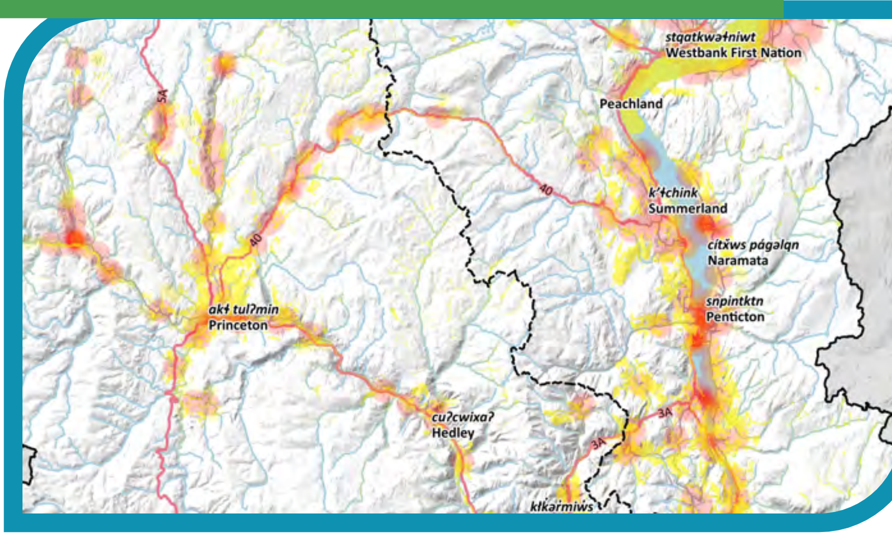
Syilx Okanagan Flood and Debris Flow Risk Assessment

Report 4 of 4: Quantitative Study



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Cover Photo: Map output from the environment indicator consequences for this project, June 2019. Ebbwater Consulting Inc. image.

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This Assessment is a testament to the power of collaboration and partnership between *Syilx* and non-*Syilx* organizations, including the project team at Ebbwater Consulting Inc. (Ebbwater), and exhibits a shared concern for how water is managed and recognized in the territory.

Support for this project came from Emergency Management British Columbia (EMBC) and Public Safety Canada (PSC) as part of the National Disaster Mitigation Program (NDMP), First Nation Adapt Program and the Real Estate Foundation of B.C. through successful applications submitted by the Okanagan Nation Alliance (ONA).

ONA would like to acknowledge Dickon Wells, M.Eng., with support by Silja Hund, Ph.D., Robert Larson, M.Sc., and Nikoletta Stamatatou, M.Sc., all of Ebbwater for the completion of this report. Cory McGregor, GIT, and Derek Cronmiller, M.Sc., P.Geo., of Palmer Environmental Consulting Group Inc. completed the debris flow hazard assessment. The report was reviewed by Tamsin Lyle, M.Eng, MRM, P.Eng. of Ebbwater.

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List of Acronyms

AEP	Annual Exceedance Probability
AHRA	All-Hazards Risk Assessment
AIDR	Australian Institute for Disaster Resilience
BC	British Columbia
BCA	British Columbia Assessment
CDEM	Canadian Digital Elevation Model
DEM	Digital Elevation Model
EMS	Environmental Monitoring System
ONA	Okanagan Nation Alliance
EMBC	Emergency Management British Columbia
FDRP	Federal Disaster Reduction Program
GDP	Gross Domestic Product
GFA	Geomorphic Flood Area
GFI	Geomorphic Flood Index
GIS	Geospatial Information System
GSM	Geology and Soils Mapping
ICI	Integrated Cadastral Information (Society)
IHA	Interior Health Authority
LiDAR	Light Detection and Ranging
NDMP	National Disaster Mitigation Program
NRCan	Natural Resources Canada
OCCP	Okanagan Collaborative Conservation Program
QGIS	Quantum Geospatial Information System
RAAD	Remote Access Archaeology Database
RAIT	Risk Assessment Information Template
RDCO	Regional District of Central Okanagan
RDOS	Regional District of Okanagan Similkameen
UN	United Nations
UNDRR	United Nations Office for Disaster Risk Reduction
UK	United Kingdom
US	United States

1 Introduction

This risk assessment project was initiated by the Okanagan Nation Alliance, funded by the National Disaster Mitigation Program (NDMP), and completed from September 2018 to December 2019. It is the initial phase of a multi-year flood and debris flow adaptation initiative. **The goal of this project is to understand the risk due to flood and debris flows within the Okanagan-Similkameen region and support priority-setting for future work**.

The *Syilx* Okanagan people are respectfully acknowledged as a distinct and sovereign Nation – the original and enduring inhabitants of this region. The Okanagan Nation Alliance is confident that by incorporating *Syilx* Okanagan values, perspectives, and processes into regional planning efforts, a new way of working with nature will emerge that is to the benefit of everyone, inclusive of the *tmixʷ* (all life forms).

Best practice dictates that adaptation to natural phenomena such as flood and debris flows be achieved through a thoughtful, risk-based planning process based on community values. Considerable effort for this project was focussed on process—it was important to embrace a diversity of perspectives and to build relationships across organizations in the region.

This Quantitative Study report is meant to be read following the Basis of Study report and is complementary to the Qualitative Study report. Along with the Map Book, the three reports form the risk assessment supporting documents; they are summarized within the context of next steps for the longer-term term initiative within the Synthesis and Recommendations report (Figure 1).

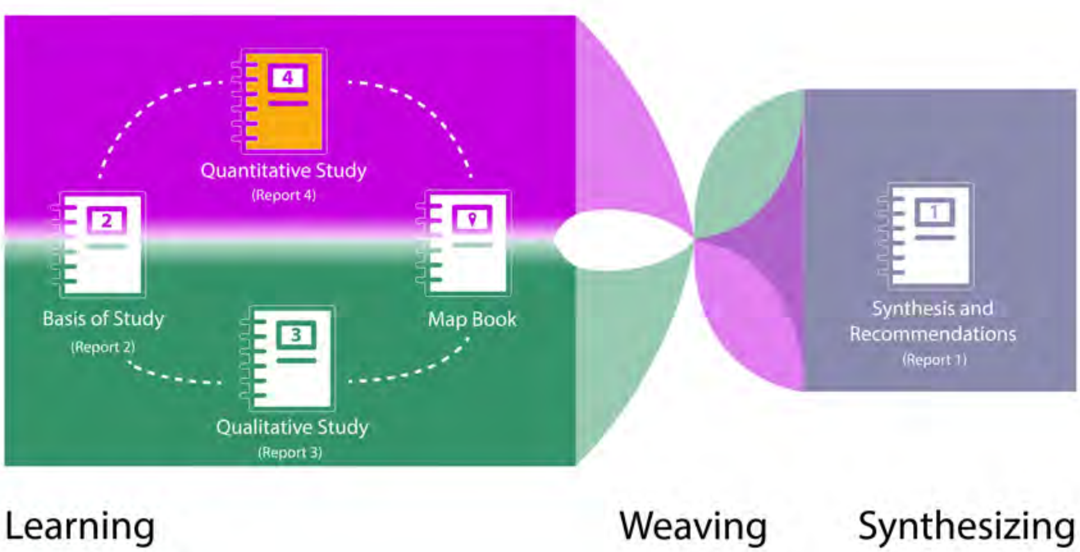

Figure 1: Project reporting structure, with Quantitative Study highlighted.

Please refer to the Basis of Study for details on the project's overall objectives, geographic scope, geohazards in the project area (including a discussion on recent flood and debris flow events), project framework, and other background materials.

1.1 Quantitative Study Objectives

Best practice dictates that adaptation to natural hazard 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. This Quantitative Study endeavours to use and present spatially consistent information, which can be integrated with the findings of the Qualitative Study. It is part of this project's holistic approach to provide information to reduce risk to flood and debris flows in the project area.

The preparation of this report has been guided by *Syilx* Okanagan perspectives, and the objectives were to:

- Identify and review hazard and exposure data for the project area.
- Work with internal and external project partners to obtain and refine data sets.
- Produce high-level flood and debris flow hazard areas.
- Layer hazard and exposure data to calculate consequences to six indicators.
- Identify and discuss areas of relatively high risk across the project area.

