Steps…

Looking ahead….we'll be back to make sure we heard you right

January 2018	Winter 2017/2018	April 2018	Spring/ Summer 2018	Fall 2018	Fall 2018
Kick-off presentation (some of you were there)	Desktop hazard mapping	Understanding exposure by learning about community values and impacts	Further analysis of hazard (field visits), exposure and risk	Stakeholder ground-truthing and resilience building workshop	Reporting (written and verbal)

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Thank You!

tamsin@ebbwater.ca
heather@ebbwater.ca
david@pecg.ca

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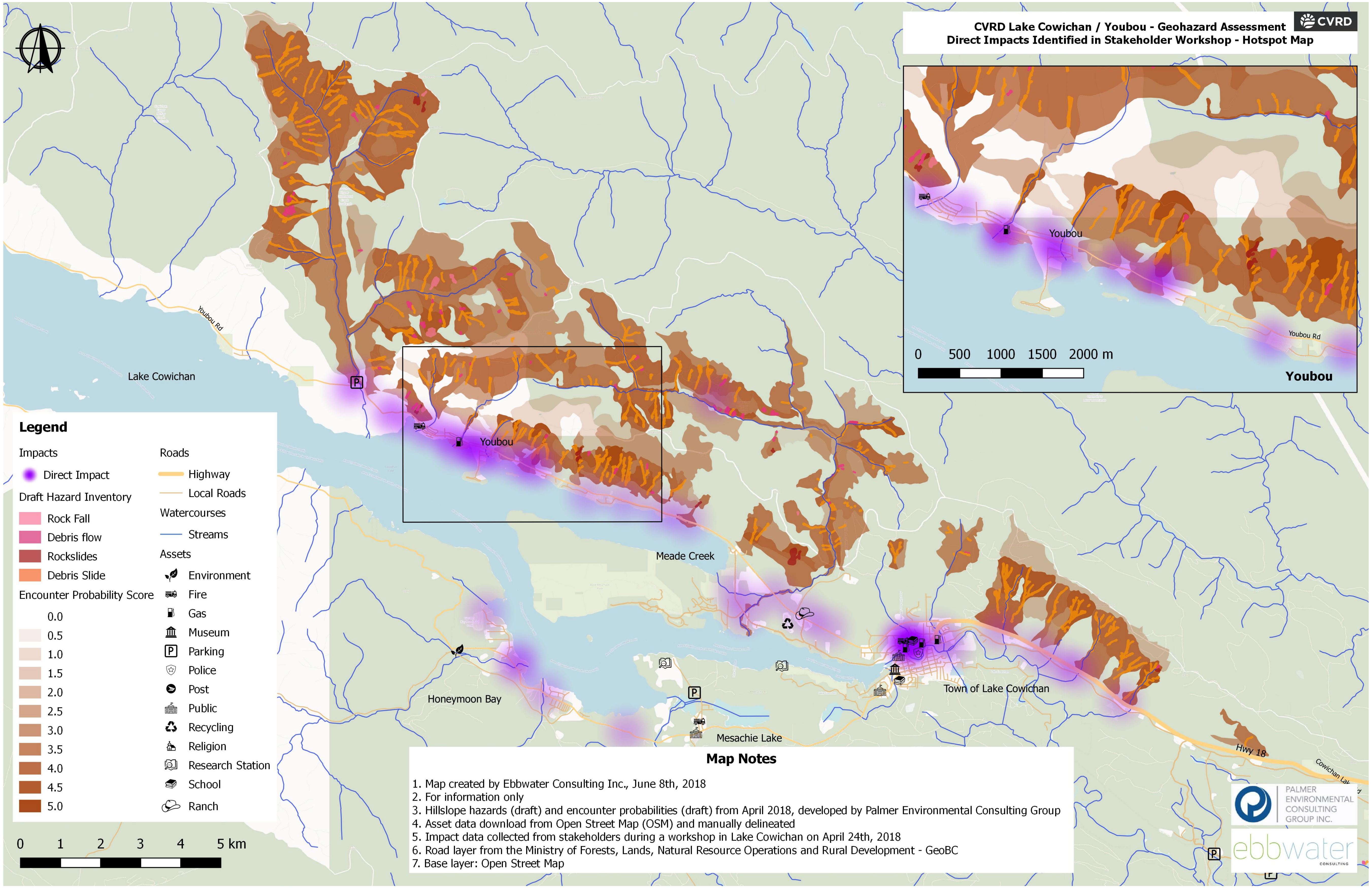
Appendix E Workshop Maps

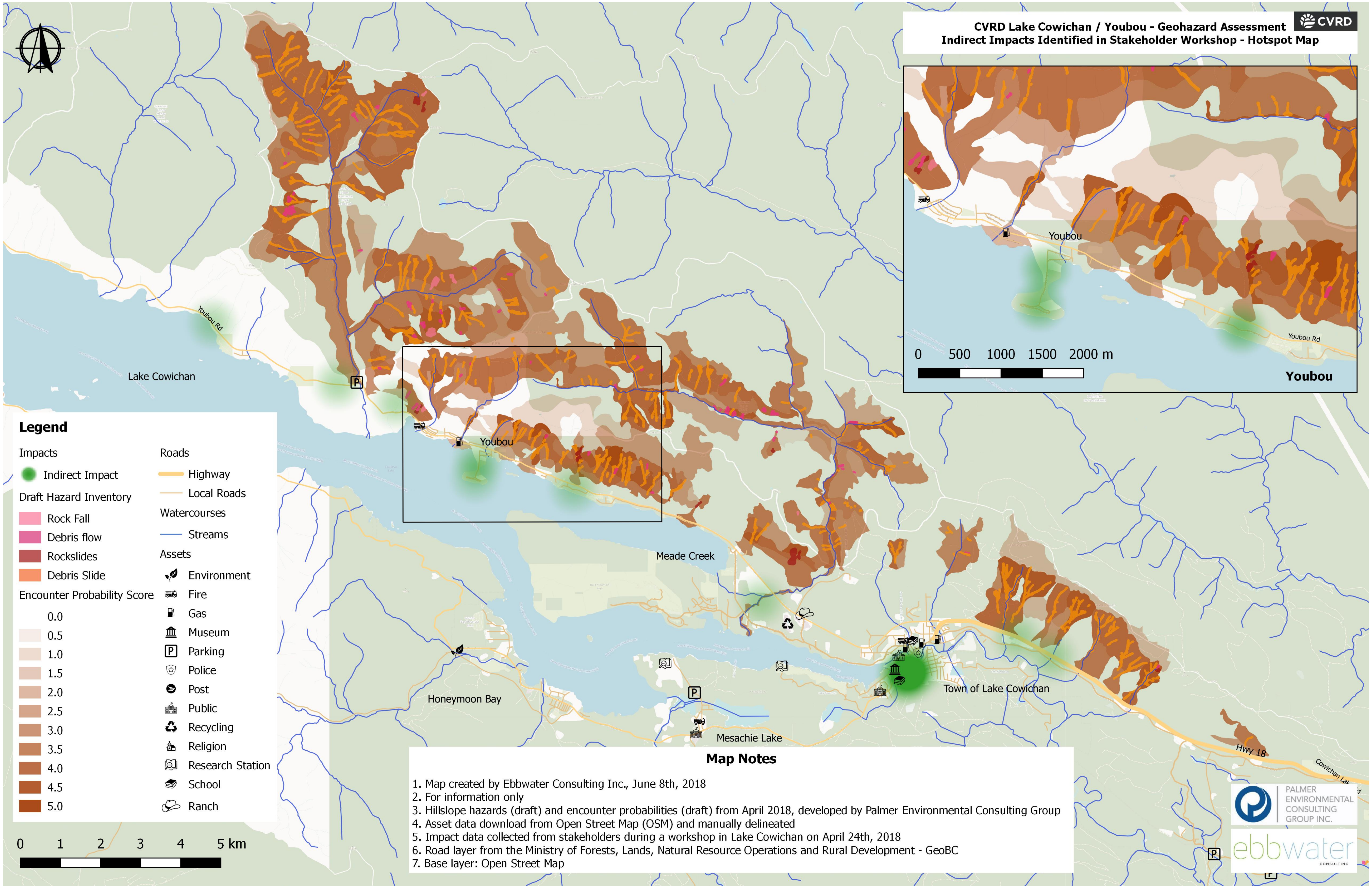
Workshop Maps – Direct Impacts Identified in Stakeholder Workshop
CVRD Lake Cowichan / Youbou – Geohazard Assessment



Map Notes

1. Map created by Ebbwater Consulting Inc., June 8th, 2018
2. For information only
3. Hillslope hazards (draft) and encounter probabilities (draft) from April 2018, developed by Palmer Environmental Consulting Group
4. Asset data download from Open Street Map (OSM) and manually delineated
5. Impact data collected from stakeholders during a workshop in Lake Cowichan on April 24th, 2018
6. Road layer from the Ministry of Forests, Lands, Natural Resource Operations and Rural Development - GeoBC
7. Base layer: Open Street Map

Workshop Maps – Indirect Impacts Identified in Stakeholder Workshop
CVRD Lake Cowichan / Youbou – Geohazard Assessment



Lake Cowichan/Youbou Geohazards

Risk Assessment

Tuesday – October 2nd, 2018

Ground Truthing Meeting – 10:30 am to 3:00 pm

Tamsin Lyle, P.Eng | Principal | Ebbwater Consulting

Heather Murdock, P.Eng | Project Engineer | Ebbwater Consulting

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Agenda

10:30	Welcome & Agenda
10:40	Workshop Introduction
10:50	Focus on CVRD Climate & Risk
11:05	Getting to Know (Geohazard) Risk
12:00	LUNCH
12:50	Risk Mapping Validation
1:50	Getting to Know and Planning for Risk Tolerance
2:45	Adaptation Planning
2:55	Closing

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Introduction

Kate Miller, M.Sc | Manager Environmental Services | CVRD

Tamsin Lyle, P.Eng | Principal | Ebbwater Consulting

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Meeting Objectives

- Review geohazard impact mapping and information collected at the first stakeholder meeting to gather additional feedback;
- Explore vulnerability and resilience to specific types of geohazard impacts, and enhance understanding of trade-offs involved in natural hazard management decision-making;
- Explore the concept of risk tolerance as well as tolerances and thresholds for geohazards in the community.

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Timeline

January 2018	Winter 2017/2018	April 2018	Summer 2018	Fall 2018	Winter 2018
Kick-off presentation	Desktop hazard mapping (Presented in Workshop 1)	Understanding exposure by learning about community values and impacts (Workshop 1)	Further analysis of hazard (field visits), exposure and risk	Stakeholder understanding (geohazard) risk (tolerance) workshop (This meeting)	Completion of Risk Assessment Reporting (written and verbal)

CVRD Climate Adaptation Program

Kate Miller, M.Sc | Manager Environmental Services | CVRD

Jeff Moore, MRM | Environmental Analyst | CVRD

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Climate Projections for the

COWICHAN VALLEY REGIONAL DISTRICT

CVRD

Getting to know (geohazard) risk

Tamsin Lyle, P.Eng | Principal | Ebbwater Consulting

Heather Murdock, P.Eng | Project Engineer | Ebbwater Consulting

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How do we measure progress on Disaster Risk Reduction?

Sendai Priority 1: Understanding Risk

Indicators for Risk

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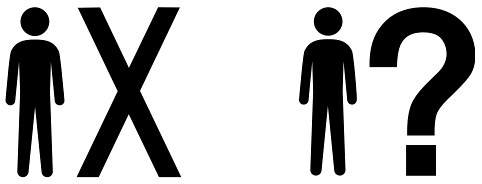
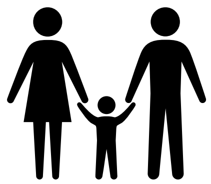
- Consistent over time
- Reliable
- Transparent
- Verifiable
- Feasible
- Useful

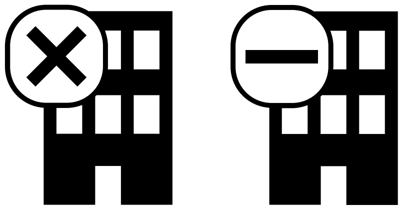
Global Indicators of Disaster Risk Reduction



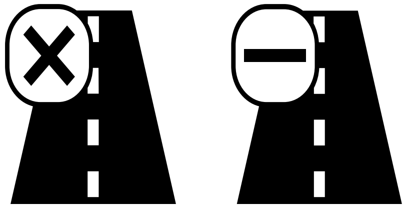
A-1 Number of deaths and missing persons attributed to disasters, per 100,000 population



B-1 Number of directly affected people attributed to disasters



C-1 Direct economic loss attributed to disasters, relative to GDP



D-1 Damage to critical infrastructure attributed to disasters

D-5 Number of disruptions to basic services attributed to disasters

Why?

It’s the right thing (and might be the prudent thing)

No deaths as mudslide tears through B.C.'s wine country

Debris from a landslide is shown from the air near Testalinden Creek, just south of Oliver, B.C. on Sunday June 13, 2010. As rescuers made their way through the debris of a landslide that struck several homes in southern British Columbia on Sunday, it began to appear that most area residents had made it out in time.

DANIEL HAYDUK/THE CANADIAN PRESS

ELIZABETH CHURCH AND REBECCA LINDELL
TORONTO, VANCOUVER
GLOBE AND MAIL UPDATE
PUBLISHED JUNE 13, 2010
UPDATED MARCH 26, 2017

A wall of mud, water and rocks roared down a mountain in southern British

GLOBAL NEWS AT 11 OKANAGAN | April 17 2018 8:40pm | 01:45

Efforts to prevent debris flow in Oliver area as evacuation alert expands

The flooding situation in rural Oliver is becoming so serious that crews are now trying to prevent a potential disaster.
Shelby Thom reports.

- Efforts to prevent debris flow in Oliver area as evacuation alert expands

French mayor Rene Marratier jailed for role in deadly flood

12 December 2014 | Europe | Share

Rene Marratier said he would appeal against the verdict

The former mayor of a French seaside town has been sentenced to jail for four years for ignoring flood risks before a storm that killed 29 people.

Rene Marratier hid the risks to La Faute-sur-Mer to avoid putting off property developers, the court said.

The storm Xynthia hit western Europe in early 2010. The storm knocked down seawalls in La Faute-sur-Mer, leading to severe flooding.

Marratier called the verdict "unjust" and said he would appeal.

On Friday, the court said that Marratier knew La Faute-sur-Mer, a west coast resort in the Pays de la Loire region, was at risk of flooding.

However, he "deliberately hid" the risk so that he could benefit from the "cash-cow"

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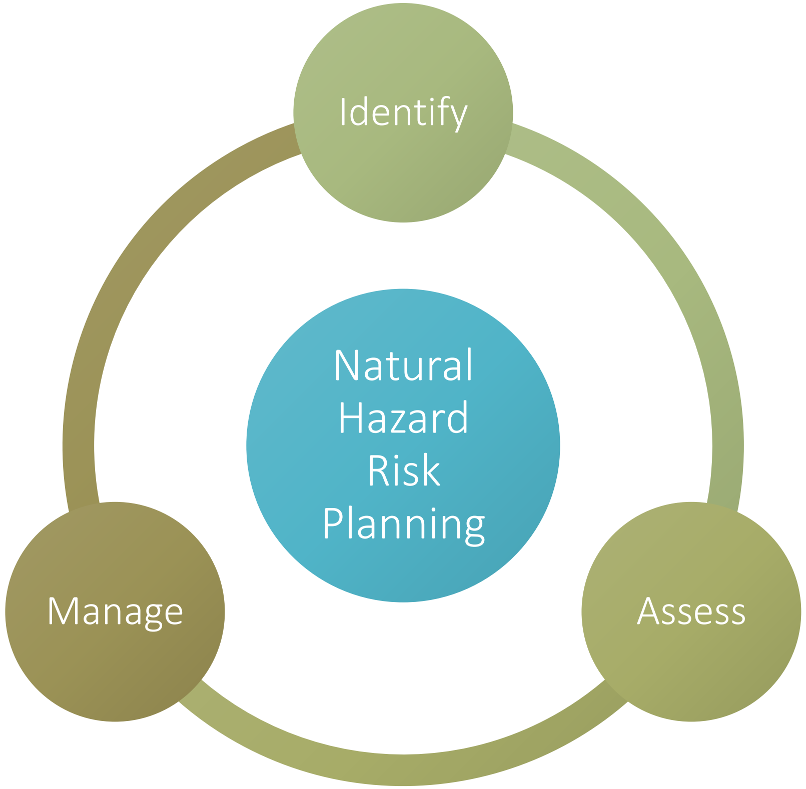
Once we understand risk, we can mitigate and improve community resilience



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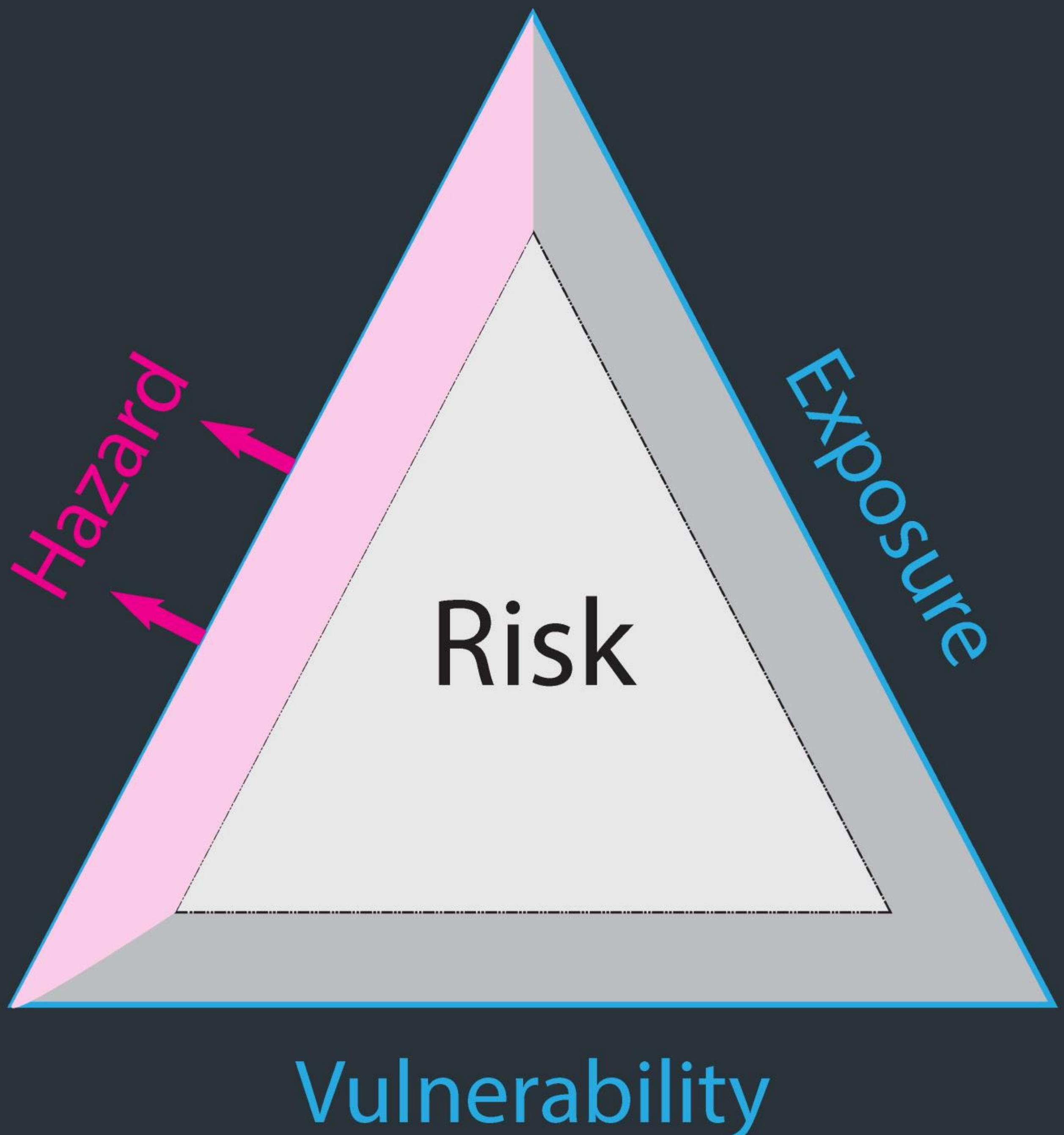
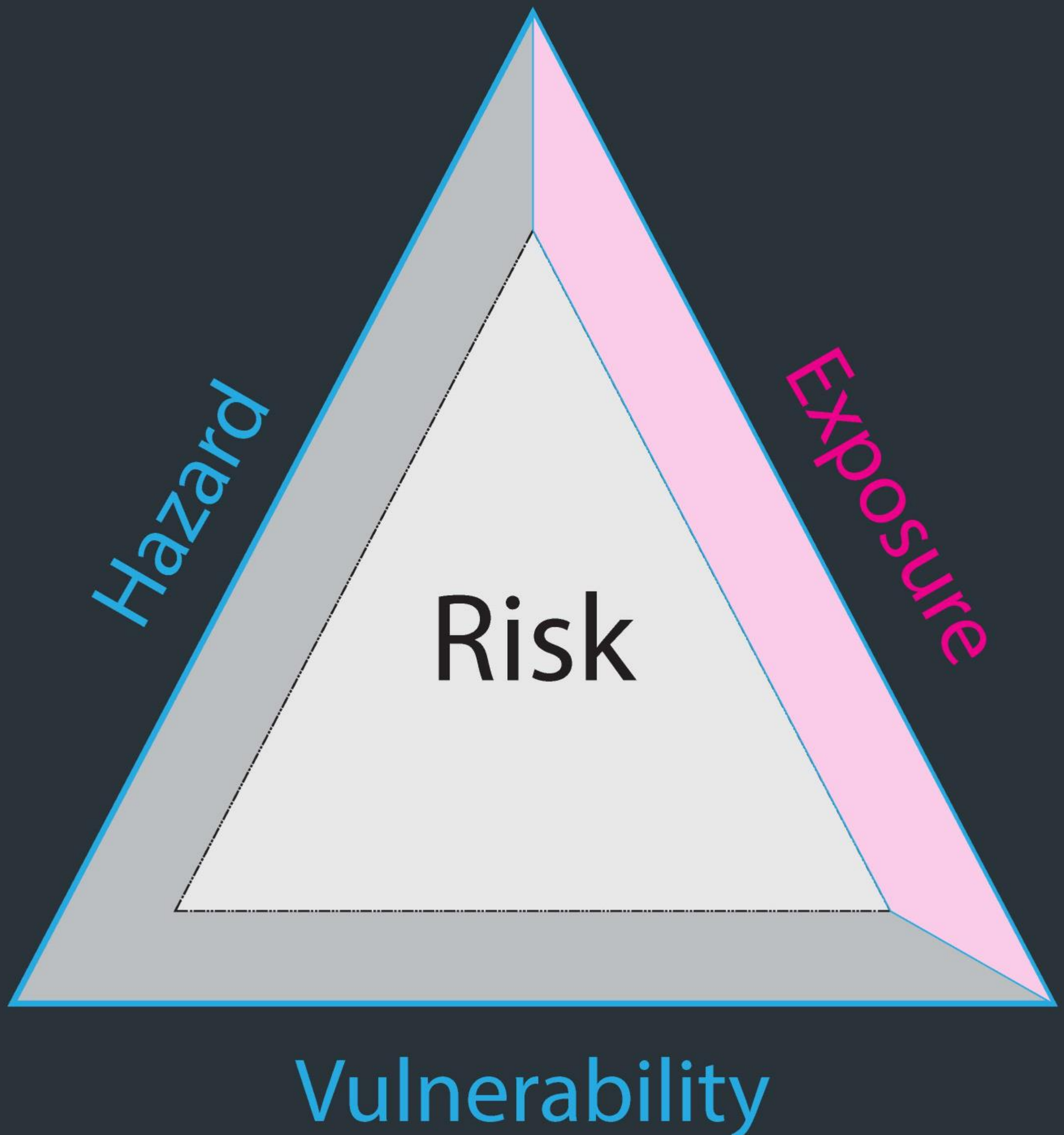
Source: www.gfdrr.org


Hazard
Exposure
Risk
Vulnerability


Hazard
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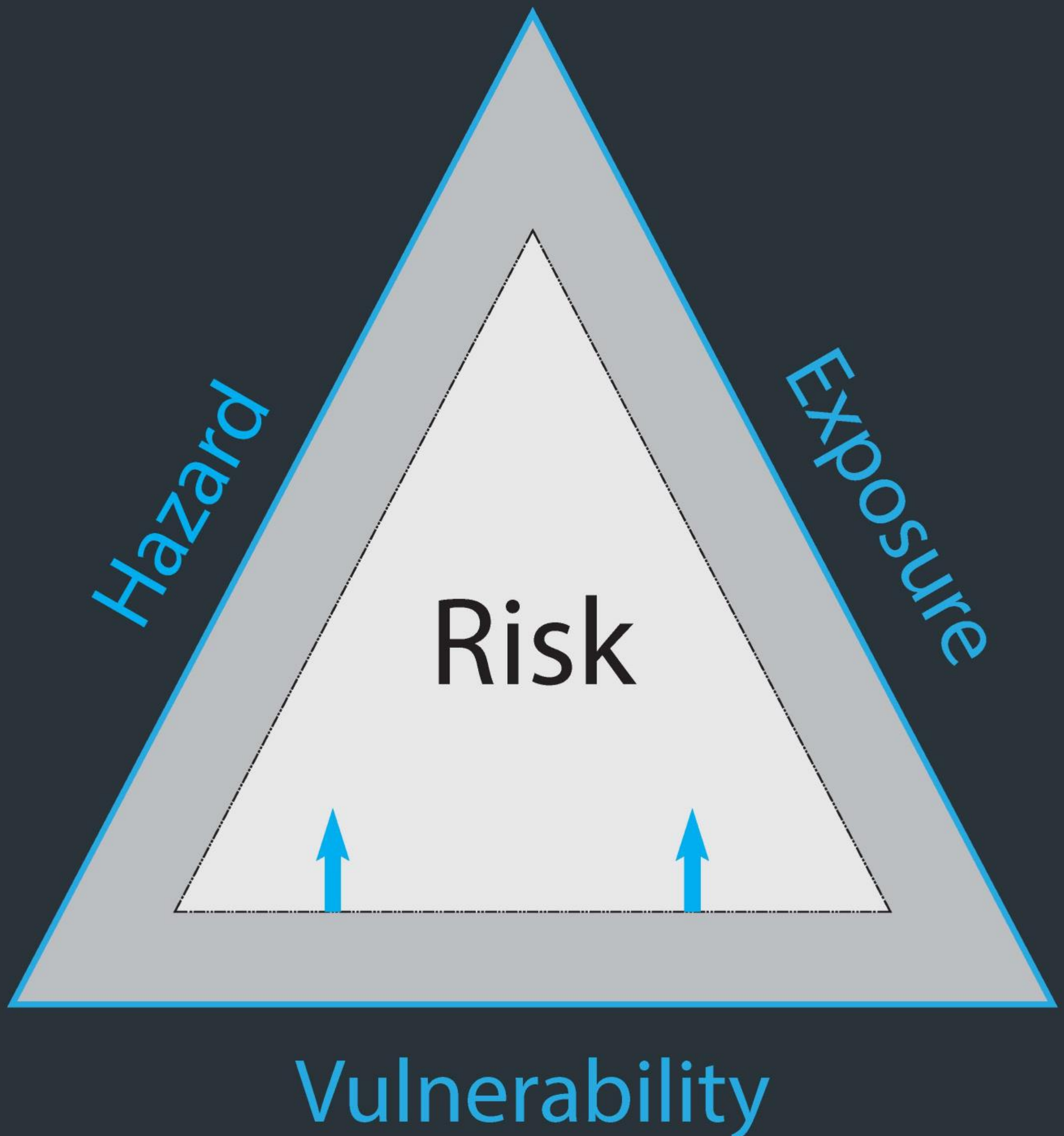
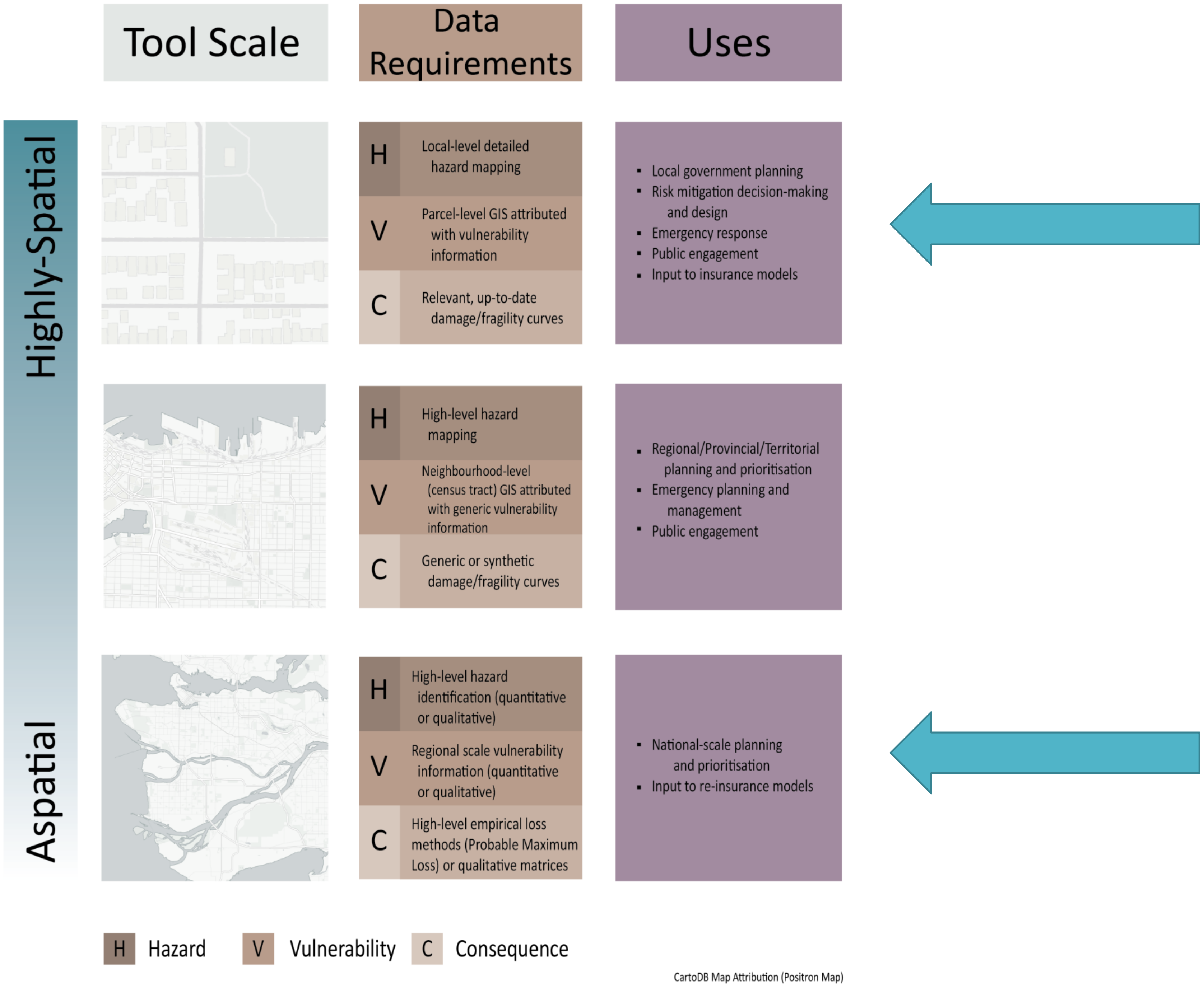
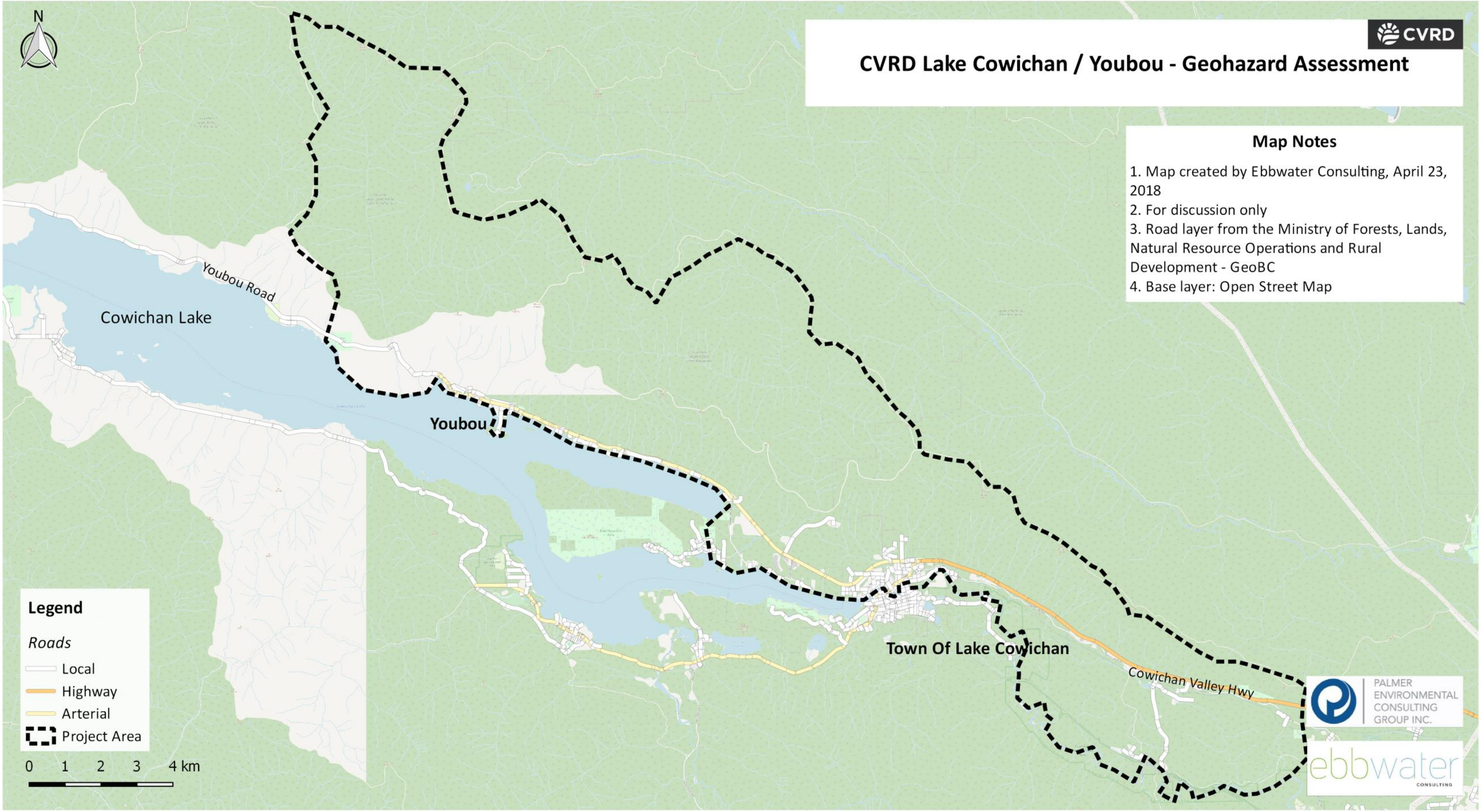