1.2 Project Area

The project includes includes the Okanagan River watershed including *kɫúsx̌nítkw* (Okanagan Lake) and the *nməlqaytkw* (Similkameen River tributary) watershed (Figure 2). The *Syilx* Okanagan people have inhabited the interior plateau since time immemorial, and the project area is located on unceded territory (see Figure 2 inset). The region is a geographic link for many animals and its climate and landscape support boreal forest species. The Okanagan-Similkameen region is a desirable place to live and visit; the region today is home to over 360,000 people (Statistics Canada, 2016) who live in 6 primarily *Syilx* Okanagan communities and over 15 primarily non-*Syilx* Okanagan communities (Figure 2).

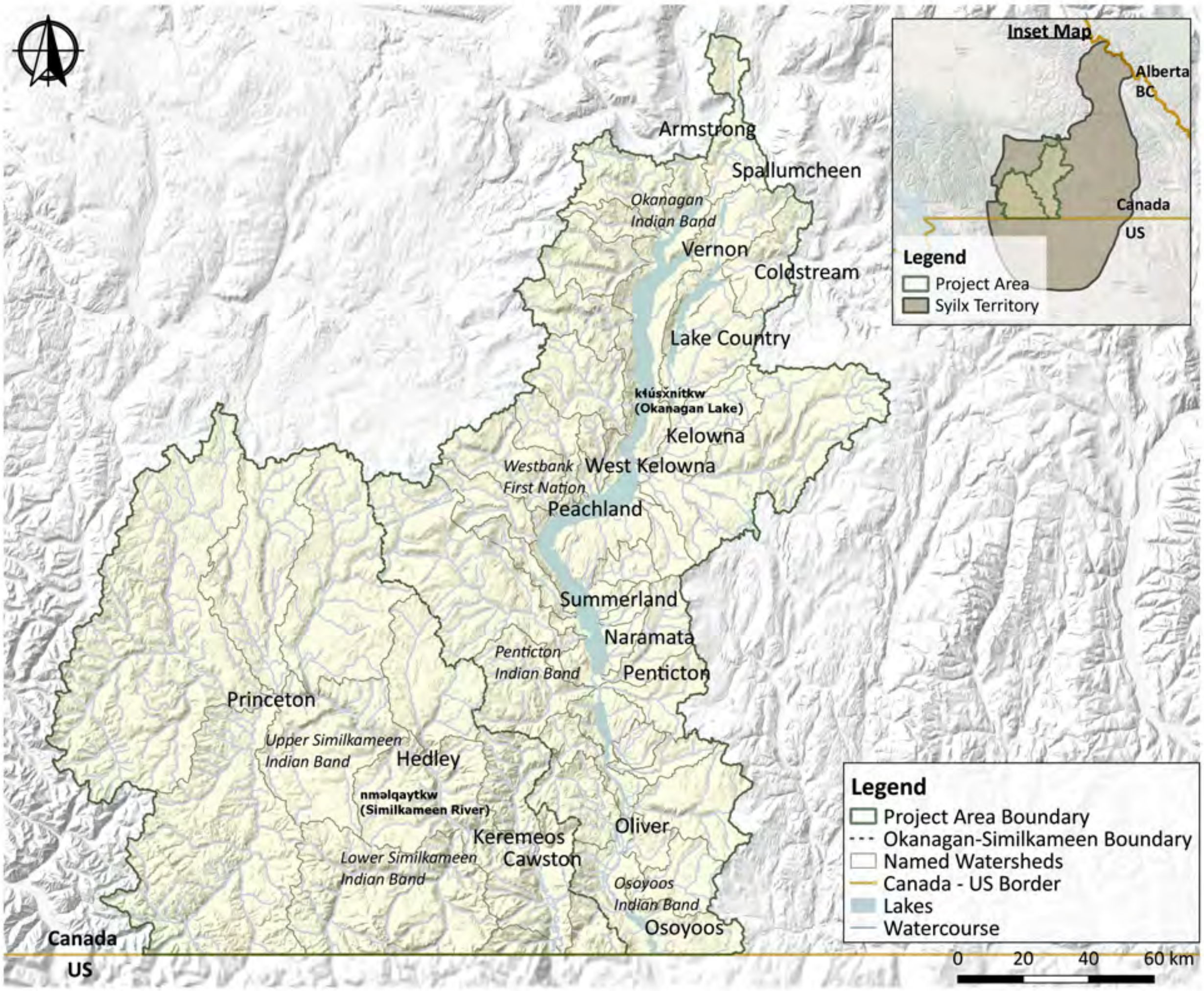

Figure 2: Project Area.

1.3 Understanding Flood and Debris Flows—from a Syilx Okanagan Perspective

In standard risk terminology, a natural hazard is usually characterized as “a bad thing” from the perspective of human beings. *Syilx* Okanagan perspectives, however, centre on ecosystems and recognize that there are positive benefits to these natural occurrences. The *Syilx* people talk about how these occurrences relate to each other (see text box below), and language within this report was deliberately used to reflect this perspective.

To stay consistent with risk terminology, the term “hazard” has been maintained within this assessment, but it is used interchangeably with “phenomenon”, which has more neutral connotations. The term “magnitude” is consistently used in place of “severity” to describe the size of the hazard and its consequences also in more neutral terms.

Flood and debris flow phenomena are briefly summarized in the following sections. These phenomena occur within a spectrum of geohazards. The Basis of Study provides more details on their types and mechanisms, as well as the role of flood and debris flows in ecosystem regeneration and the positive impacts on habitat diversity and nutrients availability. The Basis of Study and Qualitative Study also contain more detailed discussions on *Syilx* Okanagan perspectives.

1.3.1 What is a flood?

Floods occur when surface water reaches higher-than-normal levels. Floods are driven by climate processes that have influence on the watershed scale. Flood types include precipitation, riverine, dam and dike breach, and high water table. The main mechanisms causing flooding in the project area are heavy rain, snowmelt, and rain-on-snow. The careful control of reservoir outflows to manage water supply and ecosystem needs can also play a role in flooding. Flood events can affect the landscape and increase the likelihood of geohazards such as landslides and debris flows.

ṫiḱt (flood)

ṫiḱt is the word for flood. There are also words for flood land... but ṫiḱt talks about the water… it almost sounds like t'ik'wt, which is the word for lake. ṫiḱt is shallower and not still like the lake…

Richard Armstrong, *Syilx* Elder, traditional ecological knowledge specialist and *Syilx* language instructor. Personal communication, February 14, 2019.

1.3.2 What is a debris flow?

Debris flows are rapid mass movements of saturated surface material that move rapidly through channels to their outlets (debris flow fans). The high-water content of debris flows allows them to flow downhill as slurry often resembling wet concrete. Channelized debris flows commonly grow larger as they move downstream, picking-up material within the channel. Debris flows can also be initiated by rockslides, which subsequently disintegrate and release internal water or pick-up other material. Debris flows are controlled by an intricate balance of geomorphic and climatic factors and are commonly triggered by a mechanism such as a heavy rainfall event. A complex interplay exists between factors driving debris flow initiation, and unlike floods, continuous debris flow activity is not monitored for most debris flow basins.

1.4 Study Limitations

This quantitative study focused on large spatial and numerical datasets that could be efficiently processed using software to provide quantifiable interpretations that could be repeated and validated. This enabled the analysis of 2 natural hazards (one of which had 3 magnitudes), 2 watersheds, and 6 exposure indicators (for each of which several proxies and measures were used). However, quantitative data approaches present limitations. These limitations are discussed in Table 1, based on ideas from McLeod (2017) and with examples that apply to this study. Limitations related to specific data sources are discussed in later sections. In addition, the Basis of Study outlines the overall project's limitations, and contains a discussion on the advantages and disadvantages of qualitative and quantitative studies, also based on McLeod (2017).

Table 1: Quantitative Study limitations.