Hazard
Exposure
Risk
Vulnerability



What the community needs for planning → this project is developing tools for future disaster risk reduction planning

What the funder needs for planning → this project will have a deliverable of a RAIT.


N
CVRD
CVRD Lake Cowichan / Youbou - Geohazard Assessment
Map Notes
1. Map created by Ebbwater Consulting, April 23, 2018
2. For discussion only
3. Road layer from the Ministry of Forests, Lands, Natural Resource Operations and Rural Development - GeoBC
4. Base layer: Open Street Map
Youbou Road
Cowichan Lake
Youbou
Town Of Lake Cowichan
Cowichan Valley Hwy
Legend
Roads
Local
Highway
Arterial
Project Area
0 1 2 3 4 km
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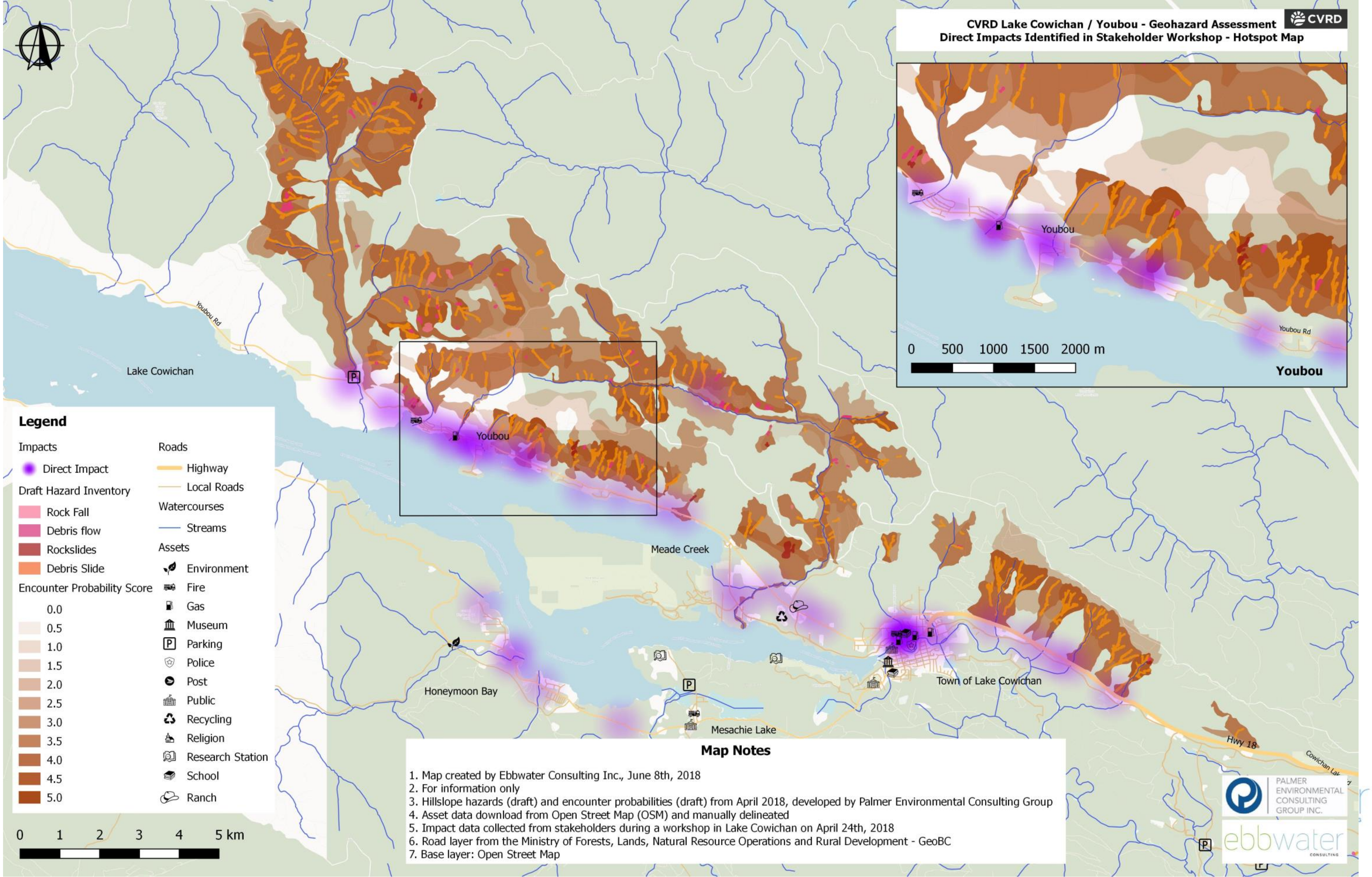

CVRD Lake Cowichan / Youbou - Geohazard Assessment
Direct Impacts Identified in Stakeholder Workshop - Hotspot Map
CVRD
Youbou
0 500 1000 1500 2000 m
Youbou Rd
Lake Cowichan
Youbou
Meade Creek
Honeymoon Bay
Mesachie Lake
Town of Lake Cowichan
Hwy 18
Cowichan Lake
Legend
Impacts
Direct Impact
Draft Hazard Inventory
Rock Fall
Debris flow
Rockslides
Debris Slide
Encounter Probability Score
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Roads
Highway
Local Roads
Watercourses
Streams
Assets
Environment
Fire
Gas
Museum
Parking
Police
Post
Public
Recycling
Religion
Research Station
School
Ranch
0 1 2 3 4 5 km
Map Notes
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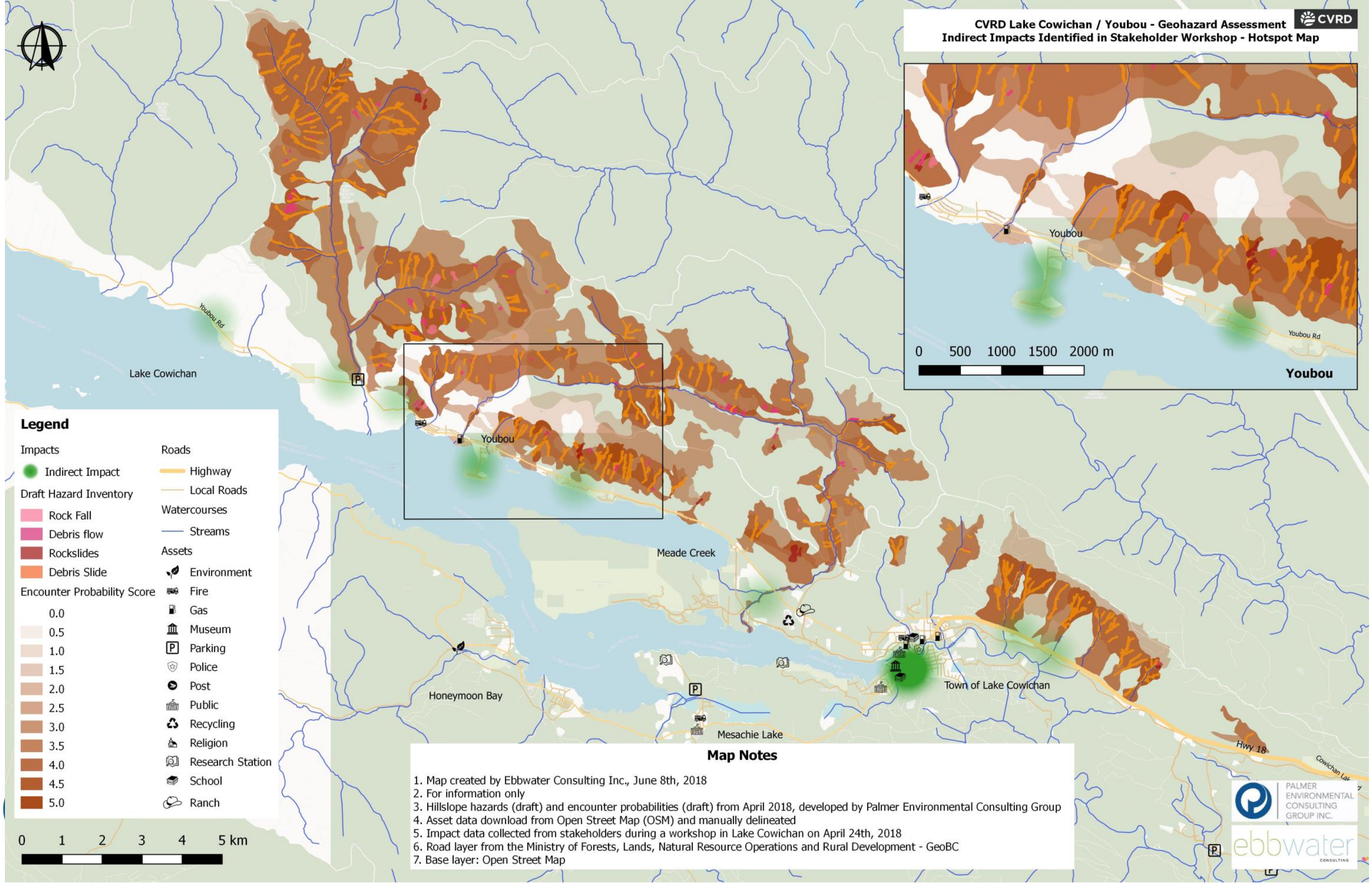

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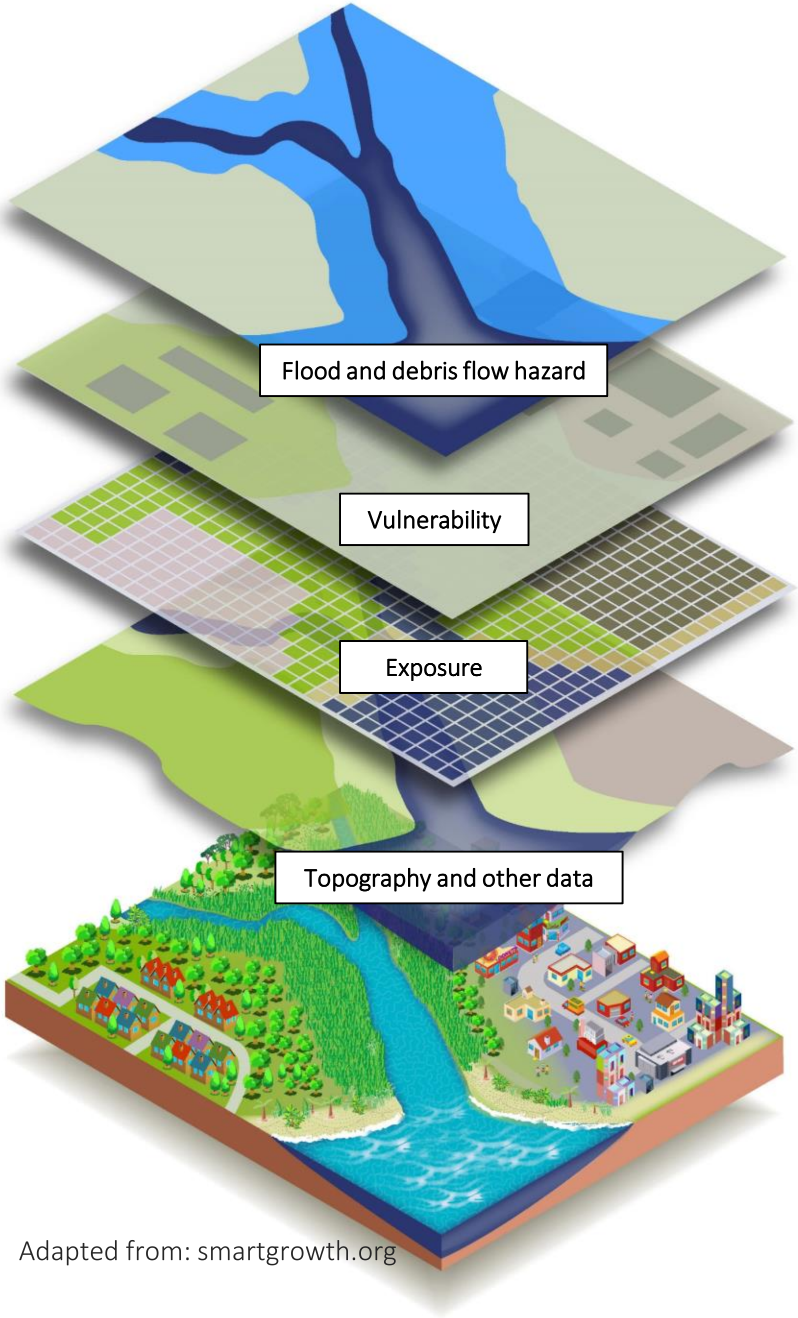
7. Base layer: Open Street Map

Process of Risk Assessment

- To get to risk, need to understand each of the elements
- Overlay the elements



Adapted from: smartgrowth.org

Exposure – it's not just dollars and cents

People

Infrastructure

Environment

Economy

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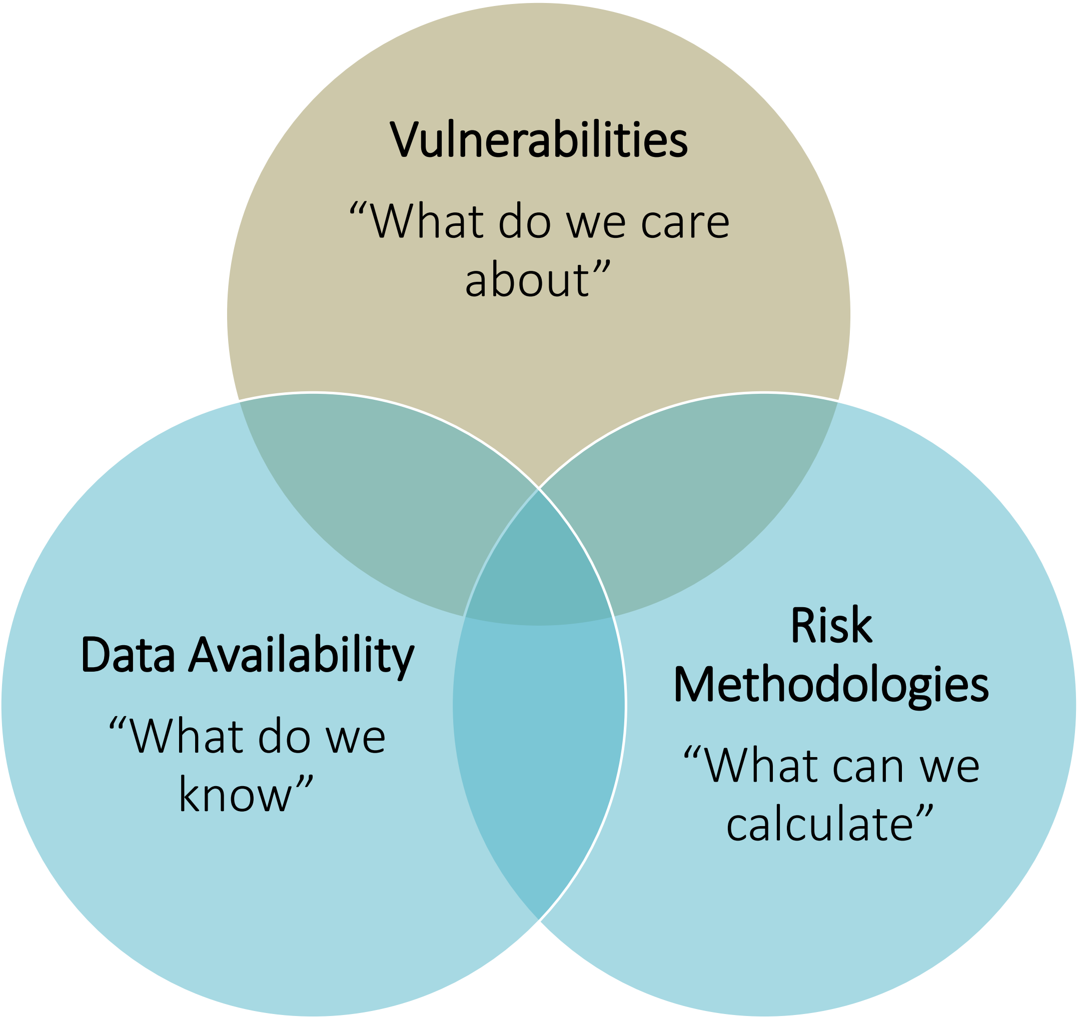
The middle of the *Venn Diagram* is very small



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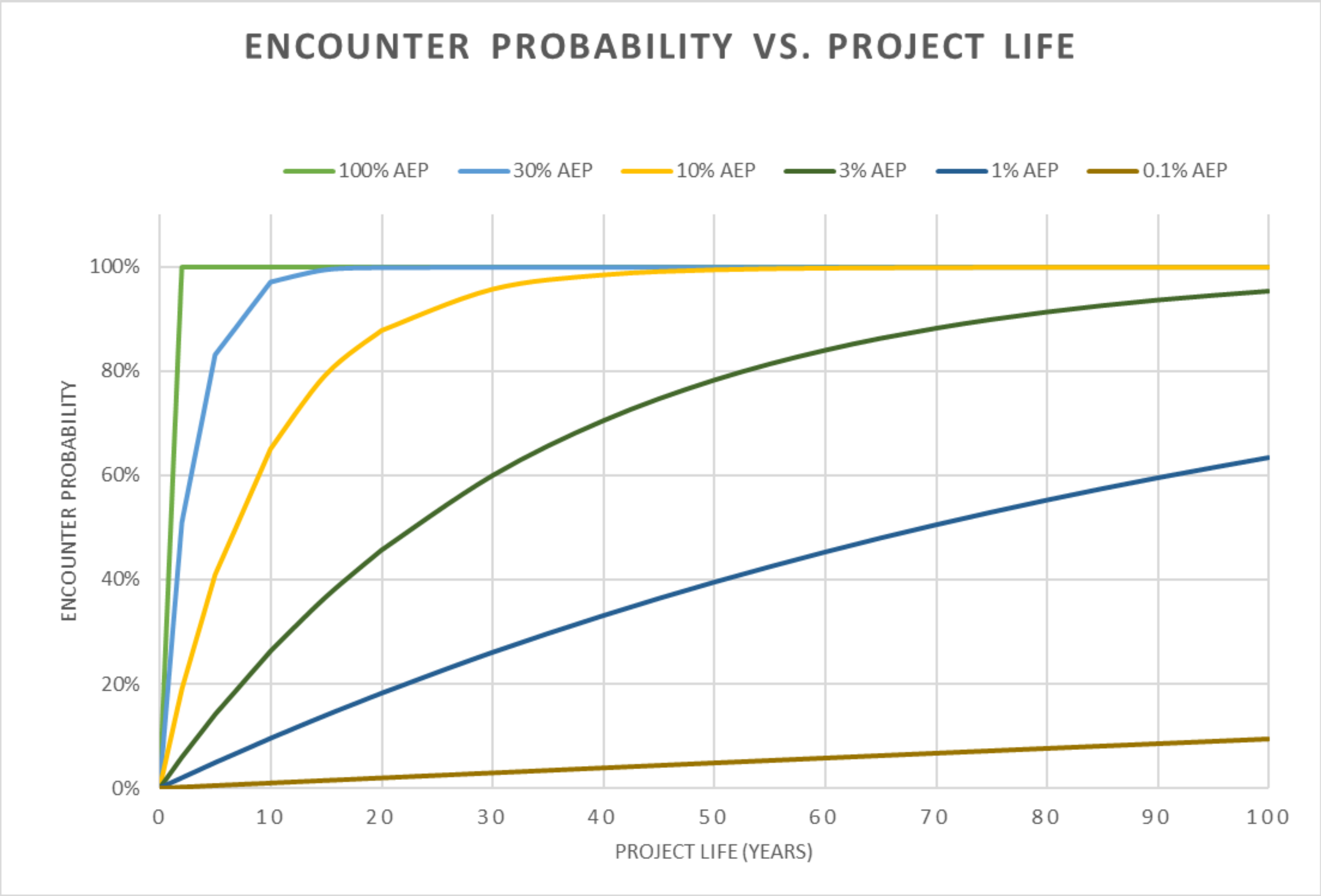
Encounter Probability.. this also matters



ENCOUNTER PROBABILITIES FOR AEP LEVELS USED FOR RISK TOLERANCE ASSESSMENT

Encounter Probabilities by the numbers

ENCOUNTER PROBABILITIES FROM GRAPH

Asset Life	AEP					
	100% AEP	30% AEP	10% AEP	3% AEP	1% AEP	0.1% AEP
10	100%	97%	65%	26%	10%	1%
20	100%	100%	88%	46%	18%	2%
30	100%	100%	96%	60%	26%	3%
40	100%	100%	99%	70%	33%	4%
50	100%	100%	99%	78%	39%	5%
60	100%	100%	100%	84%	45%	6%
70	100%	100%	100%	88%	51%	7%
80	100%	100%	100%	91%	55%	8%
90	100%	100%	100%	94%	60%	9%
100	100%	100%	100%	95%	63%	10%

Kahoot!

Game PIN

Enter

kahoot.it

LUNCH BREAK

Back to work at 12:50

Exposure Mapping Validation

Tamsin Lyle, P.Eng | Principal | Ebbwater Consulting

Heather Murdock, P.Eng | Project Engineer | Ebbwater Consulting

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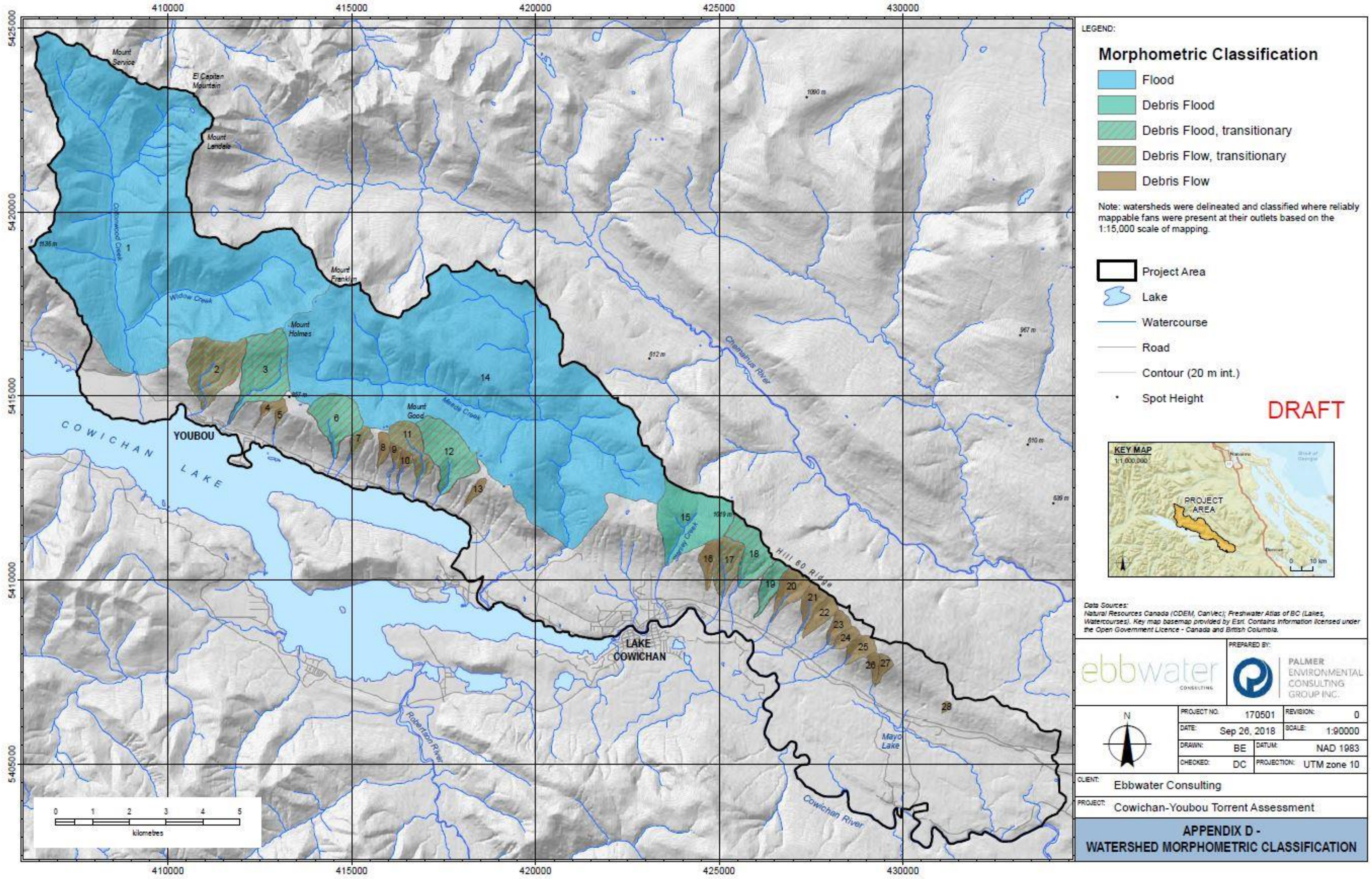
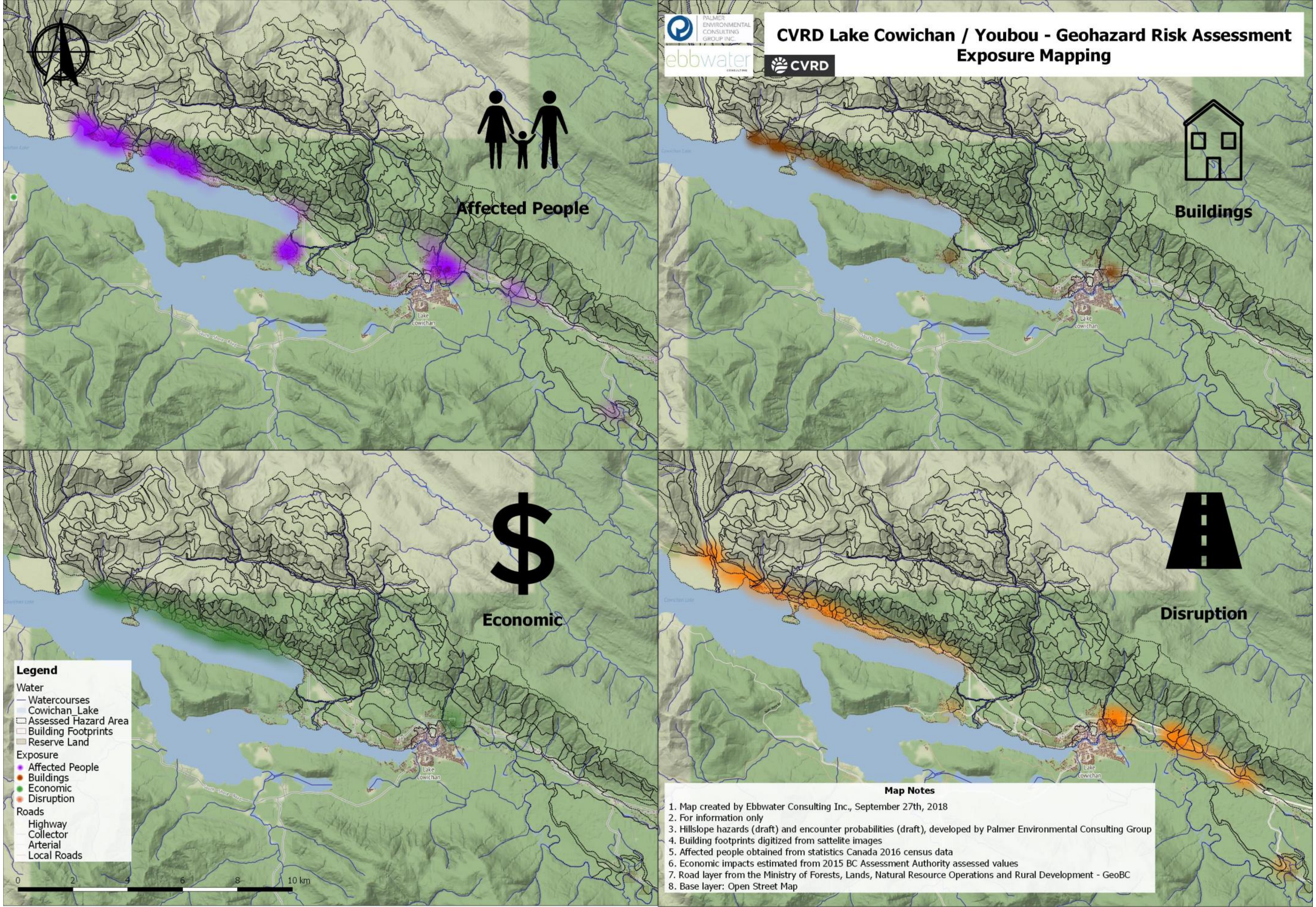