Disadvantages of Quantitative Studies from McLeod (2017)	Relation to this Study
Does not easily allow participants to explain choices or meaning.	The project team used judgment and feedback obtained from project participants within the Qualitative Study to select and analyse data sources for use. The rationale for technical decisions made was explained as clearly as possible in this report. **Implication for the longer-term initiative:** Future studies in the region should build on the methodology presented herein to align risk assessments completed at local levels. The results from this Quantitative Study should be considered in parallel with the findings of the Qualitative Study.
Poor knowledge of data and its use may negatively affect analysis and interpretation.	The project's compressed schedule did not allow for an in-depth quality control of the over 20 data sources used in this study. Based on knowledge of data sources, data quality checking efforts focused on improving data that were less trustworthy, and using data that were more spatially consistent. **Implication for the longer-term initiative:** The assessment results are valuable when considered at the scale of the project area. However, they should not be used at local scales or for applications where more accurate data are required.
Large sample sizes are needed for more accurate analysis, and more data are required to obtain and manage large study areas.	Spatially consistent data were obtained where possible. However, good quality datasets to assess indicators considering *Syilx* perspectives were lacking. Examples include the lack or inconsistency of data related to *Syilx* population distribution, and land valuation including ecosystem services. The proxy information used to assess the indicators were based on imperfect and simplified methods. **Implication for the longer-term initiative:** The results should be used to guide future priority-setting initiatives.

1.5 Risk Assessment Process

Risk is a function of both the likelihood of an event occurring, and the consequences (impacts) if that event occurs. Consequence is defined as a function of the hazard (where and how big is the event?), exposure (what's in the way), as well as vulnerability (how susceptible is it?). Figure 3 shows how risk is a function of both likelihood and consequence. Risk assessment is merely the process by which all these elements (hazard, consequence, etc.) are collected, combined and presented.

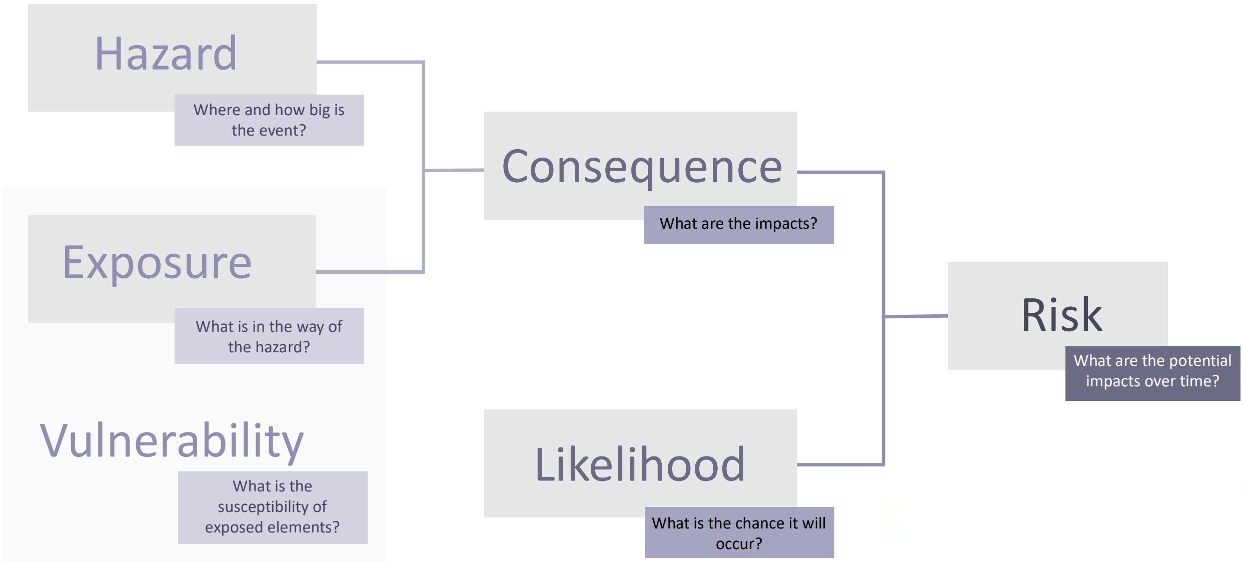

Figure 3: Risk as function of consequence and likelihood (simplified).

Key risk assessment concepts are discussed in the Basis of Study. This Quantitative Study follows the basic steps in Figure 3, with an emphasis on the hazard, exposure, consequence, and risk components. However, these basic components of risk include nuances that can be challenging to understand because they often vary in time and place. Additionally, it is difficult to articulate and make sense of the consequences. These challenges are addressed in this Quantitative Study by using a mapping technique that represents likelihood in terms of *hazard scenarios*, and consequence in terms of *exposure indicators*. The quantitative risk assessment method overview and components are summarized in Figure 4. Hazard scenarios and exposure indicators are further explained in Chapter 3 and Chapter 4, respectively.

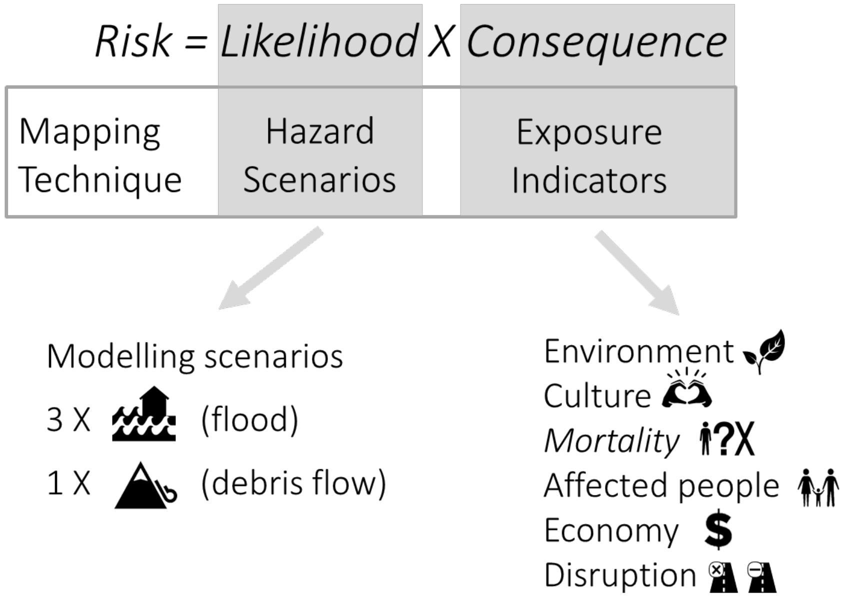

Figure 4: Quantitative risk assessment method overview and components.

1.6 Report Format

The remainder of this report is structured according to the following chapters. First, the available data sources and the means by which to assess confidence in them are discussed (Chapter 2). The methods to delineate the flood hazards, which were completed as part of separate flood and debris flow hazard assessments, are then summarized (Chapter 3). Then the data sources and the spatial processing method used to complete the exposure analysis are explained (Chapter 4), which forms the basis for the consequence analysis when overlaid with the hazard layers (Chapter 5). The quantitative consequences are discussed in terms of flood and debris flow hazards and are also separated for the Okanagan and Similkameen watersheds. Hazard likelihood and consequence layers are then scored to complete a risk assessment (Chapter 6), and the results are summarized in discussion as well as through risk matrices. This is followed by concluding thoughts (Chapter 7).

This report is heavily supported by the maps contained in the Map Book (Figure 1). This report contains the following three appendices:

- Appendix A – Data Summary
- Appendix B – Flood Hazard Assessment
- Appendix C – Debris Flow Hazard Assessment (produced by Palmer Environmental Consulting Group Inc.)

2 Available Data Sources

The data used for this study were wide-ranging and the data gathering process was a critical step. The following sections describe early phases of data gathering as well as confidence levels that were assigned to the final data.

2.1 Gap Analysis

Initially, a template of typical data used to support risk assessment (e.g. hazard data, exposure data) was prepared, and then in the early project stages, a process of evaluating and adding to this list was followed. The revised list better reflected the risk assessment needs for this project. For example, information needs were added that pertain to cultural values of relevance to the ONA and its member communities. A data information request spreadsheet was developed by Ebbwater and forwarded to identified individuals within the ONA member communities and external partners.

Based on the information gathering activities, a high-level analysis of data gaps was conducted using the data and information needs that was shared with project partners. Each line item in the data information request list was rated based on the following general priority criteria:

- **High priority:** Data has not been acquired, its availability or existence is unknown, and the data requirement is critical.
- **Moderately high priority:** Data availability, coverage, and consistency is unknown, and/or the data requirement is moderate.
- **Moderately low priority:** Data is likely available, but coverage is unknown, and data requirement is moderate.
- **Low priority:** Data has been acquired or is available, the coverage is likely adequate, and/or the data requirement is low.

Results from the prioritization exercise were used to guide continued data-gathering efforts. The datasets were then refined and analyzed as described in later sections. The final project data used are summarized in Appendix A. The QGIS software program[1] was used to view and analyze the majority of data. The program is an open-source geographic information system.

2.2 Confidence Levels

In the later stages of the project, Ebbwater applied confidence levels to the final datasets that were used in this study. Confidence levels provide an indication of the robustness of a risk assessment (AIDR, 2015). This is essential, as risk assessment outputs inform decisions, and decision makers should be aware of potential uncertainties in data. Further, data availability is a limitation in most risk assessments, and often, simplified proxies are required to describe an indicator.

Confidence levels communicate the different data quality levels in the risk assessment components and its results. They consider the reliability and relevance (AIDR, 2015). Confidence can be assessed for

[1] Quantum Geographic Information System (QGIS) is a free and open-source cross-platform desktop application that supports viewing, editing, and analysis of geospatial data. Weblink: https://qgis.org/en/site/.

consequence data and hazard/likelihood data separately, and then combined to obtain an overall risk confidence level.

Five confidence levels were used in the analysis (Table 2), which were loosely based on the AIDR guidelines (AIDR, 2015) and simplified for the purposes of this risk assessment.

Table 2: Confidence levels for consequence, simplified from AIDR (2015).

Confidence Level	Descriptor	Supporting evidence
Highest	Almost no uncertainty	Quantitative modelling/analysis with highest quality and length of data relating directly to the affected community and assessed hazard scenario.
High	Some uncertainty	Quantitative modelling/analysis with sufficient quality and length of data directly relevant to assessed hazard scenario.
Moderate	Significant uncertainty	Quantitative modelling/analysis with reasonable extrapolation of data required to derive results of direct relevance to the event being assessed.
Low	Major uncertainty	Quantitative modelling and analysis with extensive extrapolation of data required to derive results of relevance to the event being assessed.
Lowest	Fundamental uncertainty	No historical events or quantitative modelled results to support the levels

Considering that risk is the product of consequence times likelihood , the resulting risk confidence level is also calculated by combining consequence confidence levels with likelihood confidence levels (Table 3) (AIDR, 2015).

Table 3: Risk confidence level, as combination of consequence confidence level and likelihood confidence level (AIDR, 2015).

		Consequence Confidence Level				
		Lowest	**Low**	**Moderate**	**High**	**Highest**
Likelihood Confidence Level	**Highest**	Moderate	Moderate	High	Highest	Highest
	High	Moderate	Moderate	Moderate	High	Highest
	Moderate	Low	Moderate	Moderate	Moderate	High
	Low	Lowest	Low	Moderate	Moderate	Moderate
	Lowest	Lowest	Lowest	Low	Moderate	Moderate

The purpose of identifying confidence levels is two-fold. First, the confidence levels can be valuable in guiding prioritization of future data collection efforts in the region (i.e., efforts can be made to improve low confidence data sources). Second, confidence levels provide important qualitative information that can be considered in risk score comparisons. For example, if a particular risk score for an exposure indicator, hazard, or watershed appears to be lower or higher than expected, confidence levels can be considered as a potential source for discrepancies.

3 Hazard Scenarios

An assessment of hazard areas and the associated likelihood of hazard events are key components of a robust risk assessment. Flood and debris flow hazards are best estimated through the development of detailed topographical modelling combined with field assessments and ground-truthing. However, due to the scope limitations of this project, simplified approaches were developed and applied for each hazard.

The areas for each phenomenon were developed separately. While both hazards are governed largely by topographical factors, the data and methods used to characterize each hazard were distinct. The methods are summarized in the following sections, and are detailed in Appendix B and Appendix C, respectively.

3.1 Flood Hazard Areas

An iterative process was used to define flood hazard areas throughout the project's progress, applying different data and methods. In the early project stages, preliminary flood prone areas were delineated. In later stages of the project, an innovative approach was applied to delineate higher resolution flood hazard areas, based on multiple scenarios defined by hazard magnitudes.

3.1.1 Preliminary Flood Prone Areas

The flood prone areas were defined for the purpose of producing maps that would be available during the project's engagement events to obtain qualitative impacts information (see Qualitative Study). The preliminary flood prone area maps used existing data and methods as outlined in Table 4.

Table 4: Primary flood mapping sources and methods used.

Method	Description	Information Source
Historical flooded reach	This dataset represents watercourses where flooding has been observed historically (i.e., since 1808). The whole watercourse was identified due to a lack of documented specific flooded reach locations.	Septer (2006) with updates from Associated Environmental (2016, 2017)
Geology and soils mapping (GSM)	This method is based on a study that was developed and applied to the boundaries of the Regional District of Central Okanagan (RDCO) for the purpose of regional floodplain management planning. The method uses soil layers, aquifer, alluvial watercourses, to define likely flood extents for screening purposes. A validation was completed to extend the application of the method to cover this project's project area.	Associated Environmental (2016)

Method	Description	Information Source
Global floodplain mapping	This layer is based on a global flood plain study with 250 m resolution. The methodology uses Light Detection and Ranging (LiDAR) data, and the model was calibrated using flood prone zoning maps for Europe. The flood extents shown are high-level representations of the likely extent of an event with annual exceedance probability (AEP) of 0.5% (indicative return period of 1:200 years).	Nardi et al. (2019)

Further to the above, flood mapping based on hydraulic modelling was also reviewed for specific areas where this level of detail was available. The data were obtained from the Federal Disaster Reduction Program (FDRP)[2], the City of Kelowna (Associated Engineering Ltd., 2010), City of Armstrong[3], and the City of Penticton (Knight Piesold, 2017; Tetra Tech, 2018). The existing flood mapping, discussed above, that exists within the project area focuses mostly on population centres and does not cover smaller settlements and remote areas. More flood mapping is ongoing in the project area, such as the Okanagan Lakeshore Mapping Project. However, the results from that project were not available within the timeline of this project, and furthermore, it would have only filled a portion of the gaps within the large project area.

3.1.2 Geomorphic Flood Area

To fill in the gaps in flood mapping within the project area, without conducting resource- and time-intensive hydraulic modelling, several approaches were reviewed. The Ebbwater team adopted the Geomorphic Flood Area (GFA) approach as it satisfied this Quantitative Study's objectives in the following ways: 1) the approach could be consistently applied across the project area, and 2) for the risk analysis, it provided a means to define multiple flood scenarios, at a high-level.

The principal input for the GFA analysis is a digital elevation model (DEM), which provides information on the geomorphological characteristics of the watersheds. High-resolution DEMs derived from LiDAR data are beneficial for the analysis as they allow detailed capturing of topographical features. However, the project area's large extent meant that high DEM resolution required longer computer processing time. For this reason, the Canadian Digital Elevation Model (CDEM) for the region, with spatial resolution of approximately 15-23 m was used.

[2] Floodplain Maps by Region. Government of BC. Weblink: https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/drought-flooding-dikes-dams/integrated-flood-hazard-management/flood-hazard-land-use-management/floodplain-mapping/floodplain-maps-by-region.

[3] Kevin Bertles, Chief Administrative Officer for the City of Armstrong, personal communication. March 13, 2019.

The steps required to complete the GFA analysis included DEM pre-processing, calibration using existing floodplain maps, sensitivity analysis, and evaluation. Based on the DEM data input into the GFA program, a geomorphic flood index (GFI) threshold is calculated to identify flood boundaries.

3.1.3 Flood Scenarios

To complete a high-level risk assessment that acknowledged the importance of considering multiple likelihoods, three flood scenarios were developed based on the extents of low, moderate, and high magnitude events. A low magnitude flood may result in less damage, but as it occurs more frequently, cumulative damages over years could add up. On the other end of the spectrum, a high magnitude flood occurs more rarely, but is likely to result in catastrophic consequences. The GFI threshold, in conjunction with the existing flood maps, was used to develop the multiple flood scenarios. More details about this process are found in Appendix B, and Table 5 summarizes the GFI values used within the GFA program, along with the level of confidence associated with each hazard magnitude scenario.

Table 5: Flood hazard magnitude definition summary.

Scenario	GFI value	Level of Confidence
Low	-0.15	**Low** - Due to the lack of calibration data sources.
Moderate	-0.29	**Moderate** - The FDRP provide consistent, high quality calibration source. However, the modelling approach is considered relatively high level.
High	-0.43	**Low** - Due to the lack of high-quality calibration data sources.

While a full probabilistic risk assessment would require more flood scenarios and was out of scope for this high-level assessment, the three flood scenarios provided a good first approximation to assess potential flood consequences for multiple event magnitudes.