LEGEND:
Morphometric Classification
Flood
Debris Flood
Debris Flood, transitionary
Debris Flow, transitionary
Debris Flow
Note: watersheds were delineated and classified where reliably mappable fans were present at their outlets based on the 1:15,000 scale of mapping.
Project Area
Lake
Watercourse
Road
Contour (20 m int.)
Spot Height
DRAFT
KEY MAP
PROJECT AREA
Data Sources:
Natural Resources Canada (CDEM, CanVec); Freshwater Atlas of BC (Lakes, Watercourses). Key map basemap provided by Esri. Contains information licensed under the Open Government Licence - Canada and British Columbia.
ebbwater consulting
PREPARED BY:
PALMER ENVIRONMENTAL CONSULTING GROUP INC.
PROJECT NO. 170501
REVISION: 0
DATE: Sep 26, 2018
SCALE: 1:90000
DRAWN: BE
DATUM: NAD 1983
CHECKED: DC
PROJECTION: UTM zone 10
CLIENT: Ebbwater Consulting
PROJECT: Cowichan-Youbou Torrent Assessment
APPENDIX D -
WATERSHED MORPHOMETRIC CLASSIFICATION
COWICHAN LAKE
YOUBOU
LAKE COWICHAN
Mount Service
El Capitan Mountain
Mount Landale
Mount Franklin
Mount Holmes
Mount Good
Widow Creek
Meade Creek
Cottonwood Creek
Chemainus River
Hill 60 Ridge
Robertson River
Cowichan River
Mayo Lake
kilometres



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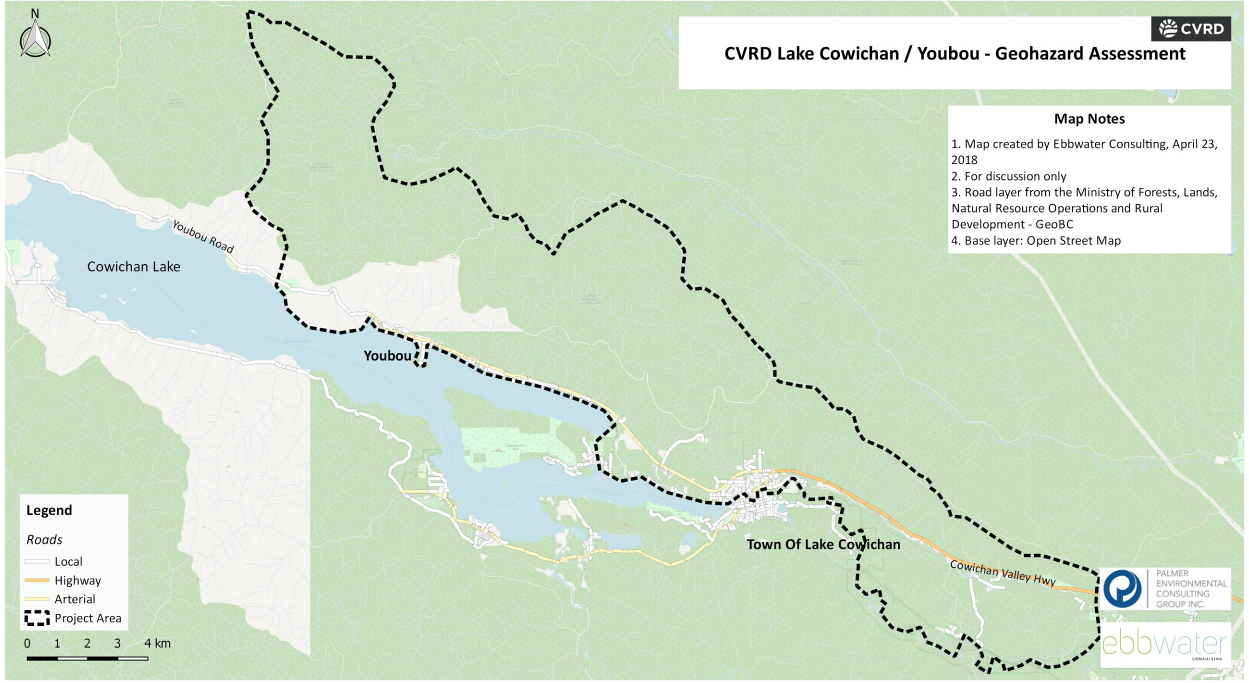
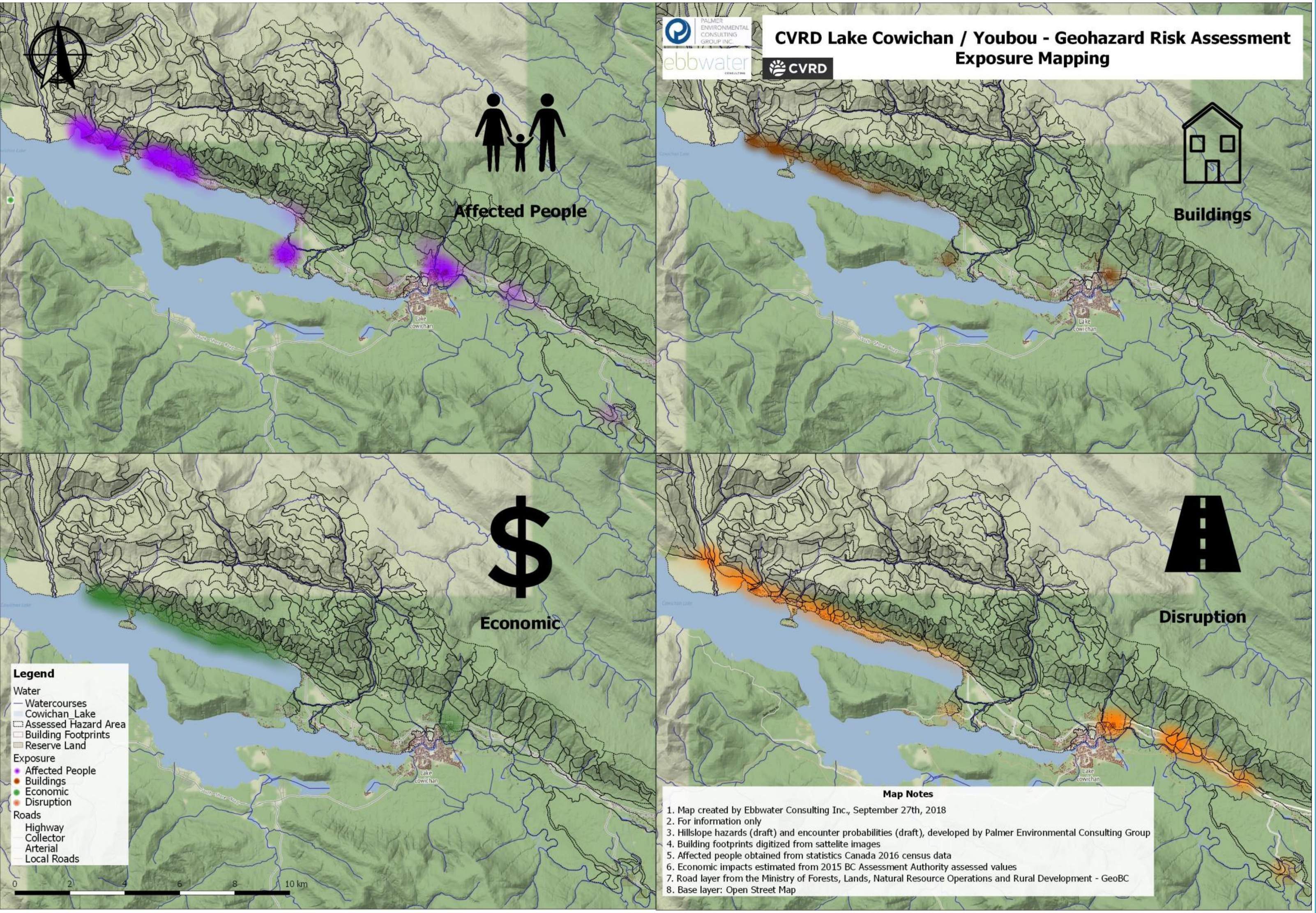
ebbwater
CVRD
CVRD Lake Cowichan / Youbou - Geohazard Risk Assessment
Exposure Mapping
Affected People
Buildings
Economic
Disruption
Lake Cowichan
Legend
Water
Watercourses
Cowichan_Lake
Assessed Hazard Area
Building Footprints
Reserve Land
Exposure
Affected People
Buildings
Economic
Disruption
Roads
Highway
Collector
Arterial
Local Roads
0 2 4 6 8 10 km
Map Notes
1. Map created by Ebbwater Consulting Inc., September 27th, 2018
2. For information only
3. Hillslope hazards (draft) and encounter probabilities (draft), developed by Palmer Environmental Consulting Group
4. Building footprints digitized from sattelite images
5. Affected people obtained from statistics Canada 2016 census data
6. Economic impacts estimated from 2015 BC Assessment Authority assessed values
7. Road layer from the Ministry of Forests, Lands, Natural Resource Operations and Rural Development - GeoBC
8. Base layer: Open Street Map

Mapping Direct & Indirect Impacts

1. Write notes on sticky notes (1 per sheet) & place on map:
   Direct Impacts – PINK/PURPLE
   Indirect impacts –YELLOW/GREEN
   Comments - BLUE

2. Group discussion at your table (20 min):
   What trends do you notice?
   What connections do you notice with what matters to others?
   Any upstream/downstream connections?
   What is missing? What questions do you have?





What trends stand out?

What else matters?

What else do we (consultants) need to know?

Getting to know Risk Tolerance

Tamsin Lyle, P.Eng | Principal | Ebbwater Consulting

Heather Murdock, P.Eng | Project Engineer | Ebbwater Consulting

ebbwater CONSULTING

THOUGHTFUL FLOOD MANAGEMENT

What's your risk tolerance?

Approaches to Risk Tolerances

Highly Quantitative

Example: District of North Vancouver

Application of ALARP principle

Type of Application	1:10,000 + ALARP	1:100,000	FOS>1.3 (static)	FOS>1.5 (static)
Building Permit (<25% increase to gross floor area)	X		X	
Building Permit (>25% increase to gross floor area and/or retaining walls >1.2m)		X		X
Re-zoning		X		X
Sub-division		X		X
New Development		X		X

Hybrid Approach: Quantitative tools and expert judgement

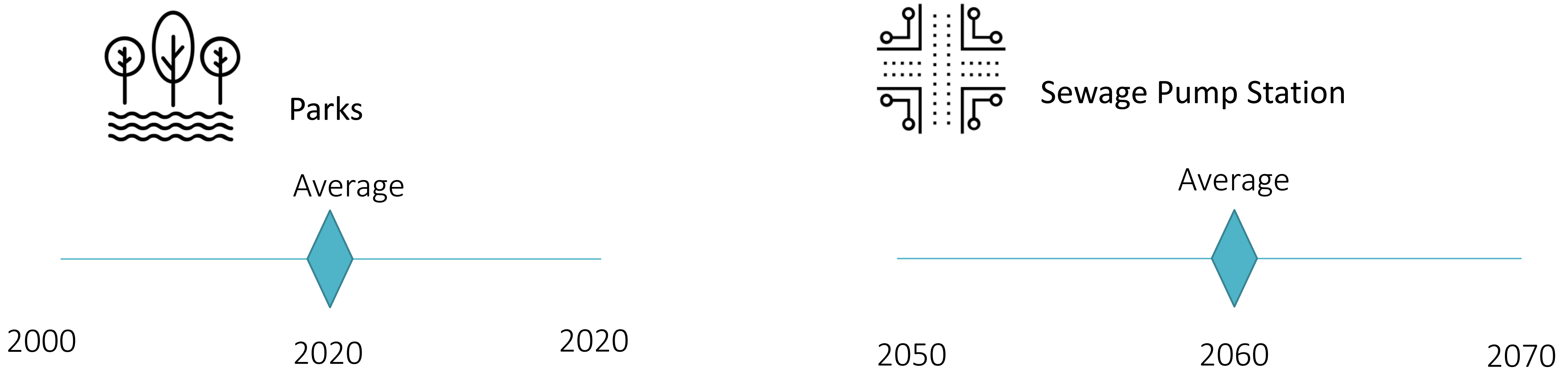
Example: City of Vancouver

Asset and tolerance based approach

Asset Classes	Asset Sub-Classes	Average Risk Tolerance (AEP)		
		Minor Flooding (5-10cm)	Moderate Flooding (20-40cm)	Severe Flooding (90-100cm)
1) Residential Property		10%	2%	1%
2) Commercial Property	Retail	17%	3%	1%
	Industrial	12%	2%	1%
3) Institutional Buildings	Government & Schools	5%	1%	1%
	Museums	40%	0.3%	0.1%
	Health Services	4%	1%	0.1%
4) Critical Infrastructure	Power Supply and Telecommunications	100%	12%	0.6%
	Water Supply	60%	5%	0.4%
	Wastewater	44%	3%	0.4%
	Roads and Transportation	100%	13%	2%
5) Parks	Buildings and Structures	30%	3%	0.4%
	Fields and Park Areas	100%	10%	2%

Example Approach:
Speed limit & ranges…

Moderate Flooding



Risk Averse

Risk Tolerant

Adaptation Planning

Tamsin Lyle, P.Eng | Principal | Ebbwater Consulting

Heather Murdock, P.Eng | Project Engineer | Ebbwater Consulting

ebbwater CONSULTING

THOUGHTFUL FLOOD MANAGEMENT

1983 Debris Flow in Lion’s Bay, BC (VIU image)

Natural hazard management is a wicked problem

High degree of technical complexity

Multiple dimensions of uncertainty
Multiple objectives

What: Enable Resilience

Reduce the Hazard

Block the water

Reduce Exposure

Stop things/people you care about getting wet

Reduce Sensitivity

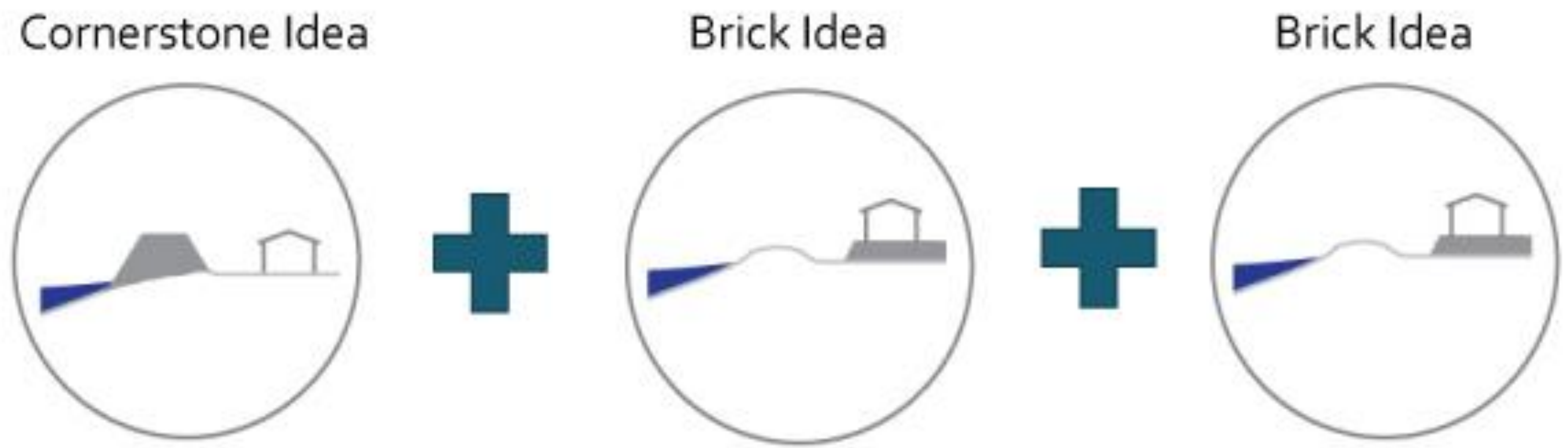
Reduce impact of getting wet

- We can't fight nature
- We can't sterilise our hazard areas

- We can reduce sensitivity to our built environment
- We can speed up our recovery
- We can safely fail instead of striving for the fail-safe solution

What: Have a Back-Up Plan

Complementary Design with Co-Benefits



e.g. A dike

complemented with property-level-protection

improved with habitat enhancement and a bike path

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ebbwater CONSULTING
THOUGHTFUL FLOOD MANAGEMENT

Next Steps…

Timeline

January 2018	Winter 2017/2018	April 2018	Summer 2018	Fall 2018	Winter 2018
Kick-off presentation	Desktop hazard mapping (Presented in Workshop 1)	Understanding exposure by learning about community values and impacts (Workshop 1)	Further analysis of hazard (field visits), exposure and risk	Stakeholder understanding (geohazard) risk (tolerance) workshop (This meeting)	Completion of Risk Assessment Reporting (written and verbal)

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

ebbwater CONSULTING THOUGHTFUL FLOOD MANAGEMENT

Thank You!

tamsin@ebbwater.ca

heather@ebbwater.ca

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

ebbwater CONSULTING

THOUGHTFUL FLOOD MANAGEMENT

Appendix D Geohazard Reporting (Palmer)

PALMER ENVIRONMENTAL CONSULTING GROUP INC.
470 Granville Street, Suite 630, Vancouver, BC V6C 1V5
Tel: 604-629-9075 | www.pecg.ca

Lake Cowichan and Youbou Slope Hazard Assessment

PECG Project #
17050

Prepared For
Cowichan Valley Regional District

December 4, 2018

December 4, 2018

Kate Miller
Manager, Environmental Services
Cowichan Valley Regional District
175 Ingram Street
Duncan, British Columbia
V9L 1N8

Dear Ms. Miller:

Re: Lake Cowichan and Youbou Slope Hazard Assessment
Project #: 17050

Palmer Environmental Consulting Group Inc., in association with Ebbwater Consulting Inc., is pleased to present the Cowichan Valley Regional District with the results of our slope hazard assessment for Lake Cowichan and Youbou.

Attached to this report are four appendices containing terrain mapping, a hazard inventory, a quantitative hazard model, and a hydrogeomorphic classification of major watersheds in the study area.

Please contact Derek Cronmiller at 867 689 5776 or derek@pecg.ca if you have any questions regarding the contents of the report.

Yours truly,
Palmer Environmental Consulting Group Inc.

Derek Cronmiller, P.Geo
Geoscientist

Robin McKillop, M.Sc., P.Geo
Principal, Geomorphologist

Table of Contents

List of Figures

List of Tables

List of Appendices

1. Introduction

1.1 Background

Palmer Environmental Consulting Group Inc. (PECG), through our subconsultant agreement with Ebbwater Consulting Inc. (Ebbwater), is pleased to provide the Cowichan Valley Regional District (CVRD) with the results of our slope hazard assessment for the watersheds surrounding the communities of Youbou and Cowichan Lake, on Vancouver Island. These watersheds have previously been identified as hazard-prone areas based on their steep slopes and history of landslides. Increasing residential development, combined with the effects of forestry and climate change on slope stability, warrant this hazard assessment. Results from this study establish a foundation for Ebbwater's risk assessment. Smith. P.Geo., Eng.L., representing Westrek Geotechnical Services Ltd., acted in an advisory and review role on this project.

1.2 Study Area

The study area (Figure 1) is located in south-central Vancouver Island, British Columbia, and includes the communities of Youbou and Lake Cowichan. The study area is approximately 16,000 ha and runs northwest-southeast. The Cowichan Valley Highway (Hwy 18) crosses the study area along the north side of Cowichan Lake and Cowichan River. The south side of the study area is bounded by Cowichan Lake in the west, and Cowichan River in the east. The north side of the study area is bounded by a drainage divide separating the Cowichan River watershed from the Nanaimo River and Chemainus River watersheds to the north.

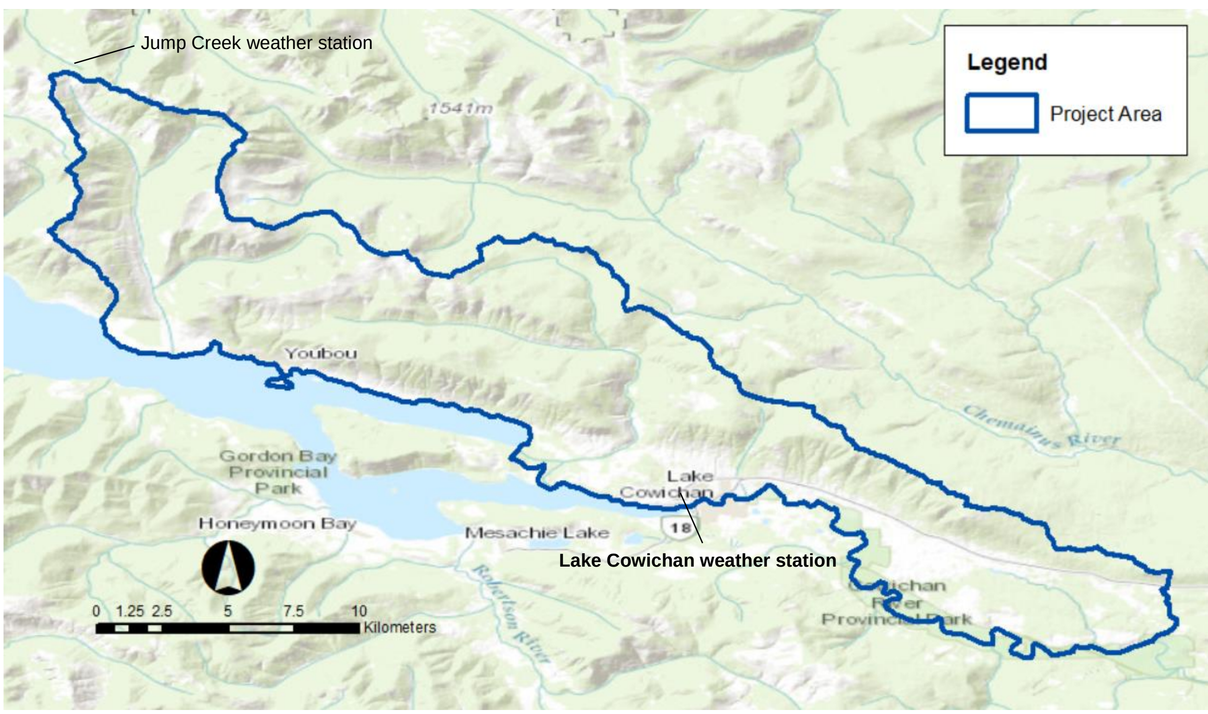

Figure 1. Lake Cowichan and Youbou slope hazard assessment study area

1.3 Objectives

The objectives of this hazard assessment are to:

- Produce detailed (1:15,000-scale) terrain mapping for the study area
- Produce a detailed, multi-year landslide inventory including qualitative and quantitative characterization of the landslide hazard in the study area
- Use the landslide inventory and terrain mapping to create a quantitative terrain hazard model to predict landslide occurrence within the terrain polygons
- Field check the mapping and inventory road and bridge infrastructure

1.4 Definitions

The following terms are used throughout this report. Landslide definitions are based on the Varnes (1978) landslide classification system.

Clearwater flood: An extreme hydrologic event where sediment comprises less than 20% of the discharge by weight (Wilford et al., 2004). These events are commonly caused by moderate to heavy or prolonged rainfall, melting snow, or a combination of the two. This term is favoured over “flood” for clarity.

Debris flood: A channelized flood of sediment-laden water, where sediment concentration can range from 20-47% by volume (Wilford et al., 2004). Peak discharges of debris floods can range from 2 to 5 times that of a clearwater flood. Debris floods are not considered a landslide.

Debris flow[1]: A rapid flow of saturated debris, typically channelized in a steep gully. A debris flow may initiate as a debris slide or rock slide that becomes channelized in a gully, and increase in size through entrainment of surficial material, organic debris and water. Debris flows are often triggered by intense or prolonged precipitation and can have peak discharges up to 40 times greater than clearwater floods (Hungr et al., 2001). Debris flows may transition to debris floods through addition of water in tributaries (Wilford et al., 2009) or where confinement is lost.

Debris slide: A sliding mass of unconsolidated surficial material. May transition into a debris flow through confinement.

Encounter probability: The probability that any given area will be affected by a landslide over a given time period.

Landslide Density: The number of landslides per unit area.

Paraglacial: A period of rapid sedimentation immediately following glaciation due to availability of unconsolidated sediments, presence of unstable glaciogenic landforms, and lack of stabilizing vegetation (Church and Ryder, 1972).

[1] This term is synonymous with the term “debris torrent” in British Columbia, which is no longer widely used in landslide studies due to the restrictive nature of its original definition and its poor linguistic fit with other landslide classifications.

Rock fall: Falling, rolling or bouncing mass of detached bedrock, with movement rates that are extremely rapid.

Rock slide: A sliding mass of detached bedrock, with rates that can vary from extremely slow (mm's/year) to extremely rapid (m's/second).

2. Physical Setting

2.1 Climate

The study area is in a Maritime climatic zone characterized by warm dry summers and mild wet winters. Climate normals within the study are summarized in Figure 2. Average annual precipitation is 2,047 mm at the Lake Cowichan weather station (Figure 1) at an elevation of 177 m above sea level, with 1,975 mm falling as rain, and the remainder as snow; most precipitation falls in the winter months. It is expected that precipitation increases with elevation; thus, much of the study area will receive more than the Lake Cowichan weather station. High elevation regions in the western portion of the study area receive as much as 4,500 mm/year (Wang et al., 2012). On average, 72 cm of snowfall occurs per year, with greater accumulations at higher elevations. Peak snowpack depth typically occurs in April with an average 1,200 mm snow water equivalent (Jump Creek weather station, Figure 1). The mild winters make rain-on-snow events relatively common. These events are a frequent trigger of large floods and landslides. The snowpack typically melts by mid-July (Jump Creek weather station).

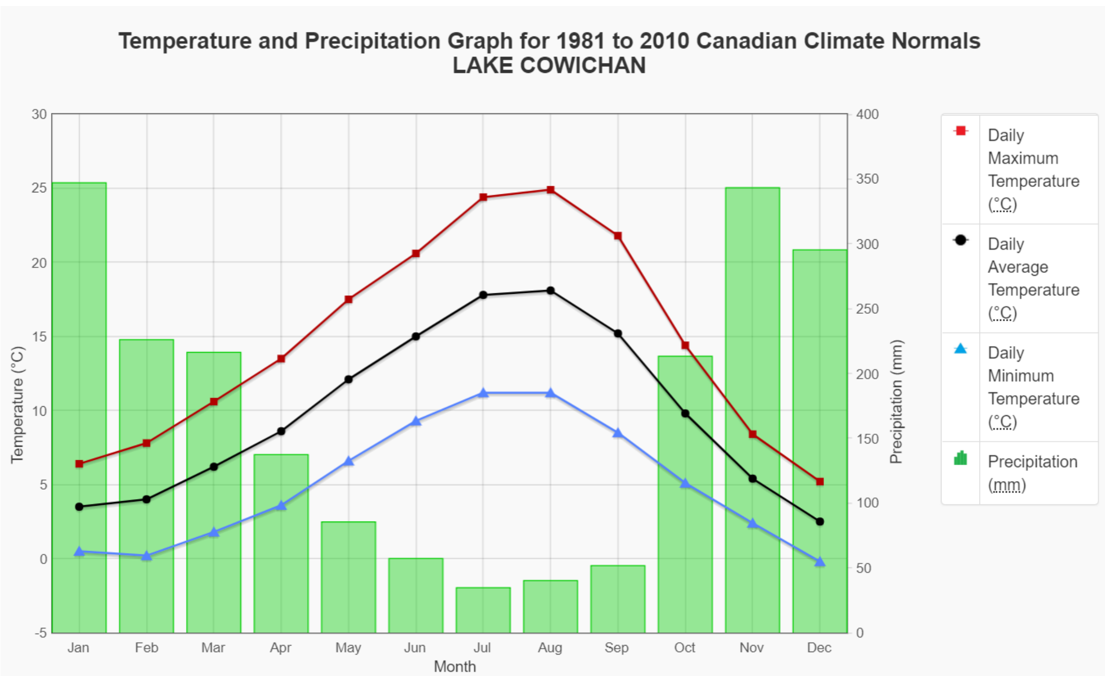

Figure 2. Environment Canada 1981-2010 climate normals from Lake Cowichan weather station, 48.83° N 124.05° W, 177 masl. Location of weather station shown in Figure 1.