3.2 Debris Flow Hazard Areas

Debris flow hazard was assessed at a basin-wide, overview level, through a systematic, multi-step process. Desktop modelling was used to generate a spatially contiguous evaluation of debris flow initiation susceptibility across the landscape, using existing datasets. Select test areas were examined independently based on interpretation of aerial photographs. Visible debris flow initiation zones were mapped manually to create a local debris flow inventory. The results of the inventory were used to validate the debris flow initiation susceptibility model.

Generalized debris flow path modelling was completed to extend the area of high and very high initiation susceptibility down slope to identify areas potentially affected by debris flows. The model output classified the project area by debris flow initiation susceptibility and highlighted potential debris flow paths for use in the risk assessment. Additional details are found in Appendix C.

There is a good degree of confidence in the debris flow initiation zones as these used a scientific modelling approach which was validated using real events. The flow paths have a lower degree of confidence as the approach is considered more high-level. For this reason, the confidence score for this hazard was deemed Moderate.

Unlike for flood hazard, multiple scenarios were not defined for debris flow hazard. This was constrained by a lack of suitable data and continuous monitoring record, the labour-intensive effort required to fill the gaps and perform such analyses (including site-specific investigations). The associated modelling and analysis that would have been required to be completed for the project area was outside of the scope of this study.

3.3 Hazards Summary

The 3 flood magnitude hazard areas and debris flow hazard areas are shown in Figure 5, and more detailed maps are included in the Map Book. The total extent of debris flow hazard areas (beige colour in Figure 5) is much larger compared to the flood hazard areas. This makes sense as debris flows initiate on hillslopes, which cover a larger area compared to creek and river channels, where floods occur.

In viewing Figure 5, readers should use caution and consider the following:

- While the flood and debris flow hazard areas delineated may appear to be extensive, the processes that drive the hazard events occur on smaller scales than the project area. Therefore, not all of the areas shown are hazardous at the same time.
- While the approach considered multiple scenarios for flood, the data available to characterize these likelihoods meant that the analysis was high-level. Since no such analysis was completed with debris flow hazard areas, the understanding of the probability of the mapped debris flow hazard events occurring remains qualitative.

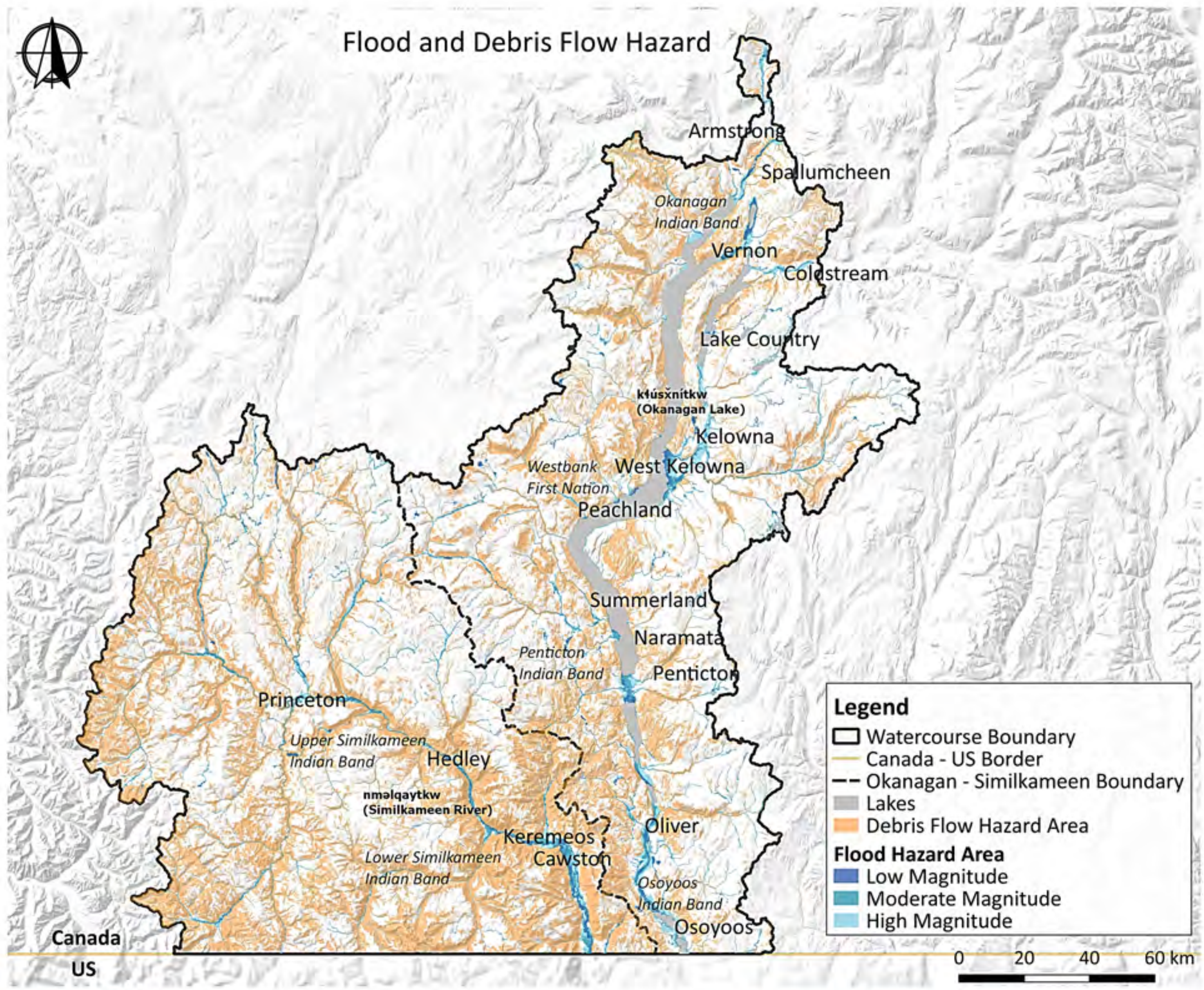

Figure 5: Flood and debris flow hazard areas.

The hazard maps were used in both the Qualitative and Quantitative analyses. The Qualitative Study describes how the maps were used to gather information on how project participants were recently impacted, or could be impacted, in the future.

In the quantitative analyses, the hazard layers were used to provide spatial boundaries for the exposure data (see Section 4.1), from which overlapping data was aggregated to calculate consequences (Chapter 5). For risk scoring, the hazard layers were assigned likelihood scores and consequence scores (see Section 6.1).

4 Exposure Indicators

A key component of a 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 be affected (the consequences or impacts). Within this project, the term “impacts” is used when describing exposure qualitatively. In this Quantitative Study, the term “consequence” is used to differentiate the exposure data source’s numerical characteristics.

The Basis of Study describes the importance of capturing a range of exposures. For this project, the following six indicators were considered: environment, culture, mortality (considered for debris flow hazard only), affected people, economy, and disruption. However, the way consequences are measured matters. It is important to think carefully about the quantitative measures used to represent exposure, rather than simply relying on easily calculated indicators. Table 6 lists the 6 consequence indicators as well as a summary of the supporting proxy data that was used in the analyses for each. A full list of exposure data and their sources is provided in Appendix A.

Table 6: Consequence indicators, and summary of supporting spatial proxy data used.

Indicator	Supporting Proxy Data
Environment	Contamination sources Environmental receptors
Culture	Cultural buildings *Syilx* and non-*Syilx* archaeological sites
Mortality	Building footprints

Indicator	Supporting Proxy Data
Affected People	Census dissemination areas Building footprints
Environment	Property assessments Building footprints
Disruption	Major and minor roads, rail, gas, electricity infrastructure, and telecommunications

The spatial data were used as follows to assess consequences:

- For each indicator, one or more proxies were developed to represent the key asset(s) of that indicator.
- Quantitative measures, which are detailed in Chapter 5, were established for each data proxy.
- Consequences were determined for each indicator by spatially calculating proxy data results using the quantitative measures.

Section 4.2 describes the proxies used for each indicator, and Chapter 5 details the quantitative consequences that were determined. The following sections outline how the exposure data were spatially processed considering the hazards.

4.1 Spatial Data Processing

For each indicator, the relevant proxy datasets were overlaid with each of the flood and debris flow hazard map layers separately, to identify assets overlapping with each hazard area.