2.2 Bedrock Geology

The study area is underlain by a complex assemblage of bedrock intersected by multiple faults, approximately paralleling the Cowichan Valley. Bedrock includes the Island Plutonic Suite, Mount Hall Gabbro, Sicker Group, Vancouver Group, Buttle Lake Group, and the Nanaimo Group (Massey et al., 2005). The Island plutonic suite consists of granodioritic intrusive rocks. The Mount Hall Gabbro consists of gabbroic to dioritic intrusive rocks. Two formations of the Sicker Group are found in the study area: the Nitinat formation consisting of calc-alkaline volcanic rocks, and the volcaniclastic McLaughlin Ridge Formation. The Karmutsen basalts of the Vancouver Group are found only in the headwaters of Cottonwood Creek. Limestone of the Mark Mountain Formation, and the chert, argillic and siliciclastic of the Fourth Lake Formation (from the Buttle Lake Group), are found in the study area. The Cowichan and Meade Creek Valley bottoms are underlain by the sedimentary rocks of the Nanaimo Group. Field observations indicate the Nanaimo group consists primarily of sandstones and pebble conglomerates in the study area.

2.3 Seismicity

The Cowichan Valley is in an area of high seismic hazard (NRCAN, 2015; Figure 3) due to plate movement at the Juan de Fuca subduction zone; many earthquakes have been recorded up to moment magnitude (M) 9 (Figure 4). The epicentres of these earthquakes are primarily located in the Salish Sea, Puget Sound, and up to 200 km off the west coast of Vancouver Island. Many low magnitude earthquakes (<M4) have occurred near the study area; however, high magnitude earthquakes are less common, and generally occur further away.

Work by Keefer (1984) found that earthquakes of sufficient magnitude (>M4) and proximity may be able to trigger landslides. Different classes of landslides may be triggered based on different magnitude-distance relationships (Keefer, 1984). These magnitude-distance relationships are shown in Figure 5, with the four nearest large magnitude earthquakes from Figure 4 plotted for reference. The landslide category "disrupted falls and slides" used by Keefer includes all landslides mapped in this study. Figure 5 shows that only three earthquakes have had the potential to trigger landslides in the study area since 1700. While not insignificant, earthquakes are not likely to trigger landslides with a frequency nearing that of climatic drivers such as rainfall.

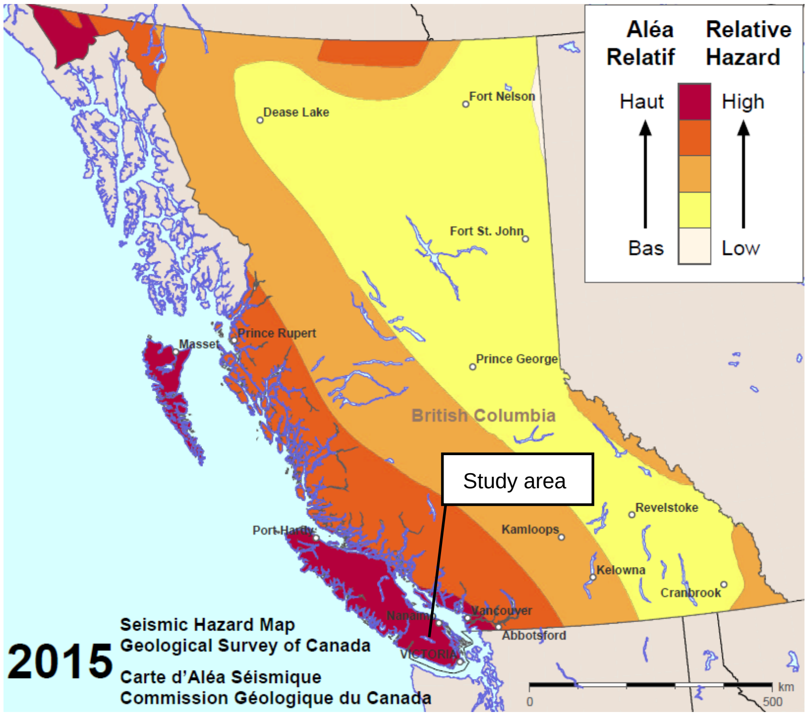

Figure 3. Simplified seismic hazard map for British Columbia (NRCAN, 2015)

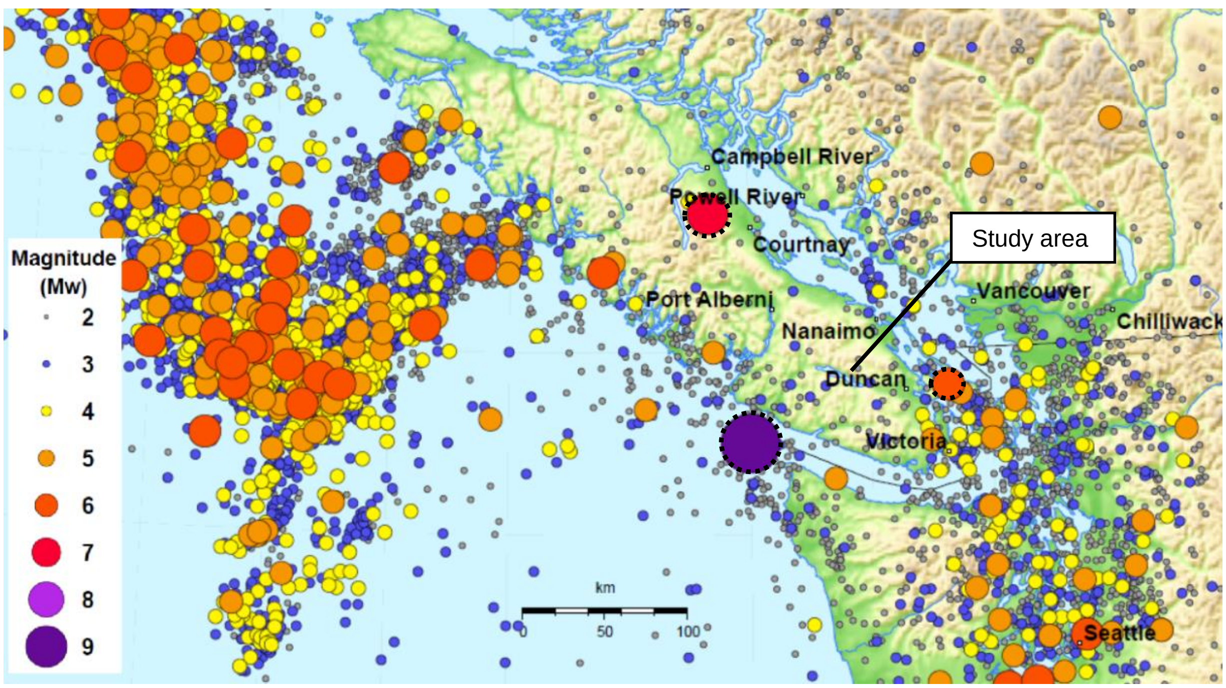

Figure 4. Inventory of earthquake epicentres in southwest BC since 1700 (Halchuck et al., 2015). The magnitude 9 earthquake occurred in 1700; the epicentre location is estimated, giving uncertainty to its position in Figure 5. Dashed boundaries indicate earthquakes plotted on Figure 5.

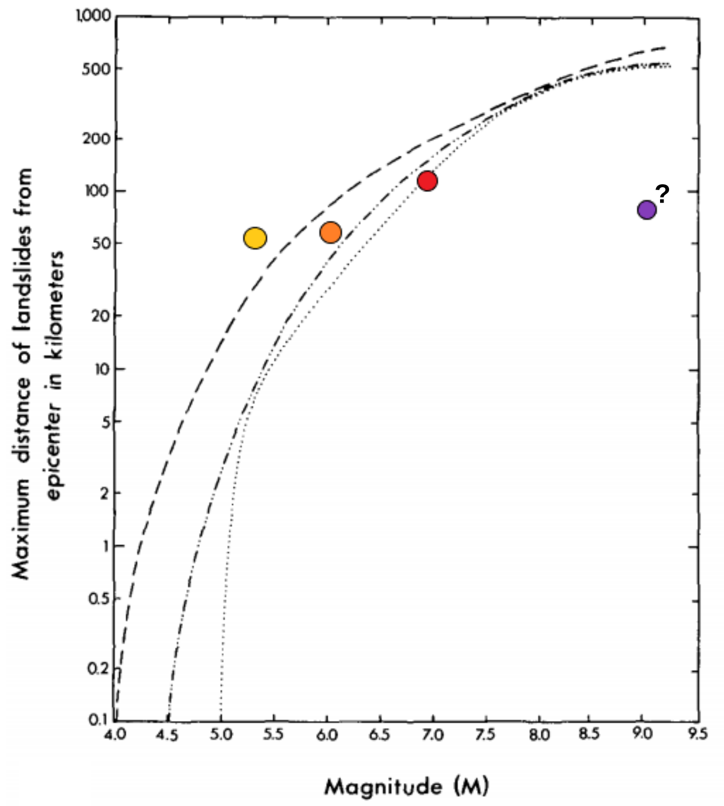

Figure 5. Relationship between earthquake magnitude and distance at which ground movement may trigger landslides, as determined by (Keefer, 1984). The dashed line represents disrupted falls and slides, the dashed-double-dotted line represents coherent slides, and the dotted line represents lateral spreads and flows. The coloured circles represent the four nearest large earthquakes shown in Figure 4. When the circles fall below a curve, the earthquake can produce landslides of that type in the study area. The distance of the purple circle from the study area is not precisely known.

2.4 Landscape Evolution: Glacial and Postglacial History

During the last glaciation, most of Vancouver Island was covered by the Cordilleran ice sheet. The glacier cover over the study area was at least 1,500 m thick (Halstead, 1966), and was strongly controlled by underlying topography, causing ice to flow along major valleys. Glacial erosion reshaped the study area, producing the steep-walled, U-shaped Cowichan Valley, and deposited till and outwash sediments across the landscape. This steepening of valley sides can lead to instability once the ice melts and retreats, debuttressing the slopes by removing the support provided by the ice.

After the retreat of the Cordilleran ice sheet, much of the landscape was covered with thick, unconsolidated sediment; many of the landforms left behind were unstable. As these landforms stabilized and before vegetation could colonize, the denudation rate through erosion and mass movement would have been orders of magnitude higher than at present time. This paraglacial period (Church and Ryder, 1972) is responsible for producing many of the large, slope-toe fans in the study area, including at Youbou Creek. As sediment availability and transport rates declined, the channels incised into the paraglacial fans and abandoned the upper fan surfaces, such that they are less frequently exposed to processes occurring in the incised channels. These inactive paraglacial fan surfaces are common in Youbou and have been the site of much of the residential development.

During the paraglacial period, many steeper mountainside slopes also became dissected by gullying processes, affecting the unconsolidated sediments and weak bedrock. These gullies, once established, are more likely to continue producing debris flows as the continued down-cutting over-steepens gully headwalls and sidewalls, and concentrates even more surface runoff (Millard, 1999).

3. Methodology

Our approach to understanding the landslide hazard within the study area relies on a combination of desktop and field analysis. Desktop mapping was used to produce a terrain map and landslide inventory. Analysis of the morphometric characteristics of each watershed in the study area with a mappable fan determined what sort of process or hazard is most likely to occur in the channels.

The mapping and morphometric results were field-verified and used in conjunction with publicly available base data (geology, elevation) to create a landslide hazard model based on the landslide inventory and terrain attributes. The hazard model output will be used by Ebbwater to conduct its risk assessment.

3.1 Desktop Mapping

3.1.1 Terrain Mapping

Terrain mapping within the study area was completed in general conformance with the Terrain Classification System for British Columbia (Howes and Kenk, 1997) and Resource Inventory Committee standards (Resource Inventory Committee, 1996). This system separates the slopes in the study area into polygons based on:

- surficial materials,
- texture of surficial material,
- landform,
- slope steepness, and
- geomorphic activity.

The terrain polygons were delineated using DAT/EM's Summit Evolution Lite, a stereo-viewing and mapping software that operates in conjunction with ESRI's ArcMap, using the 1:15,000-scale, black-and-white, 1972 aerial photographs.

3.1.2 Landslide Inventory

The landslide inventory was also completed using the DAT/EM's Summit Evolution Lite software. Three years of imagery were used to extend the observation period and give a more accurate estimate of landslide magnitudes and frequencies in the study area. The images included:

- The 1972 1:15,000-scale, black-and-white aerial photographs,
- High-resolution colour orthophotographs acquired in 2007 (50 cm pixel-size), and
- High-resolution colour orthophotographs acquired in 2014 (50 cm pixel-size).

A pixel shift was applied to both orthophotograph images using the supplied 20 m-resolution TRIM digital elevation model (DEM) provided by CVRD, enabling the production of pseudo-stereo images. The minimum visible landslide size was approximately 100 m^2.

Landslides were delineated on these images as polygons, covering the entire landslide path and characterized according to the Varnes (1978) classification. The Varnes classification differentiates landslides by their material and movement style. Four types of landslides were mapped in the study area:

- debris flow,
- debris slide,
- rock fall, and
- rock slide.

Initiation settings were grouped into four categories; natural (undisturbed terrain and vegetation cover), modified (land cover disturbed by logging or fire), road (at or adjacent to roads), and fluvial (areas where slopes have been undermined by fluvial erosion).

Each landslide was classified as follows:

- Using the Varnes (1978) classification (e.g. debris flow),
- The year of the aerial photograph in which it was first visible,
- The initiation setting of the landslide (e.g. natural, etc.), and
- The approximate area of the landslide (e.g. 2,500 m^2).

Snow avalanches also occur in the study area but were not mapped as they are beyond the scope of this study.

To understand the frequency of landslide occurrence within the study area, the length of time documented by the three years of imagery was determined based on the persistence time of landslides on the landscape; defined as a measure of how long landslides are visible on the landscape after occurrence. Guthrie and Evans (2007) found that on Vancouver Island the persistence time (years) of debris flows and debris slides (P_{DS}) is given by the empirically derived equation:

$$P_{DS} = 2.5834A^{0.3246}$$

Where *A* is the area (m^2) of a given debris flow/debris slide from the source area to the deposition zone.

The median area for debris flows and debris slides within the study area is 4,099 m^2. This yields a persistence time of approximately 38 years. The persistence time and temporal spacing of available imagery provides a total inventory duration of 80 years. Given the likelihood of delineating coalescing debris flows as one single event, which would skew the median higher, a more conservative estimate of 70 years was used as the duration for our inventory.

3.1.3 Landslide Hazard Modelling

To estimate the landslide hazard present in terrain polygons that did not have mappable landslides within them during the 70-year inventory, a model was produced to extend the encounter probabilities to all terrain polygons by correlating their terrain attributes to landslide occurrence. The result is a spatially continuous landslide hazard map for the entire study area.

The hazard model used in this study is based on the work of Rollerson et al. (2002); these authors analyzed the significance of terrain attributes in predicting post-logging landslide rates on southwest Vancouver Island. The terrain attributes they found most strongly linked to landslide occurrence were:

- slope, particularly those above 30°,

- presence of gullied terrain, and
- bedrock lithology.

The terrain polygons are used in the hazard model, giving the model the same 1:15,000 scale. Bedrock lithologies, and slopes from TRIM mapping, were added to each polygon to allow for correlation with the hazard inventory.

The area within each terrain polygon occupied by a landslide(s) was calculated from the landslide inventory. This is known as the “encounter probability” and represents the probability that any given area within a polygon will be affected by a landslide. Overlapping portions of hazard polygons are additive. The encounter probability is then divided by the number of years represented by the hazard inventory to determine an annual encounter probability. The model of encounter probability does not differentiate between the landslide types, although it could with further work.

The average encounter probability for a terrain polygon with each combination of selected attributes was calculated and assigned to each polygon with the same attributes. Where encounter probability observed from the hazard inventory was higher than the model average, the observed probability was used rather than the model average. The logic model for this process is shown in Figure 6.

The model was run multiple times using different combinations of the terrain attributes including:

- surficial material,
- surficial material thickness,
- slope gradient grouped into various categories,
- presence of gullying, and
- bedrock lithology.

A maximum of three attributes was used at one time to keep the number of polygons in each combination at a reasonable sample size. For each variable combination, results were evaluated by comparison to the landslide inventory distribution.

The model results that produced the least mischaracterizations when compared to the hazard inventory were achieved using the mean slope gradient within polygons in 10-degree increments, the presence of gullying, and bedrock lithology. These are the same variables found to be most significant in identifying post-logging landslide densities by Rollerson et al. (2002)

The four large rock slides in the hazard inventory were not used in the model because they occurred or initiated well outside the hazard inventory timeframe and were only visible due to their large size.

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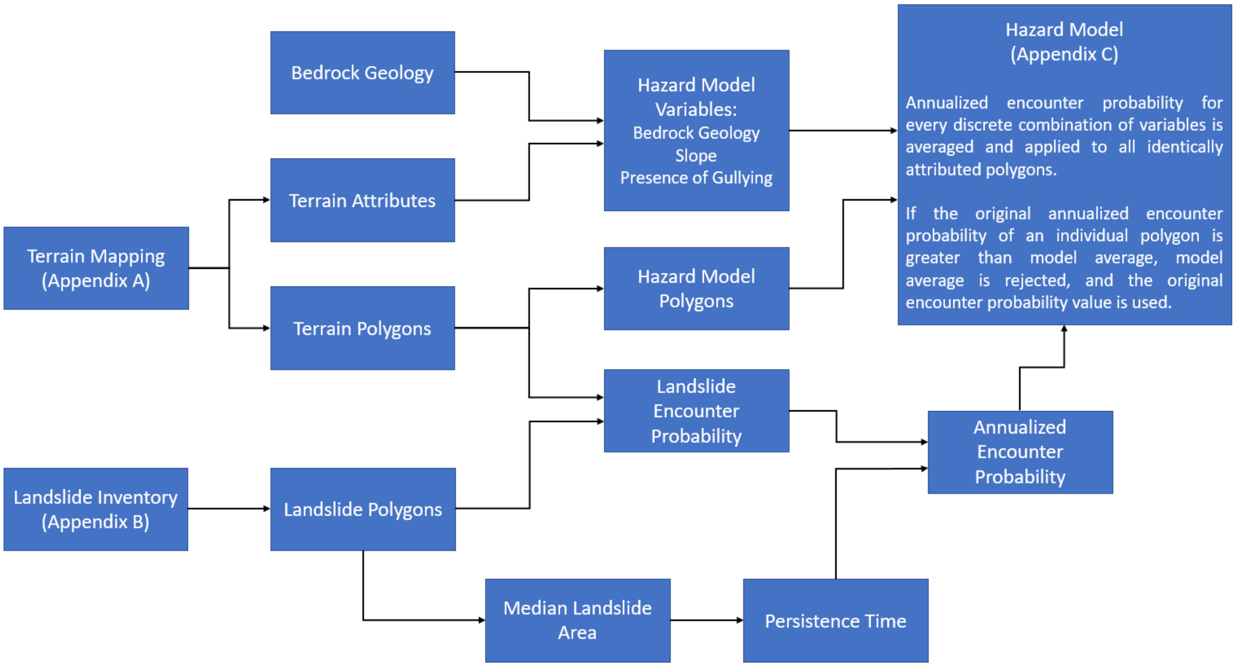

Figure 6. Logic model for hazard analysis.

3.1.4 Watershed Morphometrics

The lower slopes in much of the study area are covered by fans formed by either clearwater floods, debris floods, or debris flows. Watersheds that have produced fans large enough to be mapped using the 1:15,000-scale aerial photographs were delineated. The area, length (down-slope), and total relief was recorded for each watershed; using these attributes, the Melton ratios (Melton, 1957) and relief ratios were calculated.

The Melton ratio is defined as the watershed relief divided by the square root of the watershed area:

$$Melton\ ratio = \frac{Relief\,(km)}{\sqrt{Watershed\ area}(km)}$$

The relief ratio is defined as the watershed relief divided by the watershed length:

$$Relief\ ratio = \frac{Relief\,(km)}{Watershed\ Length\ (km)}$$

These two ratios combined with watershed length can be effective predictors of the dominant hydrogeomorphic processes within a watershed. Wilford et al. (2004) found the Melton ratio and watershed length correctly predicted debris flows in 90% of watersheds they studied. The two most effective combinations found by these authors and the classification boundaries are summarized in Table 1.

Variables	Process Class Boundaries		
	Flood	Debris Flood	Debris Flow
Melton ratio and watershed length	Melton <0.3	Melton 0.3-0.6 or Melton >0.6 and length >2.7	Melton >0.6 and length <2.7 km
Relief ratio and watershed length	Melton <0.3	Melton 0.3-0.77 or Melton >0.77 and relief ratio <0.42	Melton >0.77 and relief ratio >0.42

Table 1. Watershed morphometric classification models (Wilford et al., 2004)

The Melton ratio and watershed length were used as the primary predictors of the dominant hydrogeomorphic processes within a watershed for this study. The results for this combination were compared against the Wilford et al. (2004) process class boundaries to determine the dominant hydrogeomorphic event(s); the relief ratio and watershed length were also calculated for comparison.

Where the process class boundaries conflicted or were contrary to our field observations or desktop mapping analysis, the watershed was considered transitional. These conflicts generally arose where distinguishing between debris flow and debris flood as the process class. This is likely due to the presence of steep, gullied reaches in the lower parts of many watersheds, downslope from gently sloping upper plateaus. The gentle slopes may skew results away from the debris flow classification by increasing the watershed length but having a minimal impact on the relief.

3.2 Field Investigation

Field investigations were conducted between June 18 and 22, 2018. Weather was hot, sunny, and calm, and no snow was present on the ground. PECG staff Derek Cronmiller and Cassia Johnson were present for all days. Jeff Moore of CVRD was present on June 19 and 21. Doug Underhill and Geoff Annadale from TimberWest Forest Corp (TimberWest), and Jack Whittle, a consultant for TimberWest, were present on June 21 for the investigations of potential rock slides. Timothy Smith of Westrek was present on June 22 to visit key sites, including Youbou, Coonskin, and Swordfern Creeks.

The focus of this work was to:

- Confirm the results of the terrain mapping, landslide hazard mapping and watershed morphometrics,
- Characterize landslide hazards and fans, and
- Conduct a limited evaluation of debris passage capacity of the bridges and culverts that cross the gullied creeks and fans within the study area.

Additionally, a day was spent with TimberWest staff examining the large existing and potential rock slides and tension cracks(s) in the bedrock on the steep slopes above the north side of Cowichan Lake.

3.2.1 Terrain Mapping

Field traverses were completed though multiple mapped polygons, generally representative of the diversity of conditions within the study area. Soil pits were dug by hand to an average depth of 50 cm where there were no natural or road-cut slope exposures.

The traverses prioritized areas where the surficial materials were uncertain during the aerial photograph review, or where slope instability or potential slope instability was observed or expected. They were primarily focused on slopes above populated areas, infrastructure, or where landslide activity was identified in desktop mapping.

3.2.2 Landslide Characterization

Ground traverses were also completed to confirm the results of the landslide inventory and characterize associated landforms and processes on slopes and major fans. In addition, smaller landslides not visible in the aerial photography or orthophotography were identified and characterized.

Dendrochronology was used to aid in establishing the landslide frequency. Tree age estimates, based on the growth rings, were collected at select locations on major fans within the study area. This included (i) distinct cohorts of trees of a uniform age occupying the slopes along and within gullied channel reaches, or (ii) single trees growing on debris flow or debris flood depositional landforms, such as lobes or levees. Pioneer species like alder were selected for sampling, where possible, as they re-establish early after a slope has been disturbed, such as by a landslide; this can give a good estimate of the disturbance date.

This information was obtained from cores, collected using an increment borer (Figure 7), and was used to aid with establishing the landslide frequency.

3.2.3 Infrastructure

A limited inventory of the existing infrastructure that crosses gullied streams or fans within the study area was completed to assess the potential for debris flow or debris flood passage. This assessment was not exhaustive but is intended to give a brief account of the variety of creek crossing structures, drainage works, and other infrastructure located in or adjacent to the landslide-prone terrain, and the capacity to convey potential hazards. The locations of bridges, dams and water reservoirs are shown in Appendices B, C, and D.

Figure 7. Tree core sample collection in Coonskin Creek

4. Results

The primary outputs from this study are the terrain, hazard, and watershed classification data found in Appendices A to D. GIS files containing the detailed data used to produce these appendices have also been provided.

The following results summarize key data from the desktop and field studies.

4.1 Landslide Hazards

A total of 462 landslides was inventoried within the study area. Of these, 365 were classified as debris flows, 75 as debris slides, 16 as rock slides, and 6 as rock falls. The classification and initiation setting for each landslide type is shown in Table 2 and the complete inventory is in Appendix B.

Table 2. Number of landslides by type, in each initiation setting.

	Landslide Initiation Setting			
Landslide Classification	Natural	Modified	Road	Fluvial
Rock fall	6	-	-	-
Rock slide	15	-	1	-
Debris flow	217	69	77	2
Debris slide	10	28	25	12

Rock fall was generally under-represented within the inventory. Numerous small, recurrent rock falls were observed below the steepest slopes (e.g. bluffs) in the study area (Figure 8). The debris generally arrested at or within the treed buffer between the initiation zones and inhabited areas downslope. Because rock fall is small, it is generally not visible through the forest canopy on the aerial photographs, and therefore could not be reliably mapped.

Small debris slides and debris flows, less than 100 m^2, initiating within channelized (or gullied) terrain are also likely under-represented for the same reason as the rock fall. Many small landslides were observed in the field that were not identified on aerial photograph images due to the forest canopy.

Youbou Creek is incised up to 8 m near the apex of a paraglacial fan. No evidence of historic debris flows was found on the fan surface, although this may reflect recent site grading associated with the residential development in the area.

A dam has been constructed upstream of the fan apex to create a small water reservoir. Debris flow levees that pre-date construction of the dam were visible, and a small berm was built at the inlet of the reservoir to prevent debris from entering the reservoir.

Two distinct cohorts of trees exist within or next to the gullied channels on many of the fans throughout the study area. The ages of these trees are generally consistent, suggesting that two channel-modifying events have occurred across multiple watersheds.

Cores taken from these trees on debris flow deposits along Coonskin Creek, below the dam, yielded ages of about 32 to 37 years. This generally aligns with the cohort of trees around 40 years old within Youbou Creek and 77 Mile Creek.

A younger cohort of trees about 15 years old is present in Youbou Creek, Coonskin Creek, and 77-Mile Creek.

A large debris flow lobe, with an old-growth tree (at least 100 years old) growing on it, extended to within 15 m of the Coonskin Creek bridge.

Figure 8. A tree destroyed by recent rock fall from rock slide headscape above Cowichan Lake

Figure 9. Debris flow deposit exposed in eroded bank of Swordfern Creek

Figure 10. Debris flow lobe blocking abandoned channel through paraglacial fan on Swordfern Creek.

4.1.1 Large Rock Slides

During our desktop study, four large (>100,000 m^2) existing and potential rock slides were identified in the aerial photography; three appear to be slow-moving slumps in the bedrock, and one is a rock slide. Three of these features are located on the slopes above the north side of Cowichan Lake, east of Youbou; the bedrock on these slopes is part of the Sicker Group consisting of volcaniclastic rocks. The presence of these features was confirmed on the LiDAR-derived hillshade DEM provided by TimberWest (Figure 11).

Two of the three rockslides have experienced minor displacement, i.e., metres to tens of metres, and show no evidence of recent movement. It is likely that this movement was initially triggered during deglaciation and the landslides are currently dormant. A third rock slide failed catastrophically. Residual hazard exists at and below the over-steepened head scarp in the form of rock fall and further rock slides.

Another rock slide was identified after our fieldwork and should be ground truthed. It is located east of the community of Cowichan Lake, on the slopes north of the Cowichan Valley Highway (Hwy 18).

The approximate locations of these features have been provided to the CVRD so that follow up studies can be undertaken to determine the significance of the hazard and associated risk.

Figure 11. The location of three of the large rock slides/slope movements above the north side of Cowichan Lake (indicated by dashed white lines) overlain on a photocopy of LiDAR-derived hill shade DEM provided by TimberWest. The direction of the movement is indicated by the arrows. The lower left slide underwent rapid movement as a rock slide, as evidenced by the single, large debris cone under the well-defined headscarp. The approximate boundary of coverage provided by this LiDAR image is shown in Appendices A and B.

Figure 12. The stepped surface expression of the easternmost rock slide/slope movement above Cowichan Lake. Many back-tilted surfaces suggest a possible rotational component of movement is present.

4.2 Watershed Morphometric Analysis

The watershed morphometrics for the gullied streams within the study area are shown in Appendix D, and the numbered watersheds corresponding to named creeks are listed in Table 3.

The dominant hydrogeomorphic processes in each watershed, based on the Melton ratio and watershed length, is shown in Figure 13.

The Cottonwood Creek and Meade Creek fans are dominated by clearwater flood events. The Cottonwood Creek result was also confirmed in a previous hydrotechnical study by M. Miles and Associates Ltd. (2007), where no evidence of debris flows was found on the fan between 1938 and 2007.

Considerable large woody debris (LWD) was found on the Meade Creek fan. Much of this consisted of logging debris, suggesting post-logging landslides entered the creek and were transported downstream by flood events, reaching the fan. LWD jams can lead to changes in channel morphology, including avulsions and significant erosion.