Separate files were created for each hazard (flood hazard contained three magnitudes), which were used to select the exposure datasets as follows:

$$Hazard\ file\ (flood \times 3, debris\ flow)\ *Select*\ Exposure\ layer\ (for\ each\ indicator)$$

An example of this process is shown in Figure 6, which shows selected land parcels and building footprints for each of the 3 flood scenarios. In general, the asset layer (in this case, land parcels and building footprints) was affected by the hazard if any part of the asset intersected with the hazard layer. In cases where asset layers were very large (e.g., census areas or transport infrastructure, not shown in Figure 6), the exposure layers were clipped to identify the percentage of the asset affected by the hazard layer.

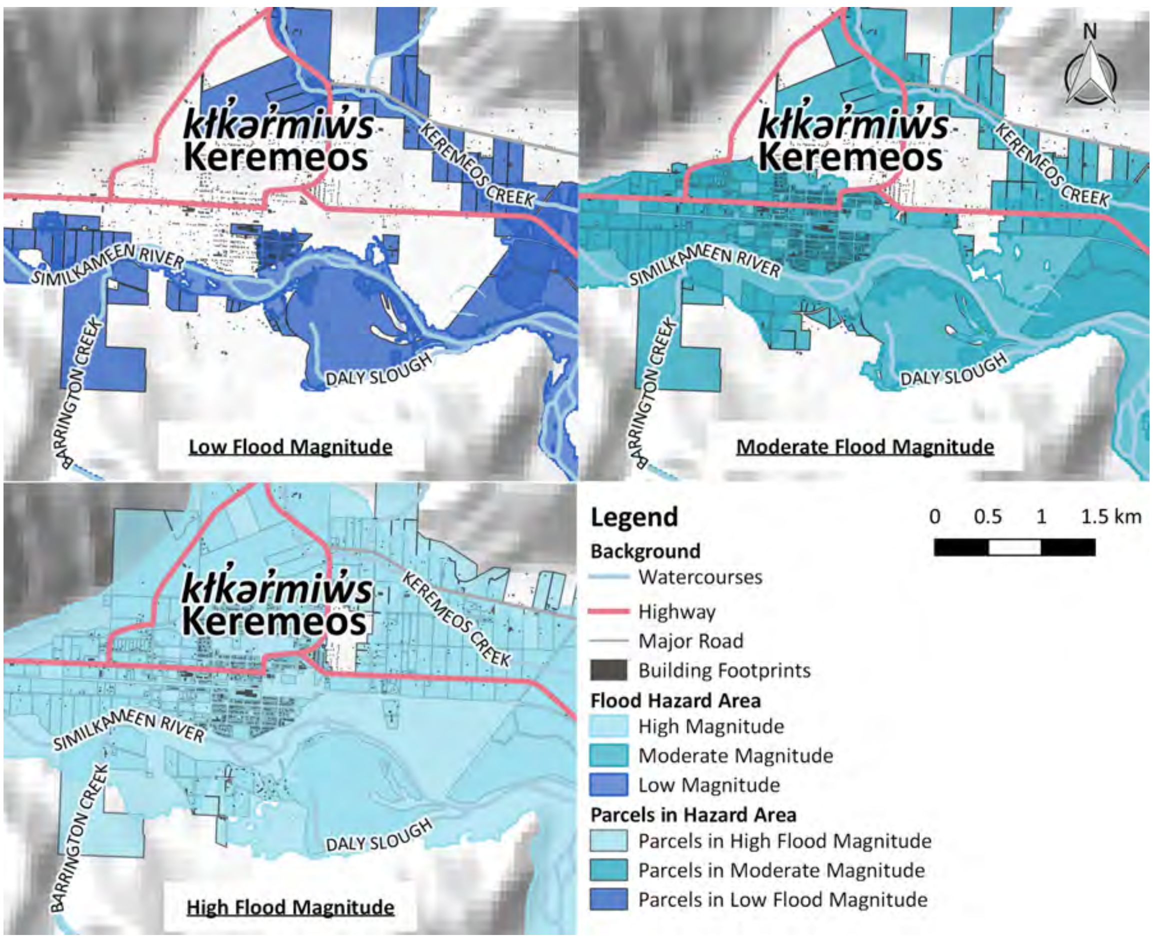

Figure 6: Example spatial data processing showing land parcels and building footprints in each of the three flood hazard magnitude areas. Darker colours show areas of overlap.

4.2 Exposure Data Sources

The following sections explain the proxies that were used to represent the various indicators. Tables at the end of each section discuss the limitations and opportunities for improvement related to the data and methods described, along with a confidence level rating and rationale.

4.2.1 Environment

The project area contains environments that are sensitive and diverse. Approximately 13% of land in the Okanagan-Similkameen watersheds is classified as having high or very high relative biodiversity[4]. Furthermore, many of the biodiversity hotspots occur in the valley bottoms. The fact that these areas occur in areas subject to flood and debris flow is no coincidence: habitat diversity results from the constant destruction and creation of habitat, which is caused by natural phenomena such as flood and debris flow (see Basis of Study for a more detailed discussion). For a more holistic perspective of environmental impacts, refer to the Qualitative Study.

Without disregarding the known positive benefits of natural hazards on ecosystems, this Quantitative Study focused on the negative consequences of flood and debris flow on the environment due to contamination. The mobilization, dispersion, and interaction of contaminants released to the receiving environment following a natural hazard event is complex. The significant effort including modelling required to fully understand these processes was out of the scope of this project. Instead, a conceptual and conservative method was developed based on the source-pathway-receptor contaminant model. Datasets were developed that were representative of a broad set of potential sources of contamination, as well as the environmental receptors that those contaminants could negatively affect.

Contamination Sources

Contamination data were obtained from three sources: land use data from the BC Assessment Authority (BCA)[5], monitoring data from the BC Environmental Monitoring System (EMS)[6], and septic tank locations obtained from the Interior Health Authority (IHA)[7]. The BCA data were screened based on their potential for landuse contamination and included transport, heavy industry and mining, manufacturing, storage, sewer, and waste and landfill sites. These data were combined with the EMS data. Sites classified as "active" within the EMS were screened based on their potential for contamination and included sewer, landfill, open burning, seepage pool, industrial, and contaminated sites. Combining these two data sets resulted in 942 potential sources of contamination.

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[4] Okanagan Biodiversity Strategy. Okanagan Collaborative Conservation Program. Weblink: http://okcp.ca/index.php/projects/current-projects/532-okanagan-biodiversity-strategy. Accessed May 15, 2019.

[5] Data were obtained with help from Haley O'Neil, Disaster Mitigation Branch, EMBC.

[6] Environmental Monitoring System. Government of BC. Weblink: https://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring/environmental-monitoring-system. Accessed April 2, 2019.

[7] Carol Leung. Environmental Health Officer, Interior Health BC. Personal communication. March 6, 2019.

A large number of properties in the project area are on a septic sewer system, which is a potential major source of contamination. The approximate location of 4,918 septic systems within the project area were obtained from the IHA. However, many of the records for older systems are still in paper format and the provided list is not complete. It was also noted that the locations are representative of the septic systems; therefore, the actual septic tank locations were assumed to be in the vicinity of the septic systems.

Pathway

Within the source-pathway-receptor model approach used, the pathway component was the most simplified. The contaminants were assumed to be transported and dispersed radially and equally on the terrain surface. Initial and final contaminant concentrations were not considered.

Environmental Receptors

Three potential environmental receptors were used: fish observations and distributions, drinking water wells, and high and very high biodiversity areas. The first two datasets were obtained from the BC Government, and third was obtained from the Okanagan Collaborative Conservation Program (OCCP)[8]. The three receptors were chosen to be representative for the project area as they cover sensitive land, water, and ground water systems. However, the datasets should not be considered comprehensive and they each have significant limitations. For example, the fish observation dataset is a collection of many Provincial datasets, however it is only accurate for the specific time of the surveys or observations. It is also limited by the number and methodologies of the surveys or observations.

Summary

The data proxies used within the source-pathway-receptor model approach were mapped using assumptions and applying spatial analysis functions in QGIS (Table 7). The pathway assumptions were included within those for contaminant sources and environmental receptors. Figure 6 illustrates the components of the conceptual model.

Table 7: Source and receptor component assumptions.

Component	Assumption
Contamination Sources	A 2 km buffer was used to assume the distance that a contaminant could be transported from its source if it overlapped with a flood or debris flow hazard area.
Environmental Receptors	A 1 km buffer was used around fish observations and drinking water wells to represent the potential migration of fish and the larger size of aquifers associated with drinking water wells. The high biodiversity areas were mapped as they were originally obtained.

[8] Okanagan Biodiversity Strategy. Okanagan Collaborative Conservation Program. Weblink: http://okcp.ca/index.php/projects/current-projects/532-okanagan-biodiversity-strategy. Accessed May 15, 2019.

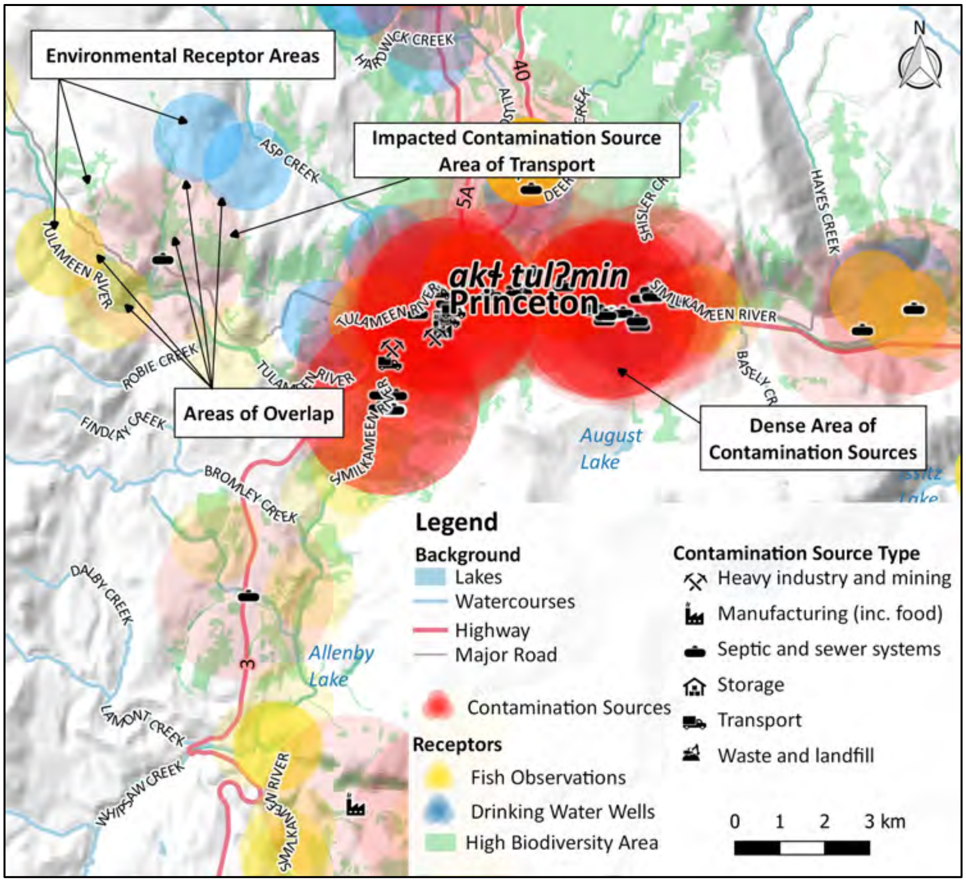


Figure 7: Conceptual model used for establishing overlap between contamination sources and environmental receptors.

If a contamination source location overlapped with the area of an environmental receptor (e.g. red areas overlapping with a yellow, blue, or green area in Figure 7), the whole receptor was considered to be contaminated. Although this is likely to produce an overestimate of contaminated areas, the approach considered that ecosystems are complex and interconnected; impacts in one area could lead to knock-on impacts elsewhere. The approach was conservative in identifying more rather than fewer impacted areas.

Limitations and opportunities for future improvement
• The severities of different sources of contamination were not distinguished. There are several potential major sources of contamination across the project area including mining sites, landfill, and contaminated sites. More detailed review of these individual sites could be considered as scope for future study. • There are clear overlaps between the environment and the economy indicators. When and where datasets allow, ecosystem services should be valued within the economy indicator consequences. Environmental elements that cannot be valued (e.g., intrinsic values), should remain within the environment indicator consequences analysis. • Sub-surface contaminant sources such as septic systems may be more vulnerable to floods compared to debris flow hazards. The approach of this assessment assumed that interactions occur at the terrain surface and did not capture this type of nuance.

Confidence Level Rating: Low
While there is good spatial data for both contaminants and environmental receptors, the approach used to measure the release, transport, and effects of these contaminants on the receptors is considered very high-level. Further study could consider a more detailed review focused on areas with high levels of severe contaminants and sensitive environmental receptors.

4.2.2 Culture

Flood and debris flow can impact a community's culture. The impacts may be tangible and quantified (e.g., damage to specific cultural sites) or intangible and unquantified (e.g., changes to the community caused by people moving away). For the culture indicator, this Quantitative Study focused on consequences based on the potential loss of culturally important sites.

Cultural sites were selected that are likely to have high social value to a community. This includes heritage and archaeological sites, indoor and outdoor recreational sites, community centres, care centres, and educational buildings. These cultural sites can obviously only capture part of what forms the culture of a community, but they can provide an indication of potential cultural consequences of natural hazards.

Syilx Okanagan and non-*Syilx* Okanagan archaeological and historic sites were obtained from the Provincial Remote Access Archaeology Database (RAAD)[9]. Cultural buildings were reviewed using the BCA land use data.

A large part of the local culture depends on access to the outdoors. Therefore, in addition to outdoor recreational sites such as parks and campgrounds, trails obtained from the Provincial Road Atlas[10] were also included. This includes hiking, cycling, motocross riding, snowmobiling, and skiing trails.

[9] Remote Access to Archaeological Data (RAAD). BC Government. Weblink: https://www2.gov.bc.ca/gov/content/industry/natural-resource-use/archaeology/data-site-records/raad. Accessed June 3, 2019.

[10] Digital Road Atlas. Government of BC. Weblink: https://www2.gov.bc.ca/gov/content/data/geographic-data-services/topographic-data/roads. Accessed April 15, 2019.

Limitations and opportunities for future improvement
• Information in the RAAD has been shown to be incomplete, out-of-date, and inaccurate (i.e., some mapped locations are more than 100 m away from the true location)[11]. The dataset contains records of known, explored archeological sites, and is therefore concentrated around developed areas including valleys. However, it is known that *Syilx* Okanagan people have used the headlands for generations and that there are likely to be many more culturally important sites in these areas that are not included in the database. Therefore, there is a very low confidence from *Syilx* Okanagan people in the database. • It is understood that the ability for *Syilx* Okanagan people to carry out cultural practices such as accessing harvesting locations has high cultural value. For sensitivity reasons, the locations of these sites are not available and have not been included in this analysis.
Confidence Level Rating: Moderate
There is moderate confidence in the datasets used due to their lower reliability. Furthermore, there are likely many more sites that are of cultural importance to the community.

4.2.3 Mortality

Mortality describes the number of deaths and missing persons due to a natural hazard event. This exposure indicator was assessed for debris flow hazards only, due to their rapid onset and destruction potential, which has caused deaths in Canada (NRCan, 2017). Mortality from floods, in contrast, is rare generally because of their slower onset providing warning time for evacuation. Mortality related to flooding is also often more complex and related to secondary effects such as bank erosion or ill health. For these reasons, the mortality exposure indicator was considered negligible and not considered.

For debris flow, the number of residential buildings in the project area was used as a proxy for mortality. Residential buildings were intended to represent potential exposure to people, as most people spend the majority of their time in their homes. It is not a perfect representation of exposed people because of the many variables noted in the table below, but it is considered robust enough to provide an indication of exposed population.

Building footprints were obtained from various local governments; however, there were significant gaps, especially in the areas of *Syilx* Okanagan communities. Gaps in building footprints were filled for the entire project area, using a subconsultant who digitized footprints based on Bing satellite imagery. Also, there was no consistent data on building types for the entire project area to estimate the proportion of buildings that were residential. For this estimate, a factor of 0.89 was applied to the total building number. This factor was based on the average proportion of buildings that were classified as being residential in the RDCO, whose dataset contained consistent and complete building types data.