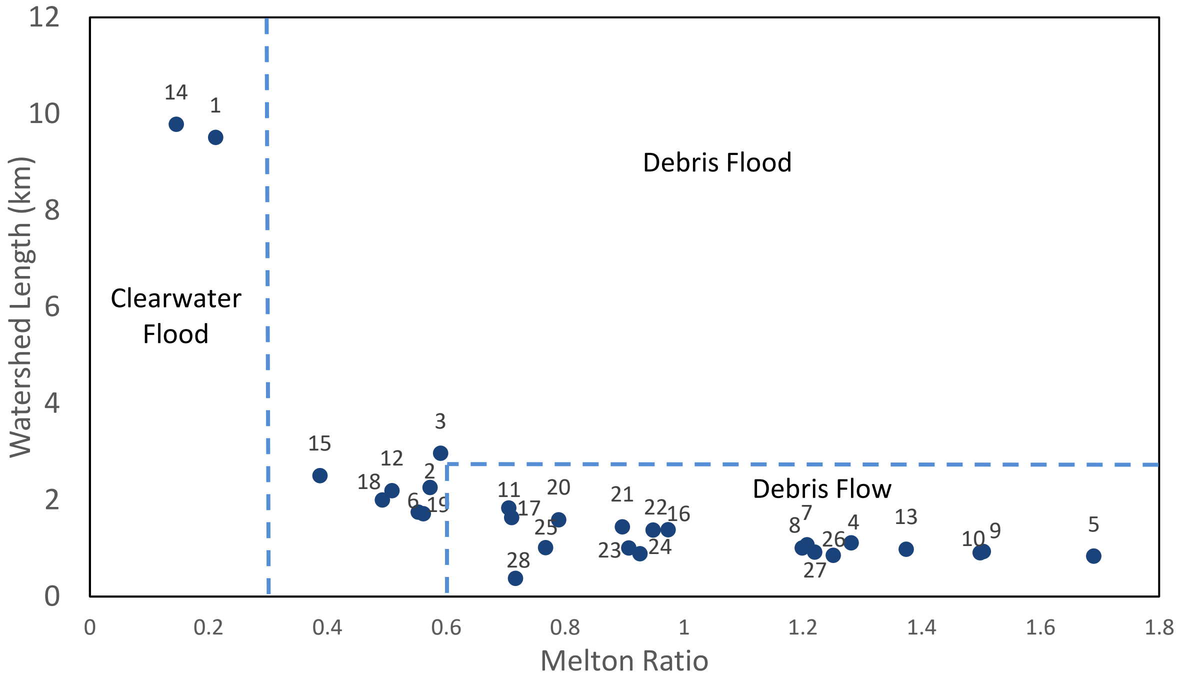

Figure 13. Classification of dominant hydrogeomorphic processes for the watersheds in the study area based on the watershed length and Melton ratio. Watershed locations are shown in Appendix D.

Watershed Number	Creek Name
1	Cottonwood Creek
2	Youbou Creek
3	Coonskin Creek
4	Utility Creek
6	Swordfern Creek
12	77-Mile Creek
14	Meade Creek
15	Stanley Creek
20	Goulding Brook

Table 3. Corresponding watershed names and numbers for named creeks.

Figure 14. Large woody debris within Meade Creek contains considerable logging debris, suggesting landslides in the upper reaches of Meade Creek may impact the Meade Creek fan.

4.3 Infrastructure

4.3.1 Creek Crossings

Highway 18 within the study area is located at the base of the steep slopes, on the north side of Cowichan Lake. Most of the creeks cross the highway in corrugated steel pipes or concrete box culverts, with diameters less than 1.5 m (Figure 15).

None of the reviewed culverts appear to have been designed for debris passage, based on their size and characteristics. They will likely be blocked and overwhelmed by future debris flows/debris floods. This could result in:

- Diversion of the stream flow onto the surrounding slopes, potentially causing road washouts and damage to private property.
- Destruction or partial destruction of the crossing structure.

Coonskin and Meade Creeks are crossed by reinforced concrete bridges and Cottonwood Creek is crossed by a single span steel girder bridge; these structures maybe capable of limited debris passage up to 2 m and 7 m height, respectively. (Figure 16).

Youbou Creek crosses Hwy 18 using a composite bridge/culvert structure, composed of three 1.1 m ovoid corrugated steel pipes encased in concrete (Figure 17). This structure is unlikely to be able to convey debris.

Figure 15. The 1.2 m high x 2 m wide, concrete box culvert on the Swordfern Creek crossing. This structure is unlikely to pass debris from debris flows or debris floods.

Figure 16. The Highway 18 bridge crossing over Coonskin Creek. It may be capable of passing small debris flows and debris foods. Exposed utilities on the upstream side of the bridge are vulnerable to impact from transported debris.

Figure 17. Culvert outlets at Youbou Creek crossing of Highway 18.

4.3.2 Dams and water reservoir

Two dams are present at the apex of the Youbou and Coonskin Creek fans.

We understand that the dam on Youbou Creek is used for drinking water (Figure 18), and it is unknown whether this dam was designed to withstand debris impacts.

The dam on Coonskin Creek is in disrepair, infilled with debris (Figure 19) and may fail. It is also unknown if this dam was designed to withstand debris impacts.

A large water reservoir is located near the Youbou Creek fan apex, at the toe of a steep slope that has been logged (Figure 20). This structure may also not be designed to withstand impacts from either a debris flow or debris slide.

Figure 18. The dam and reservoir on Youbou Creek.

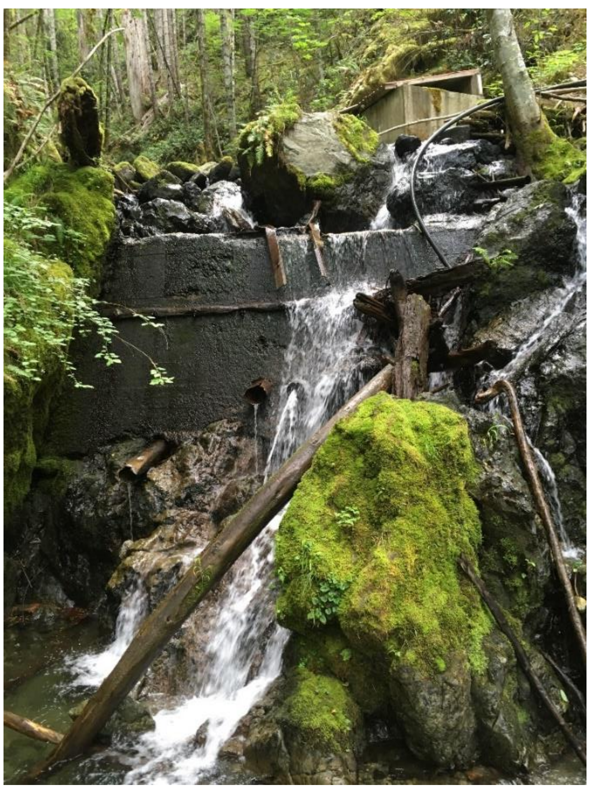

Figure 19. The dam on Coonskin Creek infilled with debris.

Figure 20. The water reservoir at the base of a steep, logged slope.

5. Discussion

5.1 Landslide Hazards

Our landslide hazard model provides an estimate on the probability of any given area in a terrain polygon being affected by a landslide. The model does not differentiate between landslide types. The annual encounter probabilities within the study area range from 0.00% to a maximum of 0.71%.

All efforts have been made to provide the maximum level of resolution in the hazard model, but spatial variability in hazard probability still exists within polygons. For example, the probability of a landslide affecting the main channel in a gullied polygon is higher than the probability of a landslide on the gully walls. Similarly, the middle portions of a fan may have a higher encounter probability than the distal portions of a fan, because a lower frequency, higher magnitude event is required to reach the distal margins.

To achieve higher resolution of hazard distribution, further work would be needed, such as landslide runout modelling, more extensive field investigations, and/or LiDAR analysis.

To identify the dominant process in channels and on fans in the study area, the hydrogeomorphic process in the most geomorphically active watersheds have been identified (Appendix D). All process types respond strongly to road building associated with logging, hydrologic disturbance to forest cover, and wildfires.

5.2 Landscape modification due to Logging

The link between logging and increased landslide frequency is well documented by Guthrie (2002, 2005); this research found that the landslide frequency related to logging and road building can increase by up to 10 times when compared to undisturbed land.

Road building associated with logging has the greatest impact on landslide frequency (Guthrie, 2005) due to the enhanced concentration of surface water, and the over-steepening of cut and fill slopes.

The removal of the tree canopy by logging causes increased infiltration into soils and surface water runoff, as interception provided by the canopy is greatly reduced. To a lesser extent, logging can also destabilize slopes as the root systems on the stumps decay.

The forested slopes above the north side of Cowichan Lake also provide a buffer inhibiting debris slide occurrence and rock fall from reaching the developed areas below. These forested slopes are owned by TimberWest and Hancock Forest Management and could be logged.

5.3 Climate change

Climate change can affect landslide activity in several ways. Increased amounts or intensities of precipitation, stronger seasonality of precipitation, changes in snowpack, and increased frequency and severity of lightning strikes and wildfire can influence landslide frequency, magnitude and distribution.

Warmer year-round temperatures can also affect landslide activity through changes to the hydrogeomorphic balance of a region.

The Cowichan Valley is predicted to receive a 5% increase in annual precipitation by 2050 (CVRD, 2017). Much of this increase is predicted to come in the form of extreme precipitation events. The intensity of extreme events is predicted to increase dramatically, with a 30% increase in rainfall on 95^{th}-percentile wet days.

High intensity rainfall events and prolonged periods of high precipitation both result in a higher frequency of landslides (Jakob and Lambert, 2009). These authors found that climate change could result in a 28% increase in debris flow frequency in Howe Sound by 2100. It is reasonable to expect a similar increase in the Cowichan Valley based on topographic and climatological similarities. The watersheds in the Lake Cowichan/Youbou study area appear to be weathering-limited, meaning that the relatively thin surficial materials and generally competent underlying bedrock do not provide an unlimited source of material for landsliding (Bovis and Jakob, 1999). Debris flow frequency can be difficult to predict in weathering-limited watersheds as extreme hydrological events will only produce debris flows if material is available for transport. The magnitude of debris flows in weathering-limited watersheds may not increase with increasingly severe hydrologic events routinely “flushing” sediment out of the watersheds. Like the watersheds in Cowichan Valley study area, Jakob and Lambert’s (2009) study areas were predominantly weathering-limited. This means an increased frequency of landslides may result in decreased volume of each event if weathering does not also increase at the same rate. The Lake Cowichan/Youbou study area may see an increase in debris flow frequency, but a decrease in debris flow magnitude.

The effect of climate change on rock fall and rock slide frequencies and magnitudes is unknown.

In addition to an increase in annual precipitation and intensity of extreme rainfall events, the CVRD is predicted to see an increase in mean annual temperature and longer summer month dry spells (CVRD, 2017). Regional average daytime highs are expected to increase by 2.7°C by the 2050s. This could increase the frequency and severity of wildfires, leading to a greater occurrence of landslides due to:

- The removal of vegetative cover on the ground and the forest canopy, which intercepts rainfall and stabilizes soils.
- The presence of hydrophobic soils on slopes burned to a moderate to high severity. This can increase surface runoff causing significant erosion, increasing the likelihood of debris flows or debris floods.

These points are supported by Hope et al. (2015), who noted that the frequency of landslides in a given area is likely to increase following wildfire, though they will primarily occur in the same terrain units as in pre-wildfire conditions.

6. Conclusions and Recommendations

6.1 Conclusions

A predictive, quantitative slope hazard model was produced for the study area based on detailed terrain mapping and a landslide inventory covering a 70-year timespan. The model helps to identify the landslide likelihood for slopes within study area using terrain attributes. Watershed morphometrics and field observations helped to classify the dominant hydrogeomorphic processes within the major gullied watersheds. The landslide hazard model and watershed classification will be used by Ebbwater to guide its risk assessment.

Our key findings are as follows:

- The study area is located in a glacially modified landscape containing steep slopes with active gullying affected by debris flows and other hydrogeomorphic events. Many of the large fans in the region are paraglacial and their surfaces appear to be largely isolated from recent geomorphic processes.

- The landslide inventory, representing a 70-year interval, identified 462 landslides, including 217 debris flows, 15 debris slides, 6 rock falls, and 15 rockslides.

- The landslides initiated primarily on steep, gullied terrain on the mid to upper valley walls. The majority become channelized and terminated in channels that were incised into paraglacial fans at or downstream from the fan apex.

- Predictive hazard modelling produced annual encounter probabilities for the study area based on terrain attributes and the landslide inventory. Annual encounter probabilities range from 0.00% to a maximum of 0.71%.

- Twenty-eight watersheds were classified based on their dominant hydrogeomorphic process; two were affected by floods, one by debris floods, fifteen by debris flows, and nine were transitional between debris flow and debris flood.

- Four existing or potential large rock slides/slope movements were identified in the study area. One failed catastrophically, likely during deglaciation about 10,000 to 14,000 years ago. The remaining three are potential rock slides and have only experienced minor displacement and could be inactive; one was not field checked. Due to the potential magnitude (>100,000 m^3) of these events and the significant risk to human life should they fail, additional investigation is warranted.

- The study area may see an increase in debris flow frequency but a decrease in debris flow magnitude in response to projected climate change.

- Seismicity is not likely to have a strong influence on landslide frequency and magnitude in the study area; however, proximal high magnitude earthquakes may trigger landslides.

6.2 Recommendations for further work

The current study is an important first step in understanding landslide hazards within the study area. As a result of the current work, several important issues that relate to the landslide risk were identified, which require further work to properly address. These include:

- Undertake runout modelling for the landslide types identified within this study.
- Conduct a detailed investigation of the large, inactive or slow-moving rockslides on the steep to very steep slopes on the north side of Cowichan Lake. This could also include an investigation of the slopes above developed regions in the Cowichan Valley that are underlain by Sicker Group rocks.
- Complete a Dam Safety Review on the dams on Youbou and Coonskin Creeks.
- Assess the landslide risk to bridges and other infrastructure (utilities, culverts) in the study area to determine if mitigation measures are required.
- Assess the landslide risk to the water reservoir near the Youbou Creek fan apex to determine if mitigation measures are required.
- Require that all Development and Building Permit applications within the study area be supported by a geohazard study done in accordance with EGBC's Guidelines for Legislated Landslide Assessments for Proposed Residential developments in BC (2010)[2]
- Develop and/or adopt a level of acceptable landslide hazard or risk to be applied to Development and Building Permit applications within the CVRD.
- Recommend that TimberWest, Hancock and other licensees conduct terrain stability assessments prior to any logging or modification of the slopes above the study area. These assessments should address the downslope risk to human life, private property, fish habitat, drinking water quality and infrastructure.

PECG can provide assistance in implementing these recommendations, where required.

[2] https://www.egbc.ca/getmedia/5d8f3362-7ba7-4cf4-a5b6-e8252b2ed76c/APEGBC-Guidelines-for-Legislated-Landslide-Assessments.pdf.aspx

7. Statement of Limitations

This report has been prepared by Palmer Environmental Consulting Group Inc. (PECG) on behalf of Ebbwater for the Cowichan Valley Regional District in accordance with the agreement between Consultant and Client, including the scope of work detailed therein (the “Agreement”). The report and the information it contains may be used and relied upon only by Client, except (1) as agreed to in writing by Consultant and Client, (2) as required by-law.

The extent of this study was limited to the specific scope of work for which we were retained and is described in this report. PECG has assumed that the information and data provided by the client or any secondary sources of information are factual and accurate. PECG accepts no responsibility for any deficiency, misstatement or inaccuracy contained in this report as a result of omissions, misinterpretations or negligent acts from relied-upon data. Judgment has been used by PECG in interpreting mass movement hazards based on desktop analyses and limited field reconnaissance investigations (at many but not all sites).

PECG is not a guarantor of site conditions or projected characteristics of mass movements but warrants only that our work was undertaken and our report prepared in a manner consistent with the level of skill and diligence normally exercised by competent geoscience professionals practicing in British Columbia. Our findings, conclusions and recommendations should be evaluated in light of the limited scope of our work.

8. Certification

This report was prepared and reviewed by the undersigned:

Prepared By:

Derek Cronmiller, P.Geo
Geoscientist

Reviewed By:

Robin McKillop, M.Sc., P.Geo.
Principal, Geomorphologist

9. References

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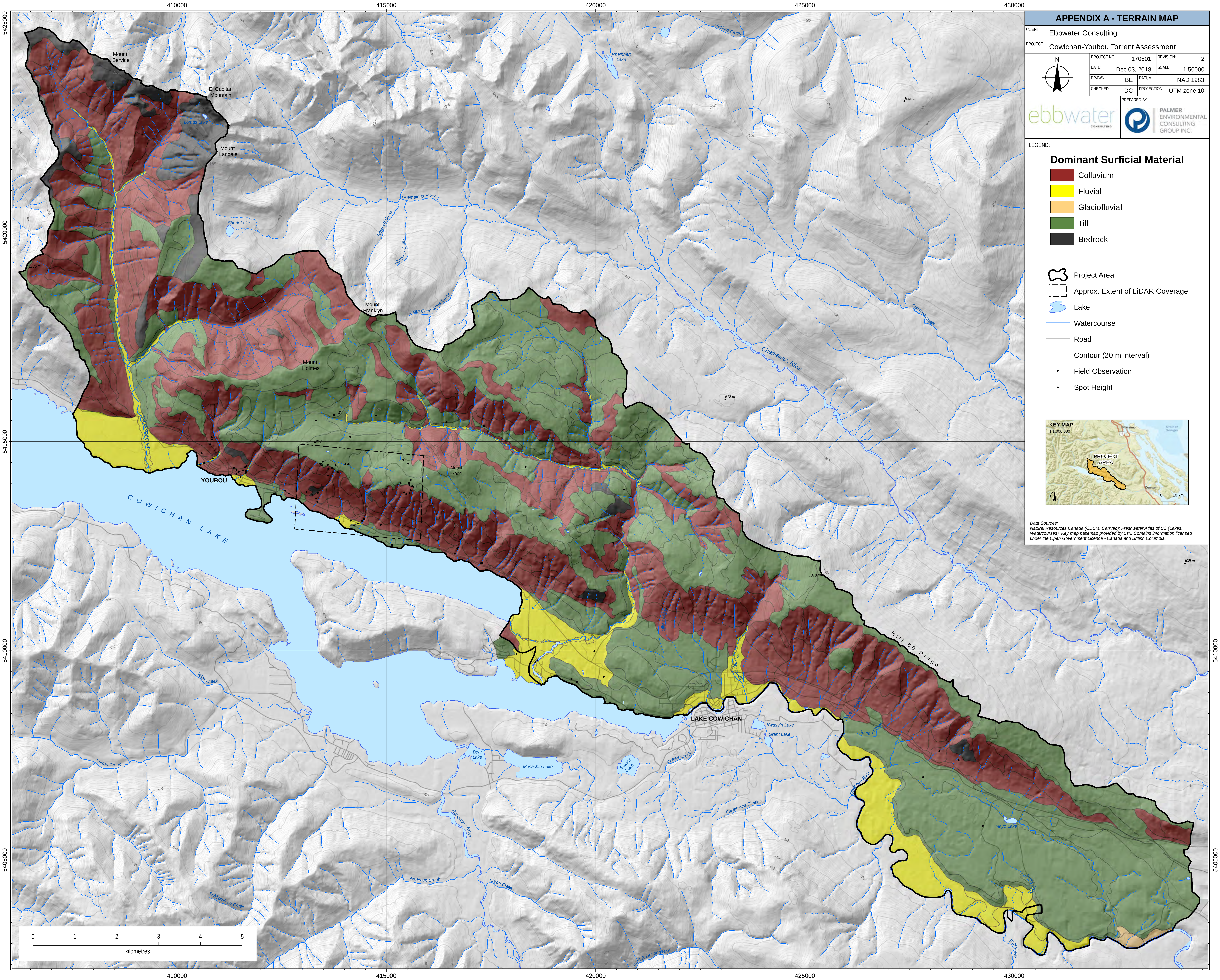
APPENDIX A - TERRAIN MAP
CLIENT: Ebbwater Consulting
PROJECT: Cowichan-Youbou Torrent Assessment
PROJECT NO. 170501
REVISION: 2
DATE: Dec 03, 2018
SCALE: 1:50000
DRAWN: BE
DATUM: NAD 1983
CHECKED: DC
PROJECTION: UTM zone 10
N
ebbwater CONSULTING
PREPARED BY:
PALMER ENVIRONMENTAL CONSULTING GROUP INC.
LEGEND:
Dominant Surficial Material
Colluvium
Fluvial
Glaciofluvial
Till
Bedrock
Project Area
Approx. Extent of LiDAR Coverage
Lake
Watercourse
Road
Contour (20 m interval)
Field Observation
Spot Height
KEY MAP
1:1,000,000
PROJECT AREA
Data Sources: Natural Resources Canada (CDEM, CanVec); Freshwater Atlas of BC (Lakes, Watercourses). Key map basemap provided by Esri. Contains information licensed under the Open Government Licence - Canada and British Columbia.
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Mount Service
El Capitan Mountain
Mount Landale
Mount Franklyn
Mount Holmes
Mount Good
YOUBOU
COWICHAN LAKE
LAKE COWICHAN
Chemainus River
Hill 60 Ridge
Sherk Lake
Mayo Lake
Mesachie Lake
Bear Lake
Beaver Lake
Kwassin Lake
Grant Lake
Miller Creek
Sutton Creek
Robertson River
Fairservice Creek
Nineteen Creek
March Creek
Ashburnham Creek
Beaver Creek
South Chemainus Creek
Rheinhart Lake
Rheinhart Creek
0
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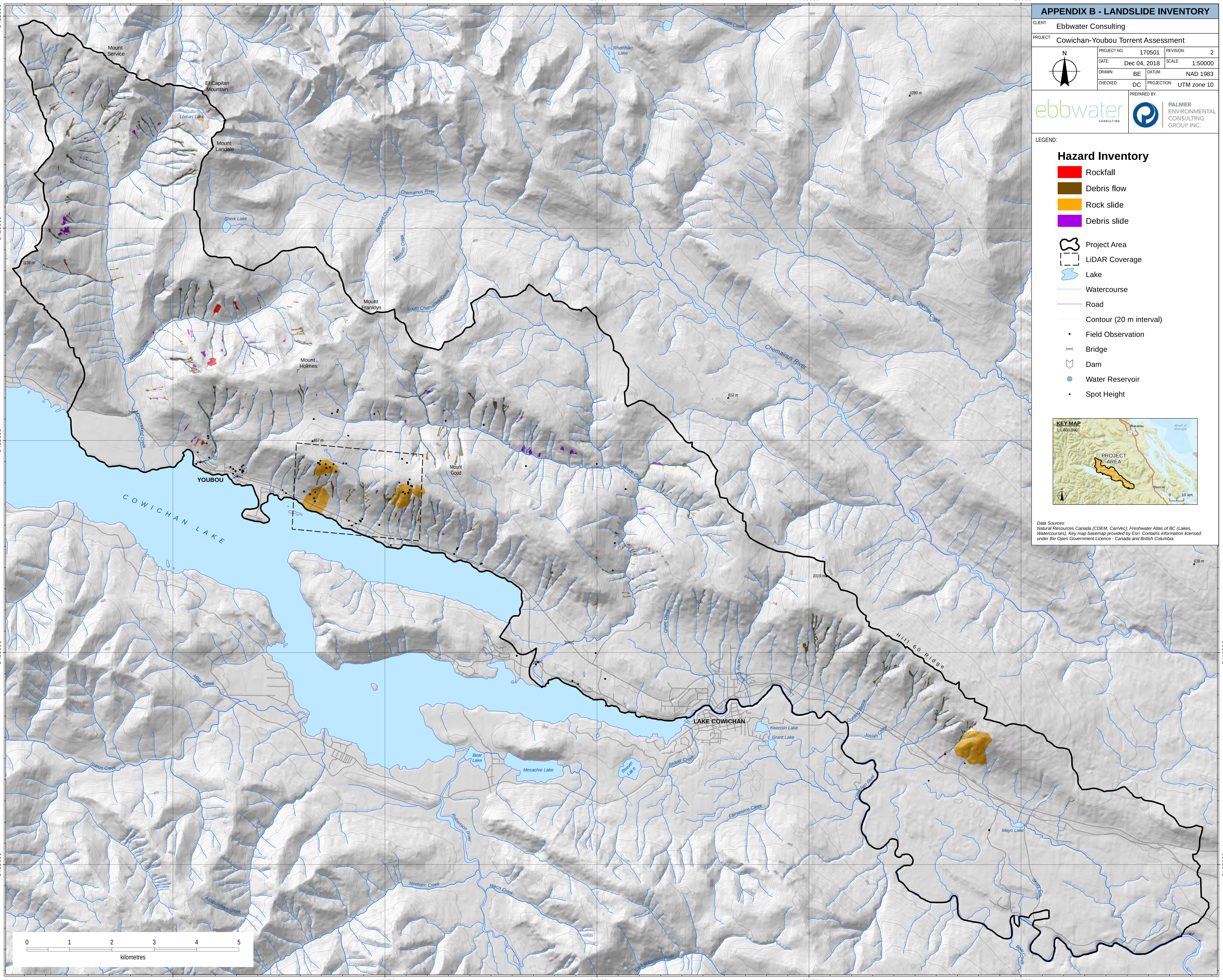
kilometres


APPENDIX B - LANDSLIDE INVENTORY
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PROJECT NO. 170501
REVISION: 2
DATE: Dec 04, 2018
SCALE: 1:50000
DRAWN: BE
DATUM: NAD 1983
CHECKED: DC
PROJECTION: UTM zone 10
PREPARED BY:
ebbwater consulting
PALMER ENVIRONMENTAL CONSULTING GROUP INC.
LEGEND:
Hazard Inventory
Rockfall
Debris flow
Rock slide
Debris slide
Project Area
LiDAR Coverage
Lake
Watercourse
Road
Contour (20 m interval)
Field Observation
Bridge
Dam
Water Reservoir
Spot Height
KEY MAP
1:1,000,000
PROJECT AREA
Duncan
0 10 km
Data Sources:
Natural Resources Canada (CDEM, CanVec); Freshwater Atlas of BC (Lakes, Watercourses). Key map basemap provided by Esri. Contains information licensed under the Open Government Licence - Canada and British Columbia.
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Mount Holmes
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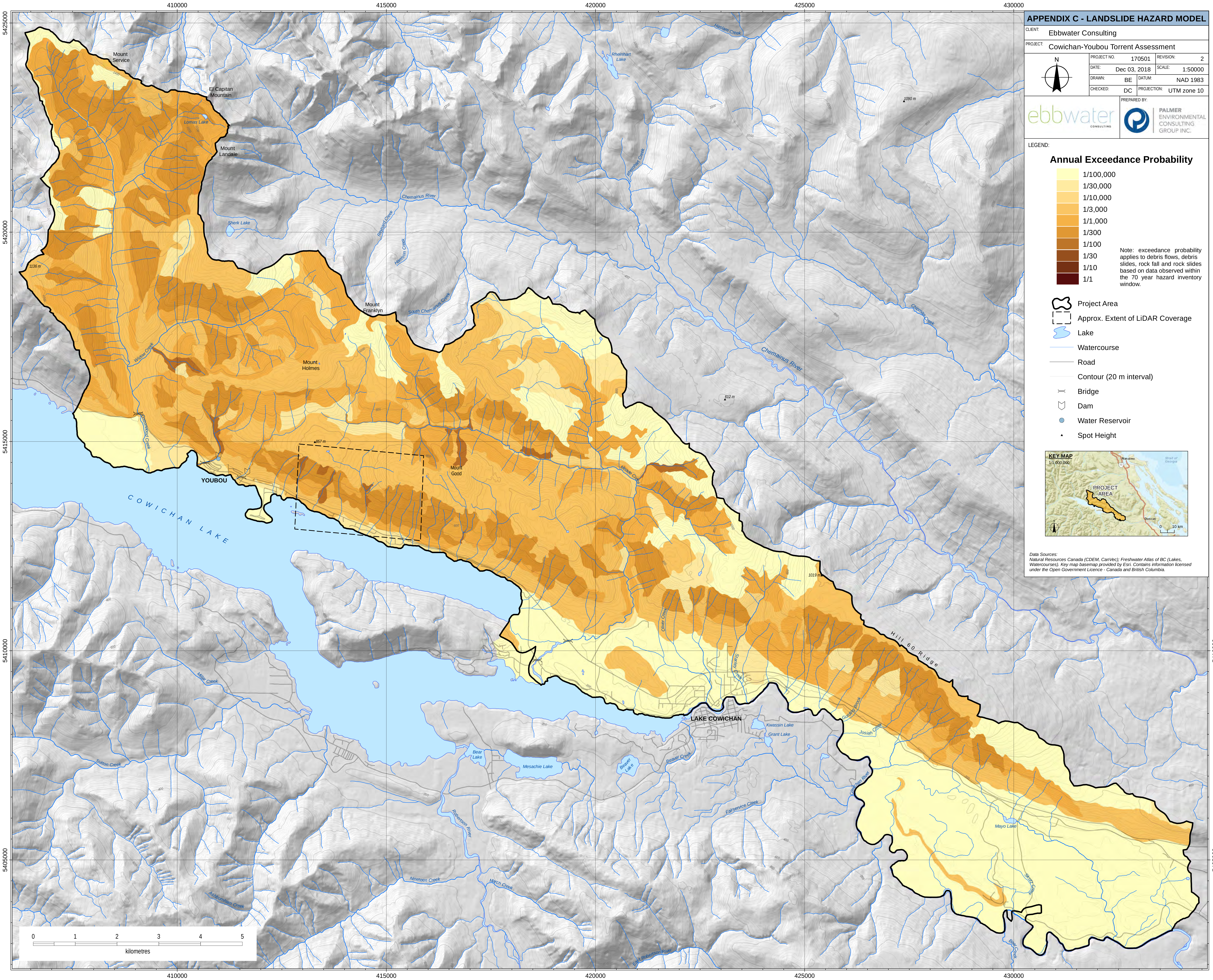
Chemainus River
South Chemainus Creek
YOUBOU
COWICHAN LAKE
LAKE COWICHAN
Hill 60 Ridge
Kwassin Lake
Grant Lake
Bear Lake
Mesachie Lake
Beaver Lake
Mayo Lake
Robertson River
Meade Creek
Oliver Creek
Stanley Creek
Josiah Creek
Beaver Creek
Fairservice Creek
Miller Creek
Sutton Creek
Nineteen Creek
Ashburnham Creek
Rheinhart Lake
1136 m
857 m
912 m
1090 m
1019 m
639 m
0 1 2 3 4 5
kilometres


APPENDIX C - LANDSLIDE HAZARD MODEL
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PROJECT: Cowichan-Youbou Torrent Assessment
PROJECT NO. 170501
REVISION: 2
DATE: Dec 03, 2018
SCALE: 1:50000
DRAWN: BE
DATUM: NAD 1983
CHECKED: DC
PROJECTION: UTM zone 10
N
ebbwater CONSULTING
PREPARED BY:
PALMER ENVIRONMENTAL CONSULTING GROUP INC.
LEGEND:
Annual Exceedance Probability
1/100,000
1/30,000
1/10,000
1/3,000
1/1,000
1/300
1/100
1/30
1/10
1/1
Note: exceedance probability applies to debris flows, debris slides, rock fall and rock slides based on data observed within the 70 year hazard inventory window.
Project Area
Approx. Extent of LiDAR Coverage
Lake
Watercourse
Road
Contour (20 m interval)
Bridge
Dam
Water Reservoir
Spot Height
KEY MAP
1:1,000,000
PROJECT AREA
0
10 km
Data Sources:
Natural Resources Canada (CDEM, CanVec); Freshwater Atlas of BC (Lakes, Watercourses). Key map basemap provided by Esri. Contains information licensed under the Open Government Licence - Canada and British Columbia.
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Mount Franklyn
Mount Holmes
Mount Good
YOUBOU
COWICHAN LAKE
LAKE COWICHAN
Chemainus River
Hill 60 Ridge
Widow Creek
Rheinhart Lake
Sherk Lake
Mesachie Lake
Bear Lake
Beaver Lake
Kwassin Lake
Grant Lake
Mayo Lake
Robertson River
Miller Creek
Sutton Creek
Nineteen Creek
Marsh Creek
Ashburnham Creek
Fairservice Creek
Beaver Creek
Stanley Creek
Oliver Creek
Josiah Creek
Cowichan River
South Chemainus Creek
Rheinhart Creek
1136 m
1090 m
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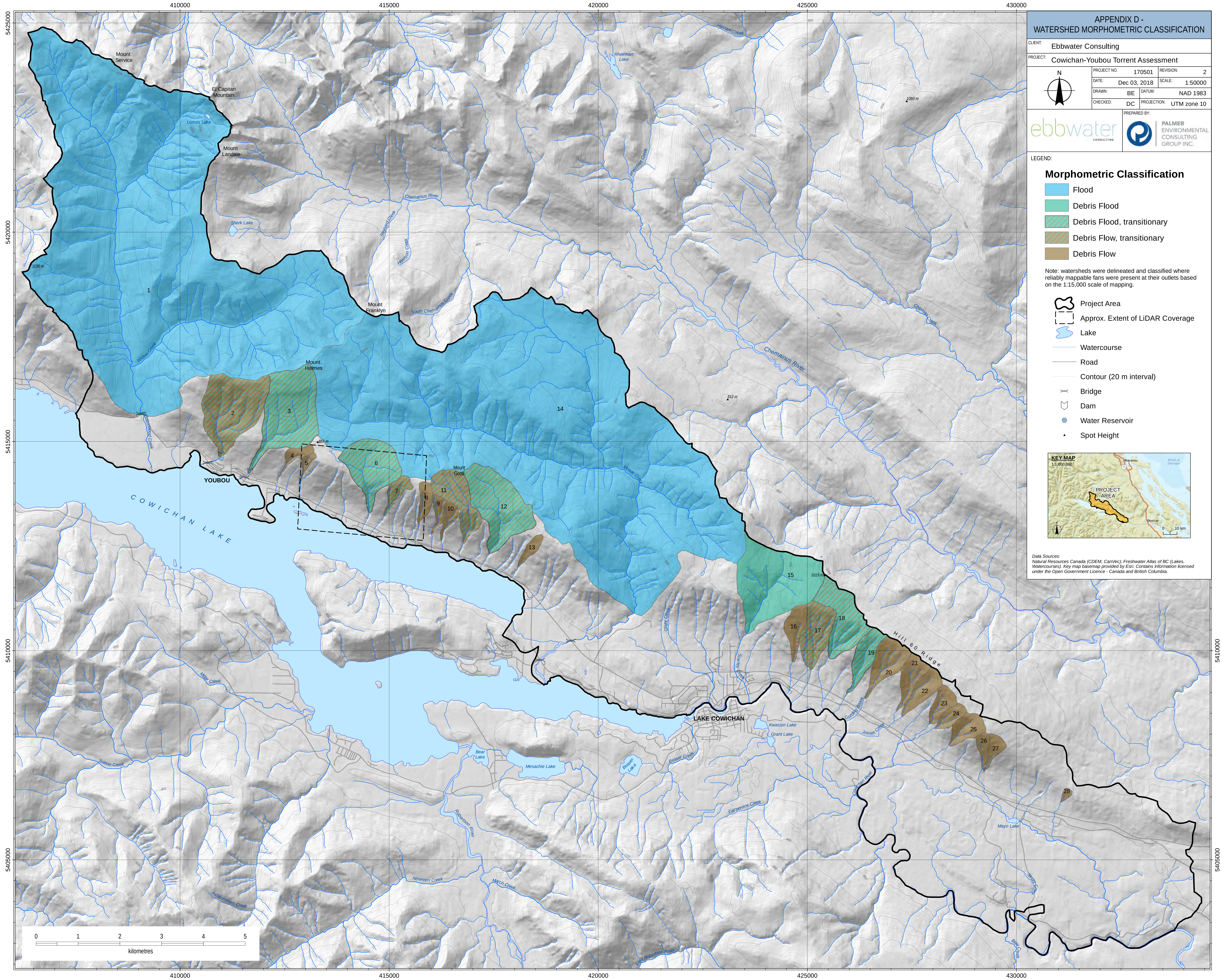

APPENDIX D -
WATERSHED MORPHOMETRIC CLASSIFICATION
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PROJECT: Cowichan-Youbou Torrent Assessment
PROJECT NO. 170501
REVISION: 2
DATE: Dec 03, 2018
SCALE: 1:50000
DRAWN: BE
DATUM: NAD 1983
CHECKED: DC
PROJECTION: UTM zone 10
N
PREPARED BY:
ebbwater CONSULTING
PALMER ENVIRONMENTAL CONSULTING GROUP INC.
LEGEND:
Morphometric Classification
Flood
Debris Flood
Debris Flood, transitionary
Debris Flow, transitionary
Debris Flow
Note: watersheds were delineated and classified where reliably mappable fans were present at their outlets based on the 1:15,000 scale of mapping.
Project Area
Approx. Extent of LiDAR Coverage
Lake
Watercourse
Road
Contour (20 m interval)
Bridge
Dam
Water Reservoir
Spot Height
KEY MAP
1:1,000,000
PROJECT AREA
0 10 km
Data Sources:
Natural Resources Canada (CDEM, CanVec); Freshwater Atlas of BC (Lakes, Watercourses). Key map basemap provided by Esri. Contains information licensed under the Open Government Licence - Canada and British Columbia.
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5410000
5405000
Mount Service
El Capitan Mountain
Lomas Lake
Mount Landale
Sherk Lake
Mount Franklyn
Mount Holmes
Mount Good
Rheinhart Lake
Chemainus River
South Chemainus Creek
YOUBOU
COWICHAN LAKE
LAKE COWICHAN
Hill 60 Ridge
Kwassin Lake
Grant Lake
Mesachie Lake
Bear Lake
Beaver Lake
Beaver Creek
Mayo Lake
Robertson River
Sutton Creek
Miller Creek
Nineteen Creek
Ashburnham Creek
Cowichan River
Josiah Creek
Fairservice Creek
1136 m
1090 m
1019 m
812 m
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2
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5
kilometres

Appendix E Mitigation Measures Report

To: Jeff Moore	From: Tamsin Lyle and Heather Murdock Ebbwater Consulting Inc.
Date: November 24, 2018	File Number: P099 CVRD Geohazard Risk Assessment
Subject: Options for Structural and Non-structural Geohazard Mitigation	

1. INTRODUCTION

Geohazards are a significant concern in British Columbia; the communities of Youbou and Lake Cowichan on Vancouver Island are no exception. The Cowichan Valley Regional District (CVRD) is aware of the potential impacts of these hazards and have engaged a consulting team to complete a natural hazard risk assessment for the area. This team is lead by Ebbwater Consulting Inc. with support from Palmer Environmental Consulting Group Inc. This work is ongoing, and has included preliminary hazard assessments (primarily desktop, with some field-checking), and exposure and vulnerability mapping. Preliminary risk assessments have been completed and are in the process of being mapped, reported, and reviewed. In the meantime, the CVRD wishes to understand potential mitigative actions to manage the natural hazard risk. This will inform discussions within the CVRD and will form a part of the final reporting for the geohazard risk project.

This memo provides a long-list of potential geohazard mitigation measures for the CVRD to explore for the north slope of Cowichan Lake. These options are primarily focused on debris flows but could be applicable to other hazard types in some cases.

This memo contains a section describing the methods used to prepare the list of mitigation options (Section 2), a long-list of options in table format (Section 3), a short discussion (Section 4), and finally conclusions and next steps (Section 5).

2. METHODS

Risk is composed of the combination of hazard, exposure, and vulnerability. In Figure 1, risk is represented by the area of the triangle, and so reducing any of the three components reduces the total risk. In general, structural mitigation measures reduce risk by reducing the hazard. This means physically detaining material (such as debris traps) or preventing it from encountering vulnerable areas (such as deflection berms). Non-structural measures reduce risk by reducing exposure and vulnerability.

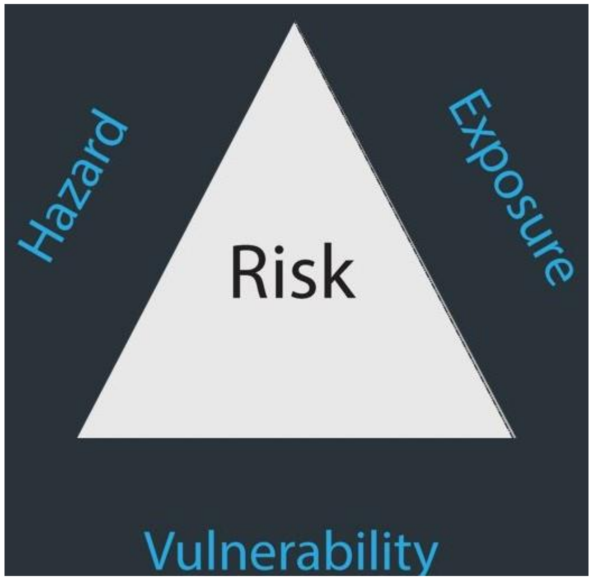

Figure 1: Components of risk.

The non-structural measures developed for this report were defined according to available literature and based on Ebbwater's experience with natural hazard management in British Columbia. The structural mitigation measures were developed primarily using input from scientific literature on geohazard risk mitigation, including Canadian and international literature. The relevant provincial guidance on hazard was consulted, including "Guidelines for Legislated Landslide Assessments for Proposed Residential Development in British Columbia." The provincial guidance, however, only provides direction on risk assessment and notes on factor of safety specifications, but does not specify mitigation options. Finally, the Norwegian Geotechnical Institute recently published a draft of the Landslide Risk Mitigation Toolbox (LaRiMit), which was also consulted. The LaRiMit database of structure mitigation measures includes descriptions of the measures, notes on design methods, functional suitability criteria, and literature references with more information on these measures[2]. Further to the literature reviews, Palmer—geohazard practitioners—provided comment on the options with regards to the applicability to the project area.

The table of measures in the section below provides a long-list of potential options but should not be considered a list of recommended measures. The intention is instead to provide examples of methods applied in other cases and/or referenced in the literature. This is a first step towards consideration of mitigation measures for the CVRD, and the intention is that it will be further refined with review and input from the CVRD.

3. LIST OF OPTIONS

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

- Protect (i.e., reducing the hazard)
- Adapt (i.e., reducing the vulnerability)
- Retreat (i.e., reducing the exposure)

The measures described in this section address all three categories of options. 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, as well as 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 2. 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 in Figure 2 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.

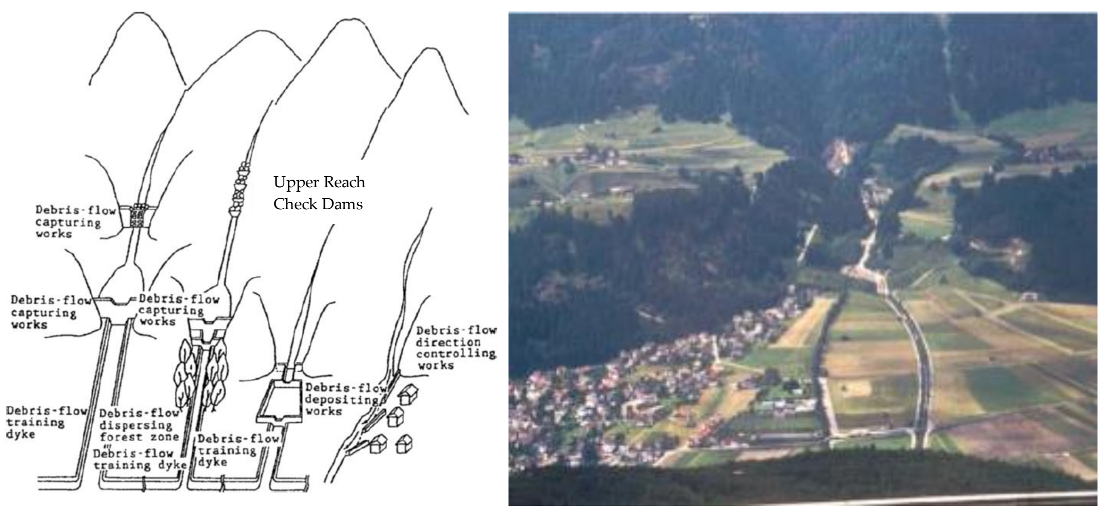

Figure 2: Examples of structural mitigation (left)[1] **to reduce debris flow hazard and an example of non-structural mitigation in an area near Innsbruck, Austria, with spatial planning on an alluvial fan.**

For the purposes of this report, and to provide some means of organizing the measures. The following categories of measures are included:

- 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 Error! Reference source not found.**)**

- 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 missing people, affected people, disruption, economic, environment, and/or cultural impacts) are noted.

Table 1: Non-Structural landslide mitigation measures.

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Categories
Non-Structural Mitigation – Category 1: Exposure reduction - spatial					
Update OCP/designate DPAs	• Planning documents could identify hazard zones spatially and implement a Designated Permit Area (DPA) for these zones (Porter and Dercole, 2011).	• Exposure and vulnerability reduced over time as new construction or renovations comply with the DPA.	• The OCP is produced by the CVRD for each electoral area. • 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	• 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. • 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).	• Affected People • Mortality and/or Missing • Disruption • Economic • Environment • Culture

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Categories
Acquire exposed or repetitive loss properties	• Repetitive loss properties (if applicable) or properties in high hazard zones could be acquired (Porter *et al.*, 2007). • Reducing exposure by removing assets from harm's way is the surest means of reducing risk.	• Exposure reduction by removing people, structures, and assets of value from hazard areas.	• This has been done in other jurisdictions in BC. EMBC has recently expressed willingness to consider property acquisition for funding.	• Depending on property values, there can be significant financial obstacles. • Public support for this approach can also be a challenge.	• Affected People • Mortality and/or Missing

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Categories
Non-Structural Mitigation – Category 2: Exposure reduction – temporal					

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Categories
Monitoring system	• Inspections of gullies and sidewalls can help to detect any signs of instability. • 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. • Regular slope inspections as part of monitoring system to evaluate the ongoing need for slide likelihood reduction measures (Porter and Dercole, 2011), (Porter *et al.*, 2017).	• A monitoring system provides timely slope condition information to support decision-making. • This can help with emergency management preparations and provide input to a warning system.	• This would be a new system/program for the CVRD. • On Private Managed Forest Lands, slope inspections and monitoring may be the responsibility of the landowner.	• Gully inspections would not require much in the way of equipment, etc. • Some level of monitoring and tracking could be a cost-effective option and significantly decrease risk to life. • It would likely be cost prohibitive to instrument all possible source slopes.	• Affected People • Mortality and/or Missing

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

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What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Categories
	• This could apply to private residences, but also public infrastructure (Porter *et al.*, 2007).				
Bedroom relocation	• Vulnerability reduction measure for homes. • 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 *et al.*, 2007).	• This reduces risk as it reduces the exposure of people during the night. • This is effective if only a portion of the house is affected by a landslide event. • Limited effectiveness for higher hazard levels.	• This is something that has been considered by the DNV. • This could be integrated into planning documents.	• This would be a new approach and would require public support. • It would be applied over time.	• Mortality and/or Missing
Non-Structural Mitigation – Category 4: Improved response and/or recovery					
Emergency management planning	• Emergency management planning should be based on the best available information of hazards and likely consequences.	• Reducing vulnerability over time with better response planning. • Improve life safety with effective evacuations.	• Integrated with current Emergency Management Plans and relevant supporting authorities.	• Some capacity-building effort will be needed to integrate new information from risk assessment. • Likely a low-regrets option.	• Affected People • Mortality and/or Missing

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Categories
	• New information from risk assessment should be integrated into emergency management plans (Porter and Dercole, 2011).			• Would perform better with a warning system in place.	

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Categories
Establish risk tolerances (to support public education and implementation of other measures)	• Engage stakeholders and possibly members of the public to establish risk tolerances. • This can be applied to asset management, land development divisions, and life safety measures. • 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 *et al.*, 2007).	• Establishing risk tolerances will help to set a threshold for "acceptable risk". • With this determined, areas of "unacceptable risk" can be identified.	• CVRD has expressed interest in establishing risk tolerances across the region. • This will help to support risk mitigation and strategic planning around hazards.	• The process of eliciting risk tolerances is challenging, requiring sufficient background information and consideration for process. • This can help to address other hazards.	• Affected People • Mortality and/or Missing • Disruption • Economic • Environment • Cultural

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Categories
Risk communication strategy	• Communication with stakeholders and public as appropriate related to understanding geohazard risk (Porter and Dercole, 2011).	• Helps to improve public understanding of problem. • Can build local capacity and resilience.	• CVRD has already developed excellent communication plans on climate and risk. This could build on previous work.	• This can be integrated into the ongoing climate communications work by the CVRD.	• Mortality and/or Missing

Table 2: Structural landslide mitigation measures.

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Category
Structural Mitigation – Category 1: Surface protection – erosion control					
Restoration of Vegetation or Geosynthetics	• Restoration of vegetation to promote interception of precipitation, attenuate runoff, and promote stronger root networks OR addition of geosynthetics to achieve soil stabilization.	• Effective for some small areas but not large debris flow zones.	• Appropriate for site-level application in some zones.	• Not appropriate for large-scale application across the project area.	• Affected People • Mortality and/or Missing • Disruption • Environment (if restoration)
Structural Mitigation – Category 2: Deviating the path of landslide debris					
Increase conveyance capacity of channel and crossing (culvert/bridge)	• Increases to channel/crossing capacity to make space for debris flow conveyance (Porter *et al.*, 2017). • Possible for some zones where there is space to increase capacity. • This is a common option for debris flow management.	• This reduces the hazard by inhibiting the build-up of material behind crossings. • Sudden failure of crossings can be avoided.	• Modifications to road at creek crossings.	• Road ownership to be addressed. • Could be expensive and should be combined with other road works.	• Affected People • Mortality and/or Missing • Disruption
Diversion channel away from development	• Construction of diversion channel to transport debris away from exposed elements (Porter *et al.*, 2017). • This is considered to be a reasonable option for debris flow management.	• This reduces the hazard by providing an alternative pathway for material away from vulnerable areas.	• Modifications to land where new channel would be needed.	• Land would need to be acquired.	• Affected People • Mortality and/or Missing • Disruption

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Category
Deflection berms	• Earth or structural berms to deflect potential debris flow away from exposed elements. • These tend to require a large footprint and be constructed on relatively gentle slopes (Porter *et al.*, 2007), (BGC Engineering Inc., 2010). • This is a common option for debris flow management.	• This reduces the hazard by deflecting material away from vulnerable areas.	• Modification to land where berm would be placed.	• Land would need to be acquired.	• Affected People • Mortality and/or Missing
Structural Mitigation – Category 3: Dissipating the energy of debris flows					
Debris-restraining structure	• Physical nets/geo-grids/stakes can be used to restrain movement of source material. • Large diameter for larger debris.	• Reduces the severity of the hazard by trapping large debris.	• Installed in the channel.	• Sufficient space and access for installation required.	• Affected People • Mortality and/or Missing
Structural Mitigation – Category 4: Arresting and detaining landslide debris or rock fall					
Debris-resisting barrier	• Barrier installed to block the flow of debris.	• Reduces hazard by providing a barrier to downslope flow of material.	• Barrier constructed upstream of vulnerable area.	• Sufficient space and access for installation required.	• Affected People • Mortality and/or Missing
Debris-flow detention basins	• Construction of a debris-flow trap (detention basin) could be considered to contain material flowing down the slope (Porter and Dercole, 2011),(Porter *et al.*, 2017).	• Reduces the hazard by providing space for the flow material to accumulate.	• Detention basin constructed upstream of vulnerable area. • This option has recently been selected for Cougar	• Good option for debris flow hazard reduction but can be costly. • Sufficient space and access for construction required.	• Affected People • Mortality and/or Missing

What	Description	Mode of Action & Effectiveness	Context	Obstacles & Opportunities	Category
			Creek, Canmore, at a cost of $43M.		

4. DISCUSSION

These options provide a starting point for the CVRD to consider what types of action could be taken to address the existing risk in the project area due to the presence of geohazards and existing exposure. It should be noted that many of the options presented here address risk to life, and not other categories of risk. Some would be expensive, if not cost-prohibitive, to implement, and their technical and financial feasibilities in this project area have not been evaluated in this report. Other measures involve new planning and emergency management approaches and would be implemented over time. It is likely that a combination of options is needed, in the long term, to help mitigate risk within the project area.

Several of these measures have been implemented in Canada, including in southwestern British Columbia, and others have been implemented internationally. The District of North Vancouver (DNV) has implemented a monitoring and warning system, for example, while the Town of Lions Bay has implemented a debris-flow retention structure to capture material. Depending on the nature of the hazard and the area, different structural and non-structural mitigation measures may be preferred. It is important to consider the options and then tailor solutions to the local context. It may be beneficial to the CVRD to contact other jurisdictions that have implemented these types of measures for peer-to-peer learning within public institutions.

5. CONCLUSIONS AND NEXT STEPS

With this long-list of options to address both exposure and existing geohazards on the north slope of Cowichan Lake, the CVRD can start to review and focus on mitigation measures of interest. These initial reviews and screenings can be paired with the results of the forthcoming risk assessment to form the basis of a decision-making process to select and implement options for risk assessment in the project area.

6. WORKS CITED

[1] S. Okubo, H. Ikeya, Y. Ishikawa, and T. Yamada, "Development of new methods for countermeasures against debris flows," in *Recent developments on debris flows*, Springer, 1997, pp. 166–185.

[2] Norwegian Geotechnical Institute, "LARIMIT," 2016. [Online]. Available: https://www.larimit.com/. [Accessed: 13-Nov-2018].

[3] M. Porter and F. Dercole, "The evolution of geohazard risk management in North Vancouver," in *Proceedings of the 5th Canadian GeoHazards Conference-GeoHazards*, 2011, vol. 5, pp. 15–17.

[4] M. Porter, M. Jakob, K. W. Savigny, S. Fougere, and N. Morgenstern, "Risk management for urban flow slides in North Vancouver, Canada," in *Proceedings of the 60th Canadian Geotechnical Conference*, 2007.

[5] M. Porter, M. Jakob, K. Holm, and S. McDougall, "Risk-based landslide safety assessments in Canada," in *Proceedings of the North American Symposium on Landslides, Roanoke, Virginia*, 2017, pp. 4–8.

[6] BGC Engineering Inc., "2009 Landslide Risk Assessment for Select Escarpment Slopes," 2010.

7. ABBREVIATIONS

CVRD Cowichan Valley Regional District

DPA Development Permit Area

EMBC Emergency Management BC

LaRiMiT Landslide Risk Mitigation Toolbox

OCP Official Community Plan

Appendix F Data Summary

The following provides a list of data used to support the reporting.

Legend

Hazard Data
Topographic Data
Exposure Data
Risk Data

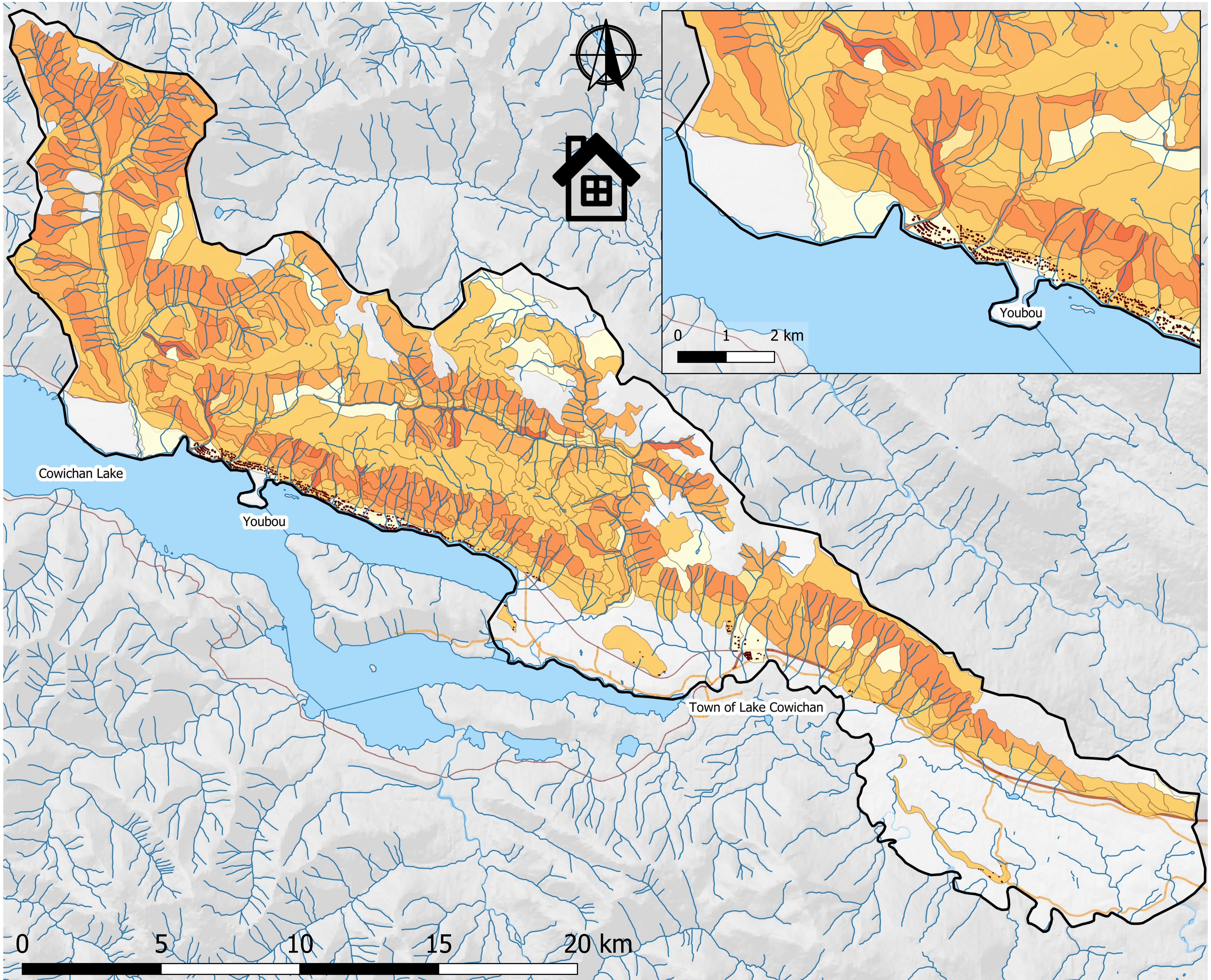
	DATA CATEGORY	FILE NAME	DATA DESCRIPTION	DATA TYPE	SOURCE
HAZARD DATA	Geohazard Model	CVRDHazardModel_Good.shp	Geohazard Model - Original Polygons with geohazard AEP	Shapefile	Palmer
	Geohazard Model	099_CVRDHazardModel_5ptRatings.shp	Polygons with geohazardAEP	Shapefile	Palmer with scoring by Ebbwater
	Catchment Areas	CVRDHazardModel_Good.shp	Classed upper catchment areas	Shapefile	Palmer
	Slope Data	CVRDSlope (TIF File)	Slope File ratster data	Raster	Palmer
	Hazard Inventory	HazardInventory.shp	Inventory of hazards in study area	Shapefile	Palmer
TOPOGRAPHY	Average Slope	AvgSlope (TIF)	Average slope in study area	Raster	CVRD
	Elevation Data	CVRDhillshade (TIF)	CVRD Hillshade in study area	Raster	CVRD
	Elevation Data	CVRDslope (TIF)	CVRD Slope in study area	Raster	CVRD

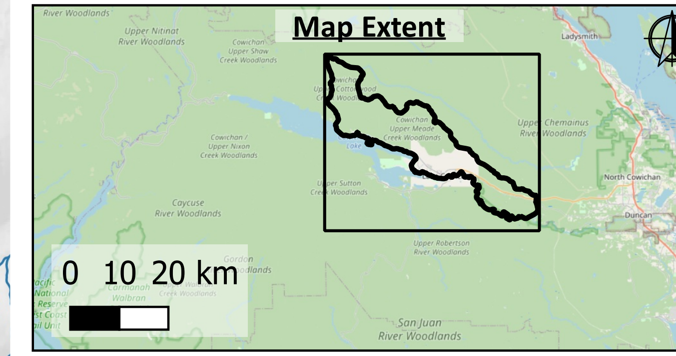
EXPOSURE DATA	Buildings	099_building_footprints_final.shp	Polygons of building outlines	Shapefile	Ebbwater
	Census	census_data.shp	Polygons of dissemination areas that intersect with study area	Shapefile	Statistics Canada via Census Mapper
	Roads	dgtl_road_atlas.gdb	Database of roads in BC	Database file	B.C. Government
	Planning (Land Zoning)	OfficialCommunityPlan-study_area.shp	Land zoning for CVRD	Shapefile	CVRD
	Property Boundaries	pmbc_parcel_fabric_poly_svw.gdb	Property boundaries for BC	Database file	BC Data Catalogue
	Property Values	099_Land_Parcels_Property_Values (xls)	Property values for study area	Spreadsheet	BC Assessment Authority via CVRD
	Environment	Cowican LakeYoubou Contamination Risk Survey (KMZ)	Potential	Shapefile	CVRD and Ebbwater
RISK DATA	Property Boundaries	099_property_risk-data.shp	Property boundaries in the study area	Shapefile	BC Data Catalogue and Ebbwater
	Environment	099_contaminant_source.shp	Potential	Shapefile	CVRD and Ebbwater
	Planning (Land Zoning)	099_OfficialCommunityPlan-study_area.shp	Land zoning for CVRD clipped to study area	Shapefile	CVRD
	Roads	Highway.shp Arterial.shp Collector.shp	Main roads in study area	Shapefile	BC Road Atlas and Ebbwater
	Workshop Impacts	099_workshop_all_impacts.shp	Workshop impacts	Shapefile	Workshop Participants and Ebbwater

Appendix G Map Package

Below is a list of the final maps for the project.

Map #	Title	Impact Type	Type of Input Data
1	Exposed buildings in project area	Mortality and/or Missing	Quantitative
2	Hotspot map of affected people based on input from workshop 1	Affected People	Qualitative
3	Population density by dissemination area for moderate geohazard	Affected People	Quantitative
4	Hotspot map of economic impacts based on input from workshop 1	Economic	Qualitative
5	Economic impacts of geohazard as reported by stakeholders	Economic	Quantitative
6	Hotspot map of disruption based on input from workshop 1	Disruption	Qualitative
7	Disruption due to geohazard based on infrastructure data	Disruption	Quantitative
8	Environmental impacts due to geohazard based on windshield survey	Environment	Quantitative
9	Direct impacts due to geohazard with input from stakeholders	Direct Impacts	Qualitative
10	Indirect impacts due to geohazard with input from stakeholders	Indirect Impacts	Qualitative
11	Land use and upper catchments	Land Zoning and Hazard	Quantitative





Notes:
1. Map produced by Ebbwater Consulting Inc. on March 10, 2020.
2. This map is designed to accompany a Risk Assessment Report (Ebbwater, 2019) and is intended for the purposes set out in that report only. See the main report for further details on the method, results and limitations.
3. A description of hazard scores is provided in the report.
4. Zones in Project Area Boundary with no colour have a hazard score of less than 0.5.
5. Impact data collected from stakeholders during a workshop in the Town of Lake Cowichan on April 24, 2018.

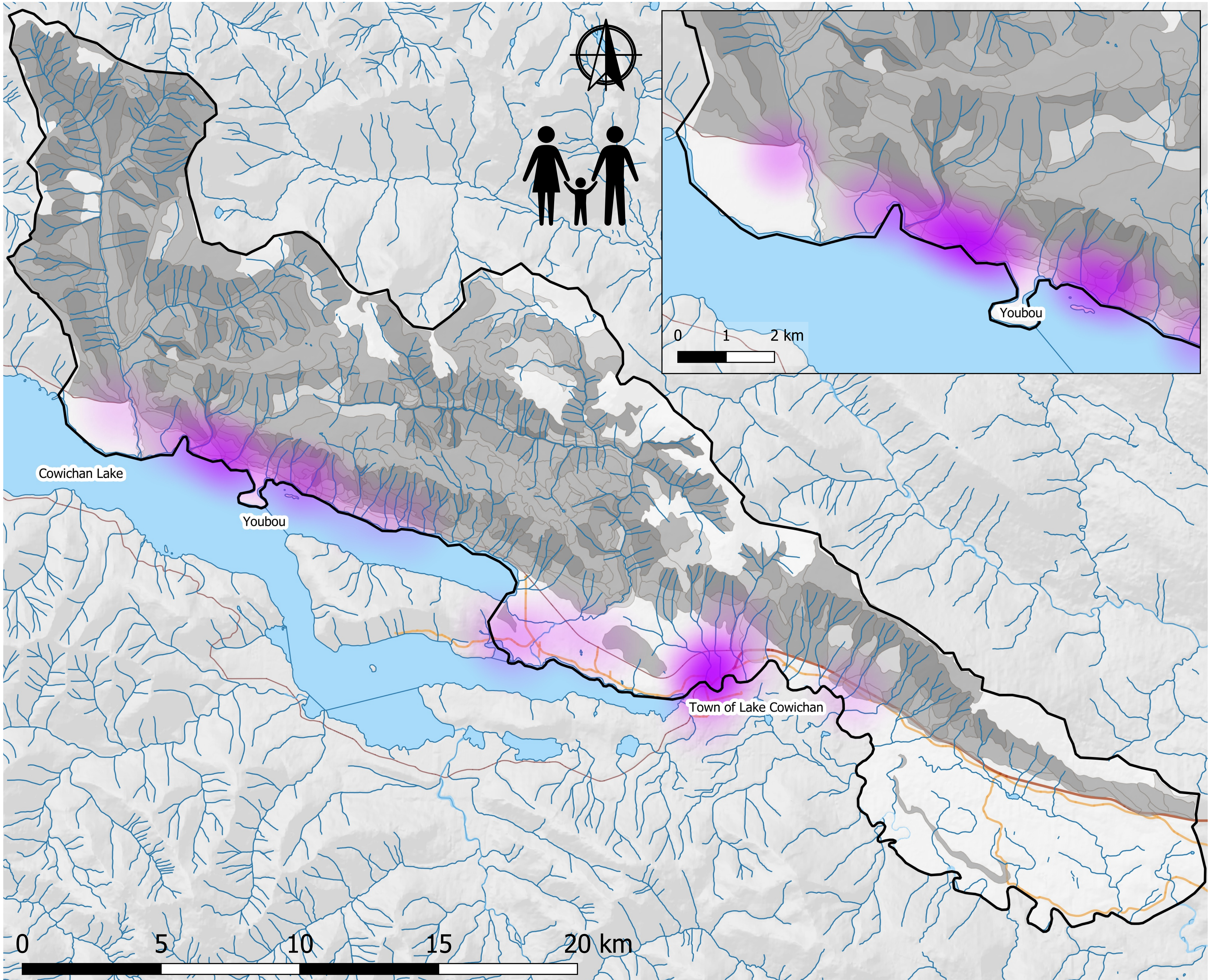
Data Sources:
1. Hazard areas from December 2018, developed by Palmer Environmental Consulting Group Inc.
2. Watercourses from the BC Fresh Water Atlas
3. Roads from BC Road Atlas
4. Base layer: Open Street Map and Canadian DEM

References:
1. Ebbwater, 2020. Geohazard Risk Assessment – North Slope of Cowichan Lake.
2. Palmer, 2018. Lake Cowichan and Youbou Slope Hazard Assessment.

Project Area Boundary	Hazard Scores
Watercourse	0.5, 3.0
Lake	1.0, 3.5
Highway	1.5, 4.0
Collector Road	2.0, 4.5
Arterial Road	2.5, 5.0
Buildings	

Date: March 10, 2020
Produced by: Ebbwater Consulting Inc.

Geohazard Risk Assessment
North Slope of Cowichan Lake
Exposed Residential Buildings



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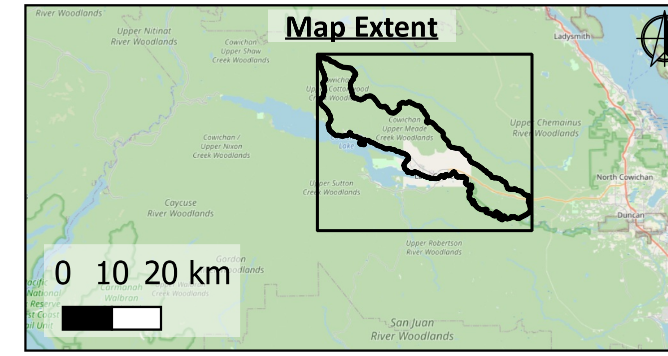

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4. Zones in Project Area Boundary with no colour have a hazard score of less than 0.5.
5. Impact data collected from stakeholders during a workshop in the Town of Lake Cowichan on April 24, 2018.

Data Sources:
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2. Watercourses from the BC Fresh Water Atlas
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4. Base layer: Open Street Map and Canadian DEM

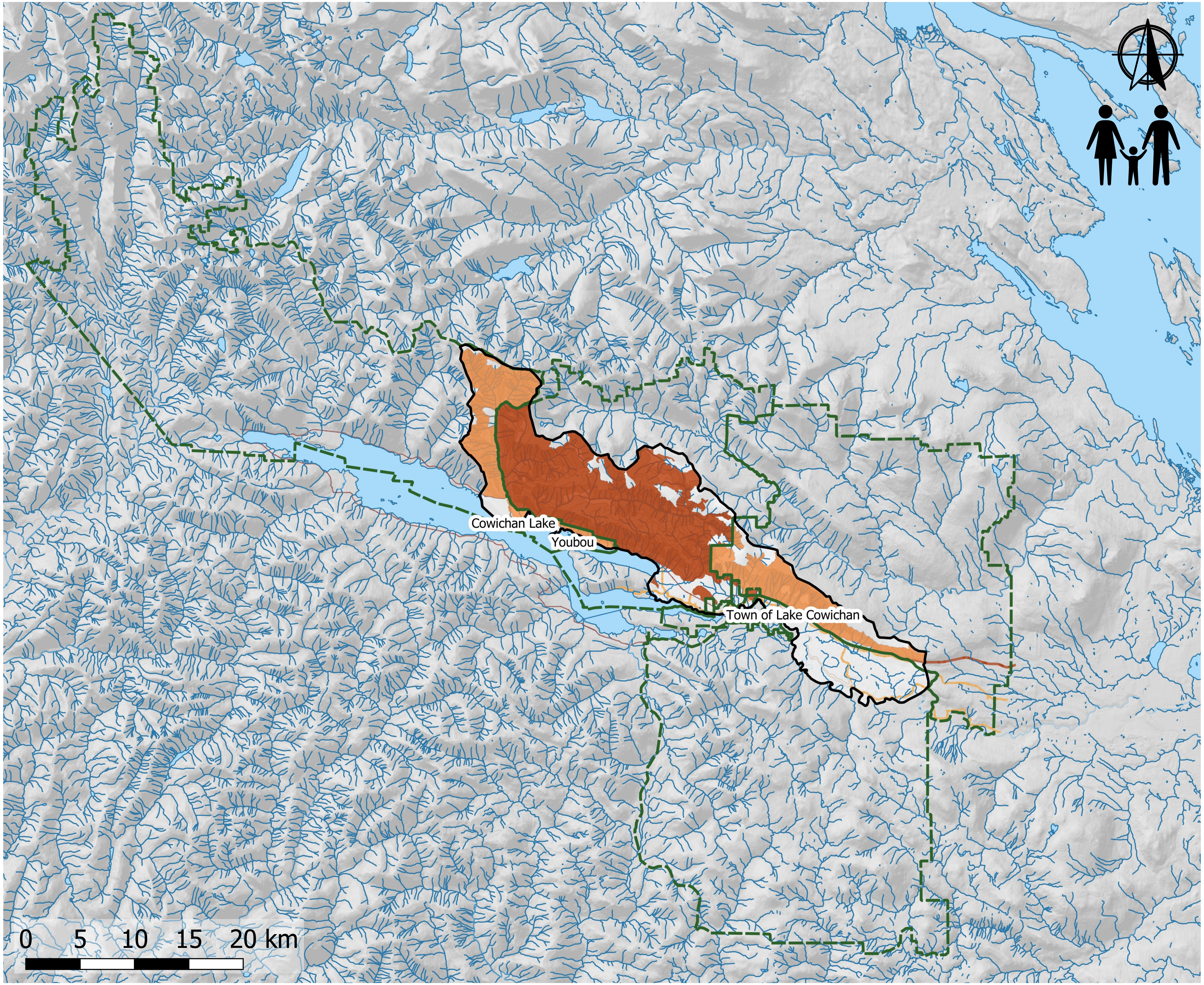
References:
1. Ebbwater, 2020. Geohazard Risk Assessment – North Slope of Cowichan Lake.
2. Palmer, 2018. Lake Cowichan and Youbou Slope Hazard Assessment.

Project Area Boundary
Watercourse
Lake
Highway
Collector Road
Arterial Road
Affected People

Hazard Scores
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0

Date: March 10, 2020
Produced by: Ebbwater Consulting Inc.

Geohazard Risk Assessment
North Slope of Cowichan Lake
Affected People



CVRD

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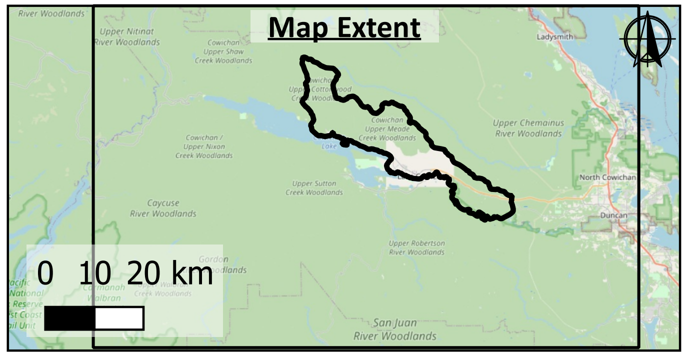
PALMER ENVIRONMENTAL CONSULTING GROUP INC.



Notes:

1. Map produced by Ebbwater Consulting Inc. on March 10, 2020.
2. This map is designed to accompany a Risk Assessment Report (Ebbwater, 2019) and is intended for the purposes set out in that report only. See the main report for further details on the method, results and limitations.
3. Population based on 2016 census data shown for assessed hazard areas.
4. Zones in Project Area Boundary with no population density shown have a hazard score of less than 0.5.

Data Sources:

1. Hazard areas from December 2018, developed by Palmer Environmental Consulting Group Inc.
2. Watercourses from the BC Fresh Water Atlas
3. Roads from BC Road Atlas
4. Population from 2016 Statistics Canada census
5. Base layer: Open Street Map and Canadian DEM

References:

1. Ebbwater, 2020. Geohazard Risk Assessment – North Slope of Cowichan Lake.
2. Palmer, 2018. Lake Cowichan and Youbou Slope Hazard Assessment.

- Watercourse
- Lake
- Highway
- Collector Road
- Arterial Road
- Project Area Boundary
- Dissemination Area Boundary

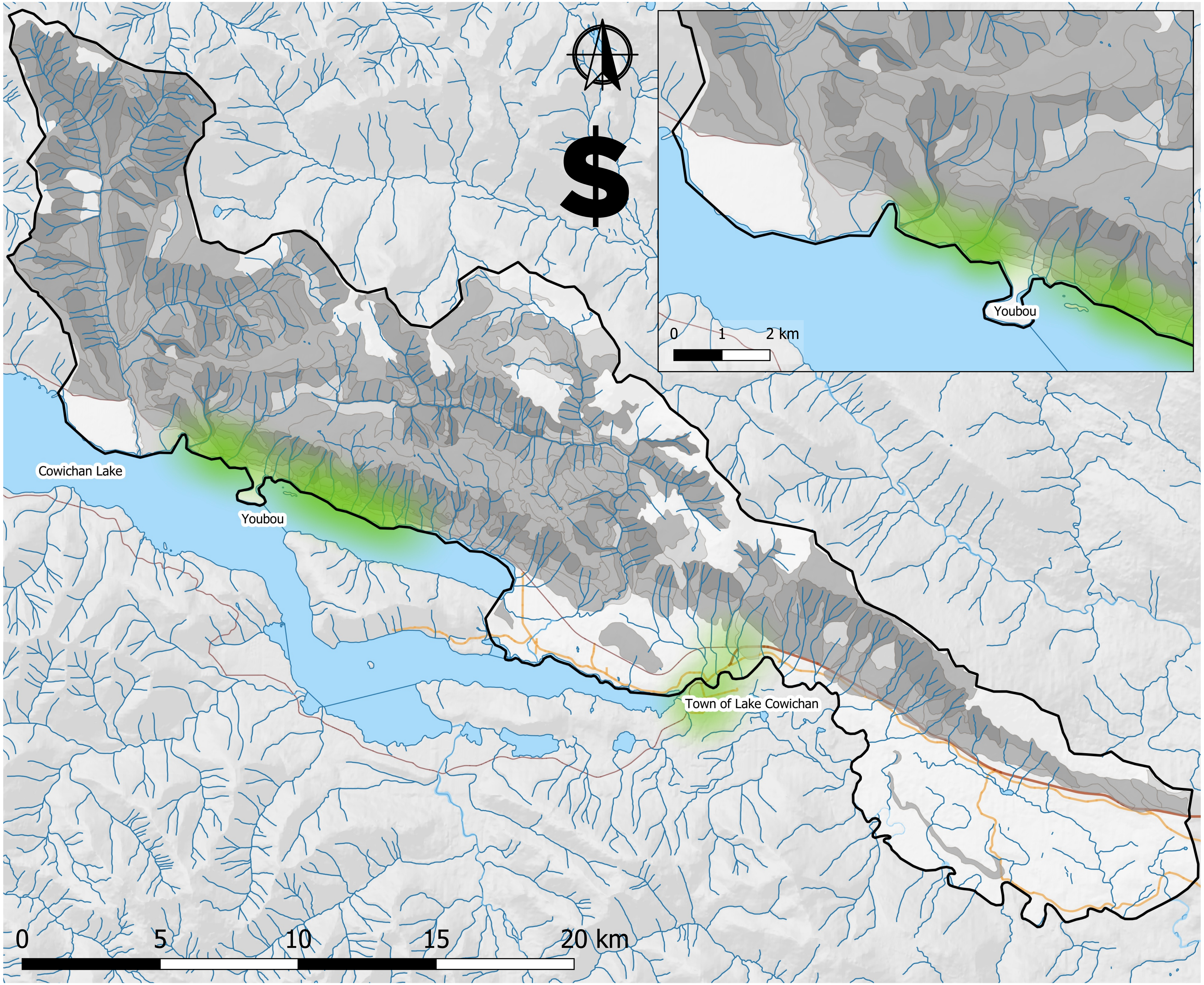
Population

- Low (0-10)
- Medium (10-100)
- High (100-1000)

Date: March 10, 2020

Produced by: Ebbwater Consulting Inc.

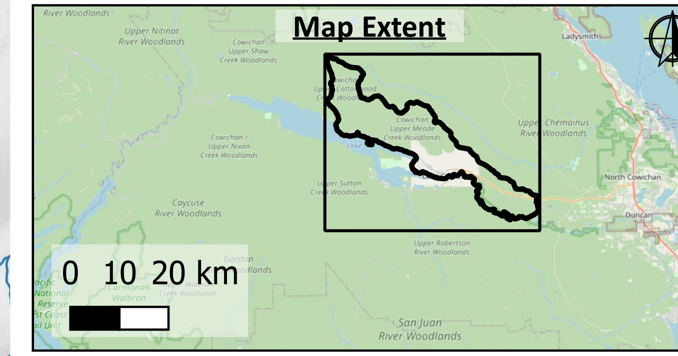
Geohazard Risk Assessment
North Slope of Cowichan Lake
Affected People - Census



CVRD

ebbwater

PALMER ENVIRONMENTAL CONSULTING GROUP INC.



Notes:
1. Map produced by Ebbwater Consulting Inc. on March 10, 2020.
2. This map is designed to accompany a Risk Assessment Report (Ebbwater, 2019) and is intended for the purposes set out in that report only. See the main report for further details on the method, results and limitations.
3. A description of hazard scores is provided in the report.
4. Zones in Project Area Boundary with no colour have a hazard score of less than 0.5.
5. Impact data collected from stakeholders during a workshop in the Town of Lake Cowichan on April 24, 2018.

Data Sources:
1. Hazard areas from December 2018, developed by Palmer Environmental Consulting Group Inc.
2. Watercourses from the BC Fresh Water Atlas
3. Roads from BC Road Atlas
4. Base layer: Open Street Map and Canadian DEM

References:

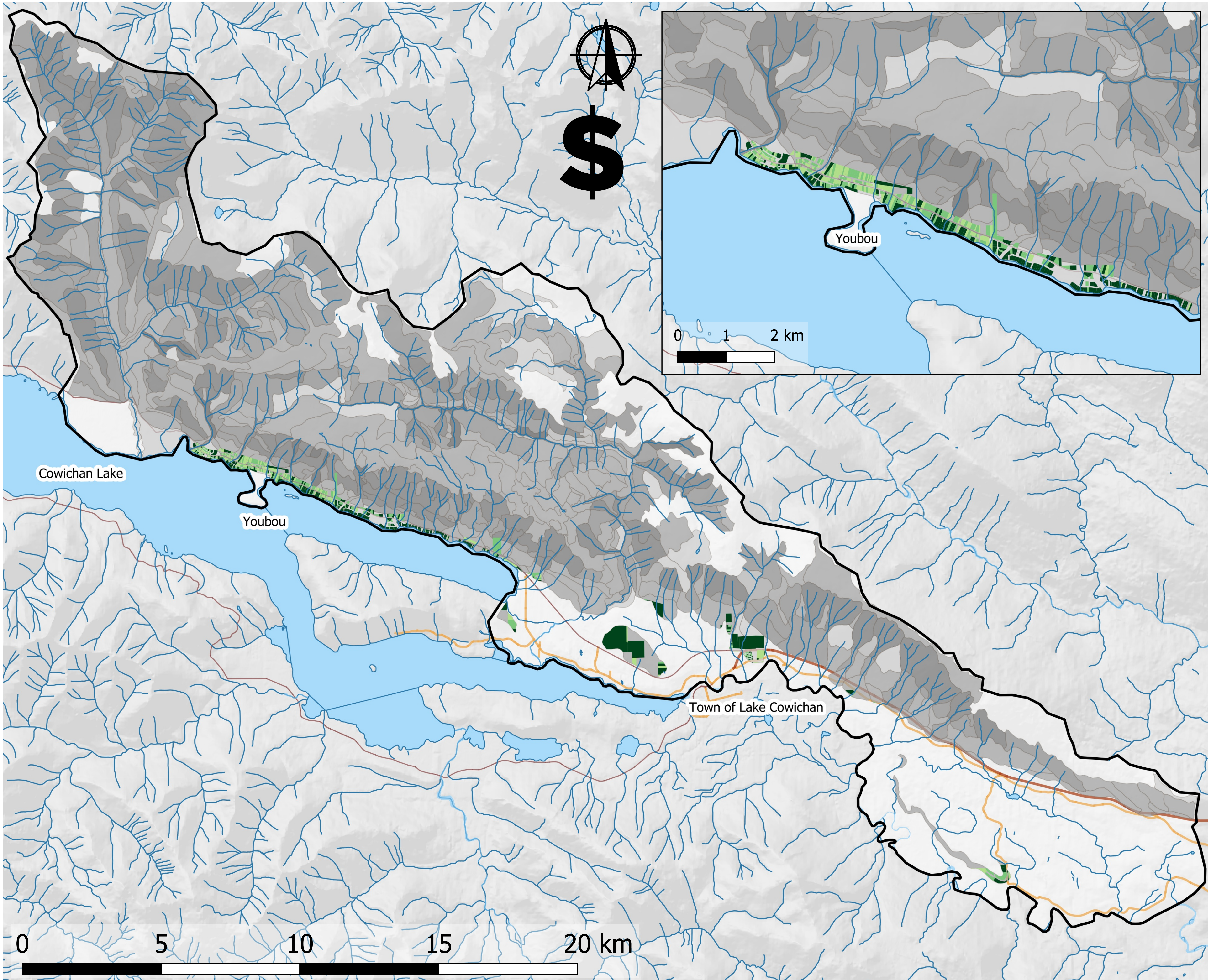
1. Ebbwater, 2020. Geohazard Risk Assessment – North Slope of Cowichan Lake.
2. Palmer, 2018. Lake Cowichan and Youbou Slope Hazard Assessment.

Project Area Boundary
Watercourse
Lake
Highway
Collector Road
Arterial Road
Economic

Hazard Scores
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0

Date: March 10, 2020
Produced by: Ebbwater Consulting Inc.

Geohazard Risk Assessment
North Slope of Cowichan Lake
Economic



CVRD

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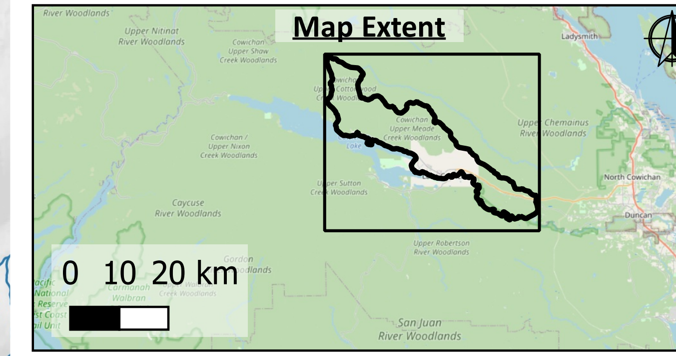

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3. Improved property value shown for assessed hazard areas.
4. Zones in Project Area Boundary with no value shown have a hazard score of less than 0.5.

Data Sources:
1. Hazard areas from December 2018, developed by Palmer Environmental Consulting Group Inc.
2. Watercourses from the BC Fresh Water Atlas
3. Roads from BC Road Atlas
4. Property values from BC Assessment Authority
5. Base layer: Open Street Map and Canadian DEM

References:
1. Ebbwater, 2020. Geohazard Risk Assessment – North Slope of Cowichan Lake.
2. Palmer, 2018. Lake Cowichan and Youbou Slope Hazard Assessment.

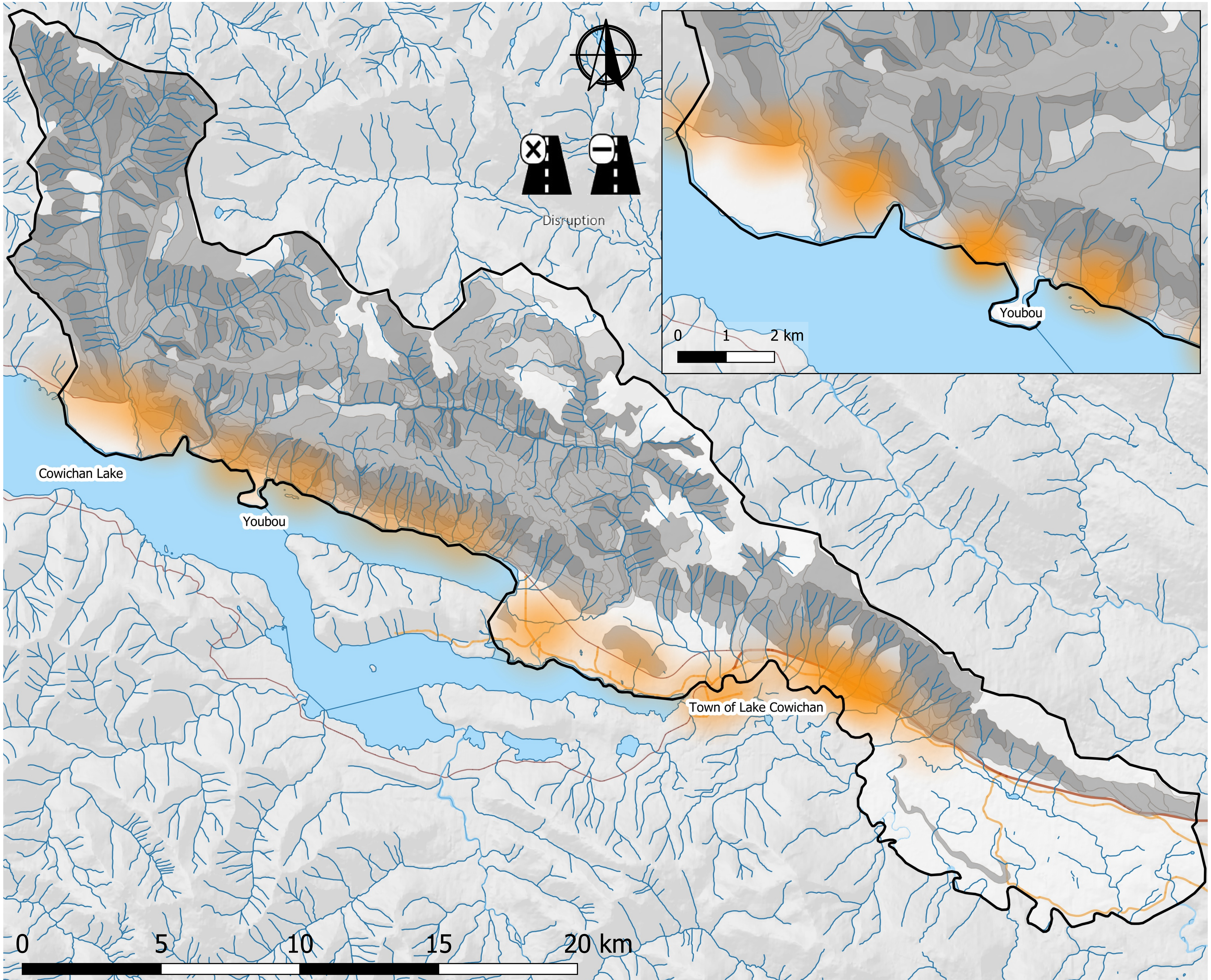
Project Area Boundary
Watercourse
Lake

Improved Property Value
Low
Medium
High

Hazard Scores
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0
Highway
Arterial
Collector

Date: March 10, 2020
Produced by: Ebbwater Consulting Inc.

Geohazard Risk Assessment
North Slope of Cowichan Lake
Economic - Buildings



CVRD

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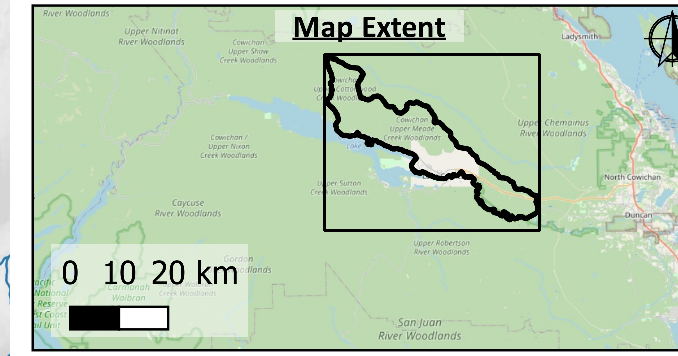

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Data Sources:

1. Hazard areas from December 2018, developed by Palmer Environmental Consulting Group Inc.
2. Watercourses from the BC Fresh Water Atlas
3. Roads from BC Road Atlas
4. Base layer: Open Street Map and Canadian DEM

References:

1. Ebbwater, 2020. Geohazard Risk Assessment – North Slope of Cowichan Lake.
2. Palmer, 2018. Lake Cowichan and Youbou Slope Hazard Assessment.

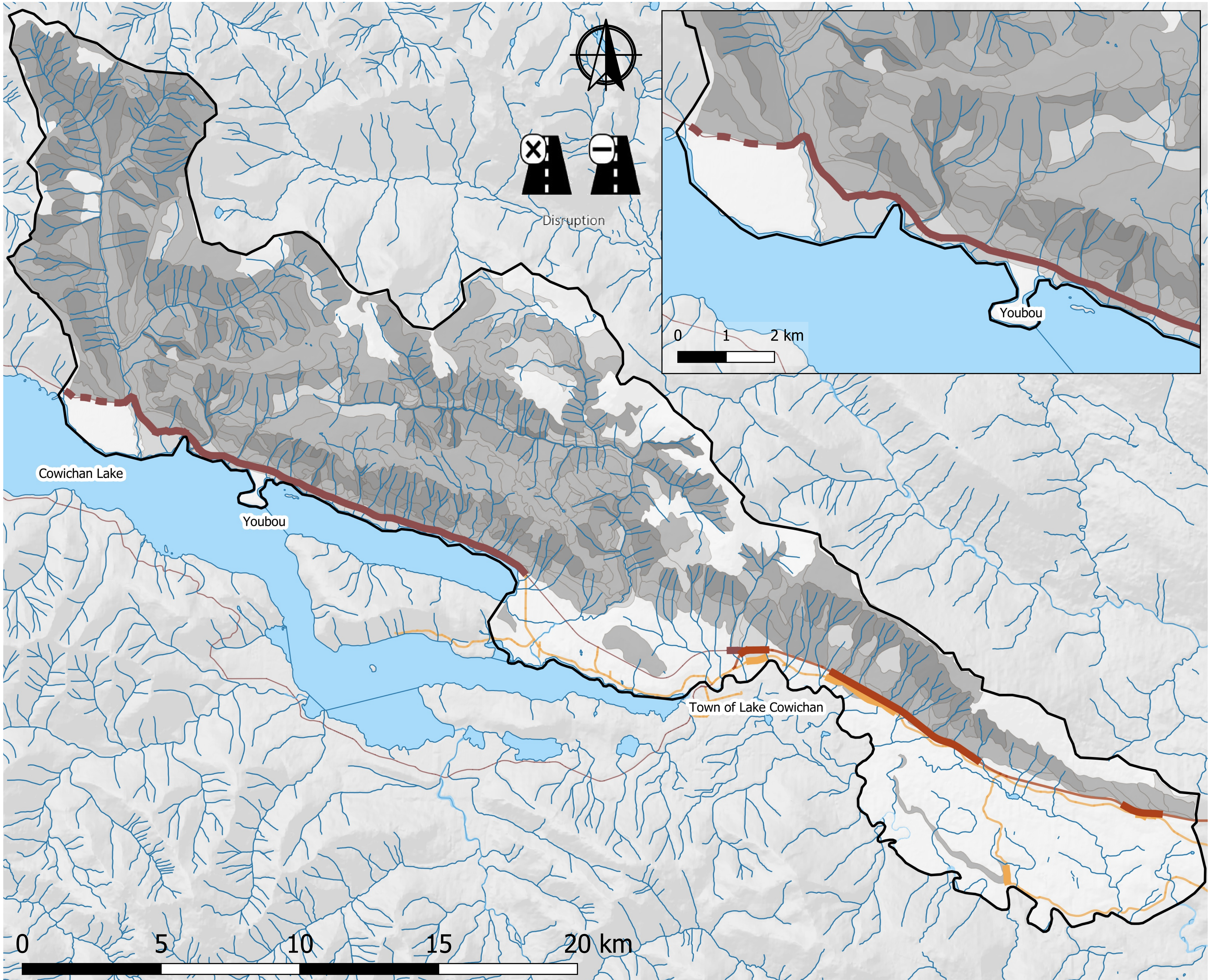
Project Area Boundary
Watercourse
Lake
Highway
Collector Road
Arterial Road
Disruption

Hazard Scores

0.5	3.0
1.0	3.5
1.5	4.0
2.0	4.5
2.5	5.0

Date: March 10, 2020
Produced by: Ebbwater Consulting Inc.

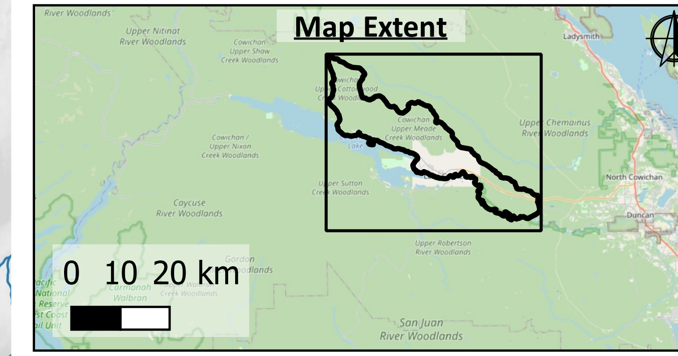
Geohazard Risk Assessment
North Slope of Cowichan Lake
Disruption



CVRD

ebbwater

PALMER ENVIRONMENTAL CONSULTING GROUP INC.



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3. Disrupted roads shown for assessed hazard areas with thick line.
4. Roads in Project Area Boundary with thin line have a hazard score of less than 0.5.

Data Sources:
1. Hazard areas from December 2018, developed by Palmer Environmental Consulting Group Inc.
2. Watercourses from the BC Fresh Water Atlas
3. Roads from BC Road Atlas
4. Base layer: Open Street Map and Canadian DEM

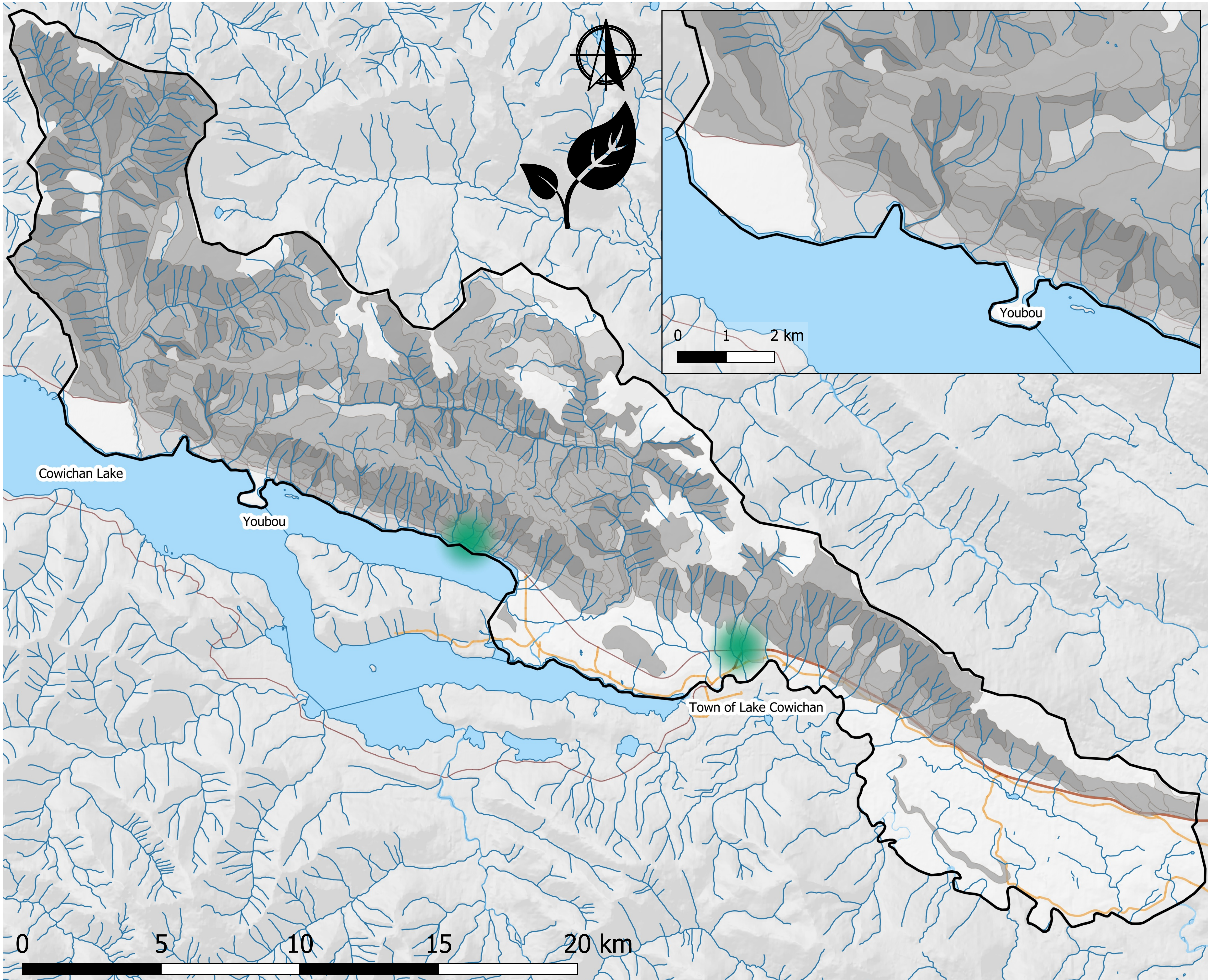
References:
1. Ebbwater, 2020. Geohazard Risk Assessment – North Slope of Cowichan Lake.
2. Palmer, 2018. Lake Cowichan and Youbou Slope Hazard Assessment.

Project Area Boundary
Watercourse
Lake
Highway
Collector Road
Arterial Road
Disrupted Highway
Disrupted Collector
Disrupted Arterial

Hazard Scores
0.5 3.0
1.0 3.5
1.5 4.0
2.0 4.5
2.5 5.0

Date: March 10, 2020
Produced by: Ebbwater Consulting Inc.

Geohazard Risk Assessment
North Slope of Cowichan Lake
Disruption - Roads



CVRD

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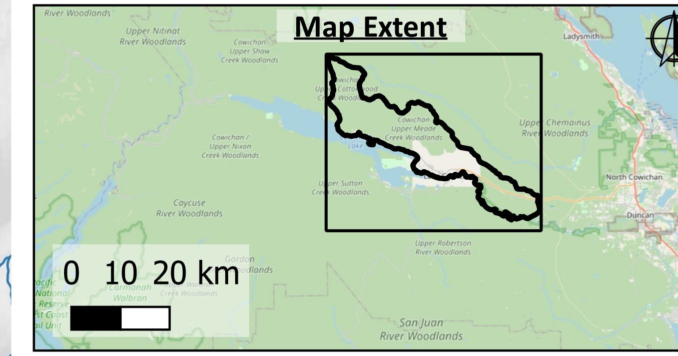
PALMER ENVIRONMENTAL CONSULTING GROUP INC.



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Data Sources:
1. Hazard areas from December 2018, developed by Palmer Environmental Consulting Group Inc.
2. Watercourses from the BC Fresh Water Atlas
3. Roads from BC Road Atlas
4. Potentional contamination sources from CVRD 2018 windsheild survey
5. Base layer: Open Street Map and Canadian DEM

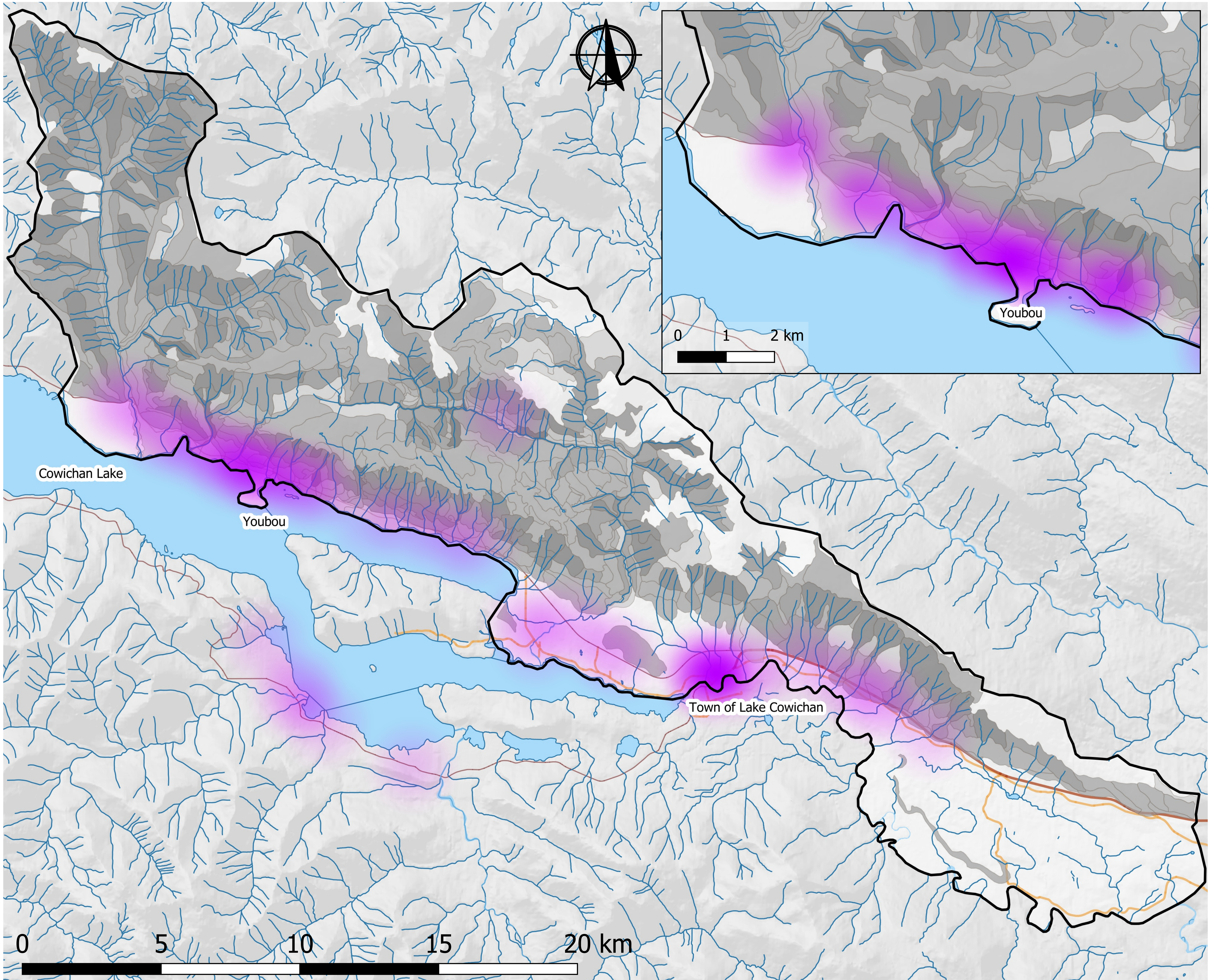
References:
1. Ebbwater, 2020. Geohazard Risk Assessment – North Slope of Cowichan Lake.
2. Palmer, 2018. Lake Cowichan and Youbou Slope Hazard Assessment.

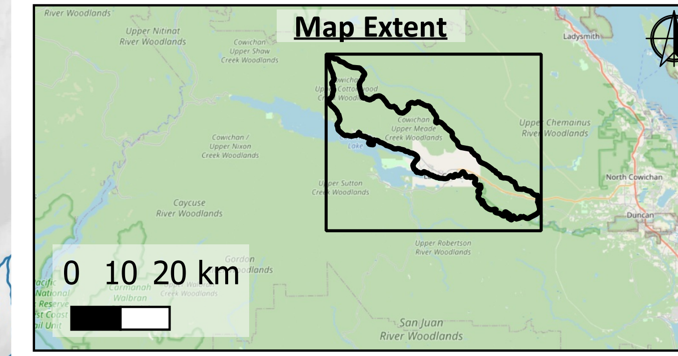
Project Area Boundary
Watercourse
Lake
Highway
Collector Road
Arterial Road
Potential Contamination Source

Hazard Scores
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0

Date: March 10, 2020
Produced by: Ebbwater Consulting Inc.

Geohazard Risk Assessment
North Slope of Cowichan Lake
Environment - Contamination





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3. Roads from BC Road Atlas
4. Base layer: Open Street Map and Canadian DEM

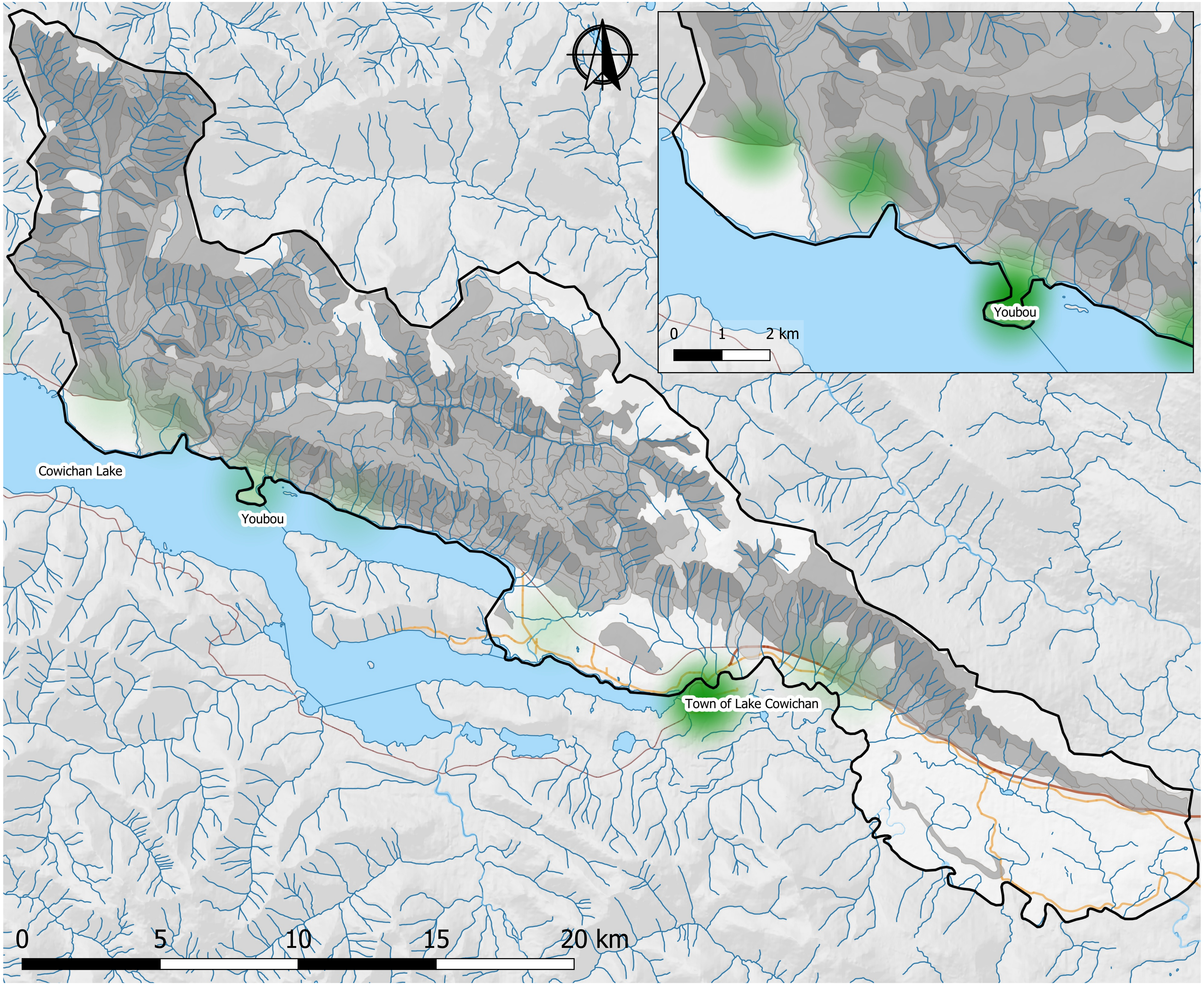
References:
1. Ebbwater, 2020. Geohazard Risk Assessment – North Slope of Cowichan Lake.
2. Palmer, 2018. Lake Cowichan and Youbou Slope Hazard Assessment.

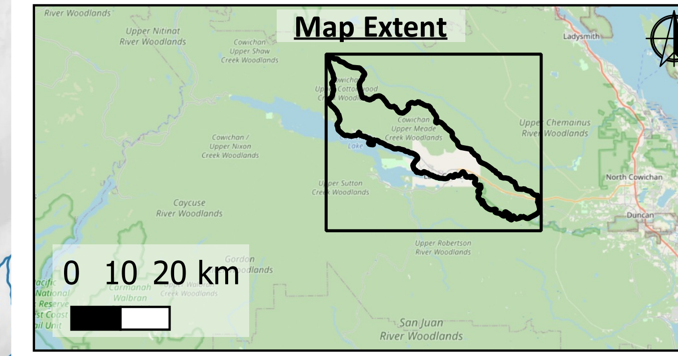
Project Area Boundary
Watercourse
Lake
Highway
Collector Road
Arterial Road
Direct Impact

Hazard Scores
0.5 3.0
1.0 3.5
1.5 4.0
2.0 4.5
2.5 5.0

Date: March 10, 2020
Produced by: Ebbwater Consulting Inc.

Geohazard Risk Assessment
North Slope of Cowichan Lake
Direct Impacts Map





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Data Sources:
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2. Watercourses from the BC Fresh Water Atlas
3. Roads from BC Road Atlas
4. Base layer: Open Street Map and Canadian DEM

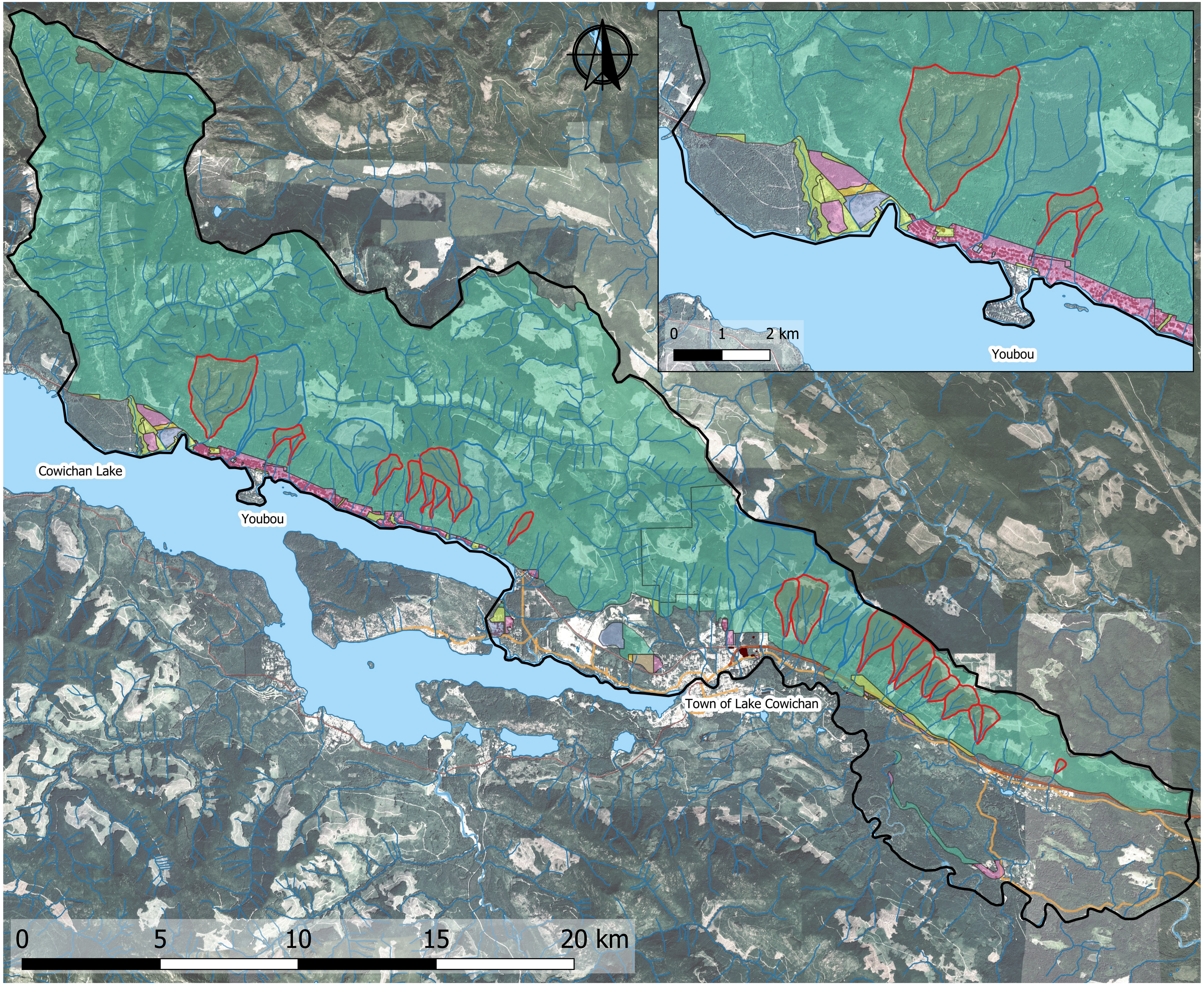
References:
1. Ebbwater, 2020. Geohazard Risk Assessment – North Slope of Cowichan Lake.
2. Palmer, 2018. Lake Cowichan and Youbou Slope Hazard Assessment.

Project Area Boundary
Watercourse
Lake
Highway
Collector Road
Arterial Road
Indirect Impact

Hazard Scores
0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0

Date: March 10, 2020
Produced by: Ebbwater Consulting Inc.

Geohazard Risk Assessment
North Slope of Cowichan Lake
Indirect Impacts Map



CVRD

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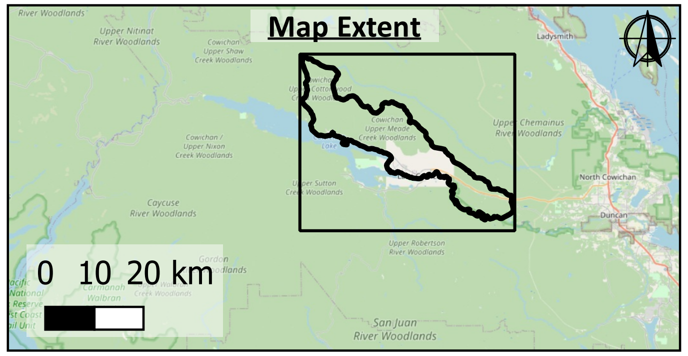

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3. Land zoning shown for assessed hazard areas.
4. Zones in Project Area Boundary with no land zoning shown have a hazard score of less than 0.5.

Data Sources:
1. Hazard areas from December 2018, developed by Palmer Environmental Consulting Group Inc.
2. Watercourses from the BC Fresh Water Atlas
3. Roads from BC Road Atlas
4. Land zoning from CVRD 2016 OCP
5. Base layer: Open Steet Map and Google Sattellite

References:
1. Ebbwater, 2020. Geohazard Risk Assessment – North Slope of Cowichan Lake.
2. Palmer, 2018. Lake Cowichan and Youbou Slope Hazard Assessment.

Upper Watersheds
- Debris Flow
- Debris Flood
- Watercourse
- Lake
- Highway
- Collector Road
- Arterial Road

Project Area Boundary

Land Zone
- Residential
- Commercial
- Industrial
- Forestry
- First Nations
- Parks and Institutional

Date: March 10, 2020
Produced by: Ebbwater Consulting Inc.

Geohazard Risk Assessment
North Slope of Cowichan Lake
Land Zoning in Hazard Zones

Appendix H Recommendations Table

Table with list of recommendations, page, and section – TAMSIN to add groupings and priorities.

Appendix H Summary of Recommendations

Section No.	Page No.	Recommendation	Priority	Effort
executive summary and 10.1	xiv and 102	Address the risk to life	HIGH	HIGH
executive summary	xv	Continue to promote education and preparedness	HIGH	LOW
executive summary	xv	Develop and nurture connections with partners	HIGH	LOW
executive summary	xv	Avoid any increase in geohazard risk	HIGH	LOW
5.2.1	39	[Youbou Road] The potential risk to these buildings (further discussed in the next section) is significant and should be addressed as soon as possible.	HIGH	HIGH
5.2.6	52	This level of cultural impact is moderate, and this potential impact should be communicated to local First Nations.	LOW	LOW
5.3	57	Indirect and direct impacts are equally important; they should all be considered in any mitigation planning process	MEDIUM	MEDIUM
7.2	83	Include feelings of community security in decision process and future planning	MEDIUM	LOW
8.4	87	DPAs should be updated and modernised as OCPs are revised	HIGH	MEDIUM
10.3.1	104	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.	HIGH	HIGH
10.3.1	104	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.	HIGH	MEDIUM
10.3.1	104	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.	HIGH	MEDIUM

Section No.	Page No.	Recommendation	Priority	Effort
10.3.2	104	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 spatially and by hazard.	**HIGH**	**LOW**
10.3.2	105	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.	**HIGH**	**MEDIUM**
10.3.2	105	This assessment could be expanded in the future to look at the whole CVRD.	**MEDIUM**	**HIGH**
10.3.3	105	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.).	**MEDIUM**	**MEDIUM**
10.3.4	105	*Ensure changes* to infrastructure are enabled 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. As assets are upgraded new design for debris hazard must be considered.	**MEDIUM**	**LOW**
10.3.4	105–106	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).	**MEDIUM**	**LOW**
10.3.4	106	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.	**MEDIUM**	**MEDIUM**

Section No.	Page No.	Recommendation	Priority	Effort
10.3.5	106	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 Private Managed Forest Land Act [2003] to include natural hazards. It may also be possible to leverage the Water Sustainability Act [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.	HIGH	LOW
10.3.5	106	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.	HIGH	LOW
10.3.6	107	With this project and the other case studies complete, the results should be communicated widely amongst local stakeholders.	MEDIUM	LOW
10.3.6	107	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. 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.	HIGH	LOW
10.3.7	107	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. Consider interdisciplinary approaches to community-based risk tolerance and reduction activities.	MEDIUM	LOW

Section No.	Page No.	Recommendation	Priority	Effort
10.3.8	108	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.	MEDIUM	LOW
10.3.9	108	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. Updated and well-conceived emergency preparedness and response plans will help to lessen the impacts of hazards on local communities.	MEDIUM	LOW
10.3.9	108	Early warning systems can help in this endeavour as they provide information that can tie in with activating different aspects of a response plan. Consider creating an early warning system	HIGH	MEDIUM
10.3.10	109	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. Consider the development of a post-disaster plan.	LOW	MEDIUM
10.4	109	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. 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.	HIGH	HIGH
10.4.2	110	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.	HIGH	MEDIUM
11	112	**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	HIGH	MEDIUM

Section No.	Page No.	Recommendation	Priority	Effort
		considered as options and refined as plans move forward.		
11	112	**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 it plans forward and develops *disaster risk reduction policies and strategies*.	**HIGH**	**MEDIUM**