[11] Wendy Hawkes. Referrals Coordinator, Lower Similkameen Indian Band. Personal Communication. March 4, 2019.

Limitations and opportunities for future improvement
• An assumption in the use of residential buildings as a proxy for mortality is that this approximates the number of people affected. The accuracy of the assumption is dependent on the location within the project area. For example, occupancy may vary in time (e.g., people move between different places in a day, week, or year), and based on location (i.e., developed areas house more people per home compared to undeveloped areas). • Future studies could consider warning, evacuation, and social vulnerability factors (e.g., demographics, resident versus tourist, etc.) that could affect mortality. • A further assumption of this proxy is that all residential buildings within the hazard area result in mortality during a debris flow event (i.e., a mortality rate is not applied). While this is an overestimation, the proxy gives an indication of the potential scale and distribution of the resultant impact. Specific formulas could be applied to estimate risk of mortality, such as that described in Jakob et al. (2013).
Confidence Level Rating: Lowest
While the spatial data is very good there is no relationship between the presence of the hazard and the likelihood of mortality impacts.

4.2.4 Affected People

The number of people affected by flood and debris flow hazards can be related to lost shelter, employment, schooling, etc. These proxies are used to measure the broader impacts to society, when the supporting data is available. For this study, the number of people affected was mapped exclusively using the most recent (2016) Canadian Census data[12]. However, the data was checked using building footprint data and applying an assumption for the number of occupants in residential buildings. This assumption is further explained in Section 5.4.1.

The maps for this indicator show the relative population density of different parts of the project area that may be affected by flood or debris flow. However, the census data population is not well represented in rural areas. This is because dissemination areas are relatively large compared to hazard areas and the census data does not capture the spatial distribution of people within them. The number of people affected was therefore calculated based on multiplying the total number of people within the dissemination area with the proportion of the area overlapping the hazard area.

For the purpose of this study, the census areas that spanned both the Okanagan and Similkameen watersheds were wholly assigned to the watershed containing the majority of the hazard area. In other words, census areas were not split if they crossed the boundary between the two watersheds.

[12] Census Profile. Statistics Canada. Weblink: https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/index.cfm?Lang=E. Accessed March 15, 2019.

Limitations and opportunities for future improvement
• The results show the areas where people "live", rather than the areas they use. This does not consider that some people spend significant amounts of time outside of their homes. *Syilx* Okanagan people spend time on the land, away from their "homes" in hunting and fishing camps. Also, on a seasonal basis, a portion of the region's population frequents camping and recreational areas. The approach taken was in part chosen to avoid double-counting as some of this information is captured in the culture and disruption indicators. • Census data does not follow watershed boundaries, making it difficult to accurately estimate the number of people that reside in areas of natural hazards that are governed by watershed processes. • The analysis does not consider indirect impacts to people who are assumed to be outside of the hazard area. From this perspective, the number of affected people could be greater than the numbers reported. • Characteristics such as the duration of hazards, if they were considered, could increase understanding of the severity of consequences to people.
Confidence Level Rating: Moderate
There were identified weaknesses in the recent census data related to overlapping with hazard areas; however, these were checked and validated using good quality building footprint data.

4.2.5 Economy

This indicator represents potential economic loss resulting from a natural hazard. This includes primarily direct damage and reconstruction costs to public and private buildings as proxies. It can however also include indirect economic losses, such as emergency response costs and economic losses due to disruption of business operation. The indicator is typically reported in dollars of damage. In this study, the direct economic consequences related to exposed buildings is based on BCA building values.

To estimate building damage in dollars, depth-damage curves are often used, particularly for flood hazard. Depth-damage curves relate water depth and building damage, based on building characteristics (such as building material, number of floors, basement, etc.). However, detailed and reliable data are required for this analysis, which were not available consistently for all buildings throughout the project area. Existing depth-damage curves were developed for other jurisdictions in Canada (IBI Group, 2015), the US (FEMA, 2008), and the UK, where local conditions and building types are much different from the project area. Therefore, the curves are not readily transferable. Based on these data and methodological limitations, the total building values were used as a simple proxy.

The BCA data was used differently, depending on the hazard, due to the difference in nature of the two as follows:

- **Flood:** Used building value only (i.e., not total land values). It was assumed that when the water recedes, the majority of the damage will have occurred to the property infrastructure, and not to the land.

- **Debris flow:** Used total land values (i.e., building and land). It was assumed that events are likely to cause the land to lose value, as land surface and infrastructure are likely to be severely damaged and debris is likely to remain across the land. The amount of land that loses value was assumed to be proportional to the land parcel area that overlaps with the hazard area.

Where data was available from BCA, the official assessment fabric was used as a special representation of the exposure. However, BCA does not include complete land and building value information for First Nation Reserves. For these locations, average property values obtained from the BCA where available, were applied to the building footprints.

Limitations and opportunities for future improvement
• Indirect economic consequences were not considered but they can be substantial. • More information related to at least three areas should be investigated and integrated in the future: fisheries, tourism, and ecosystem services.
Confidence Level Rating: Low
Available data was limited; therefore, only total building damages were accounted.

4.2.6 Disruption

This indicator describes damage to critical infrastructure and disruption of basic services, which can potentially have more widely spread cascading effects on society. This can include damages to health facilities, emergency response facilities, governmental facilities, educational facilities, transportation infrastructure, roads, electrical systems, sewer pumps, etc. Spatially, disruption impacts can be different in rural versus urban communities. Rural communities have less redundancy in critical facilities—they are often only serviced by a single road or power supply. Therefore, damages to these systems can have large consequences.

The following proxies to measure direct consequences for this indicator, based on data that was available consistently across the region, were used: roads, rail, gas and electric structures, and electric powerlines. These systems are highly linked to other areas of disruption. For example, disruption to roads could mean that critical facilities are not accessible, or disruption to power may affect their ability to function.

Road and railway data was obtained from provincial datasets. As local roads are likely to have easy alternate routes, only major roads were considered. For simplification, it was assumed that major roads would represent the majority of road-related consequences. Major roads were divided further into three categories: highway, arterial, and collector.

Utilities data was obtained from the Integrated Cadastral Information (ICI) Society[13], through EMBC. The data was reviewed to establish the most important assets. It was assumed that underground assets are unlikely to be affected by flood or debris flow hazards. All gas and electric structures apart from poles

[13] Integrated Cadastral Information Society. Weblink: https://www.icisociety.ca/services/.

were included as it was assumed that damage to these structures is likely to have a large impact on the network. Primary overhead cables were included for debris flow only; it was assumed that those lines are unlikely to be damaged during a flood.

Limitations and opportunities for future improvement

- Critical infrastructure facilities including hospitals, water, and wastewater infrastructure were not included in the analysis due to lack of available and consistent data. They should be included where possible.
- The hazard mapping included dike sections and the locations of 299 active dams in the project area and their dam consequence ratings. However, consideration of the consequences of dam breach were out of the scope of this project. Dike risk assessments have been completed or are currently being completed in BC. Future risk studies should consider these dam and dike risk studies.
- Cascading effects could be considered based on a dependency analysis of linear infrastructure networks. This type of analysis could consider how damage from a hazard event affecting an “upstream” network location could affect other parts of the network that are linked “downstream”.
- For road infrastructure, the severity of disruption is dependent on the capacity of the culverts and crossings. For example, if there is a high bridge with sufficient cross-sectional area above the flood water level for debris to pass through, then the possibility of blockage 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. These details were not considered in the assessment. They would be more feasible and worthwhile to include in smaller-scale studies.

Confidence Level Rating: Moderate

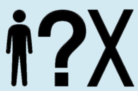
A wide range of proxy data was used with good spatial information. However, there are some important critical infrastructure assets missing.

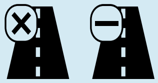
4.3 Summary of Exposure

Table 8 contains an overview of the indicators and proxies including the overall confidence levels. The table also summarizes the quantitative measures and assumptions used in the consequence analysis, which is presented in the following section.

Table 8: Summary of indicator proxy data quantification measures and assumptions.

Indicator and Proxies	Quantitative Measure	Assumption
	Environment **Confidence Level: Low**	
Contamination sources	*2 km buffer around sources (range of industries/landuse/activities such as mining, manufacturing, septic systems).*	*Where they overlap with hazards, contaminants could be transported radially from their source.*

Indicator and Proxies	Quantitative Measure	Assumption
Environmental receptors	*1 km buffer around receptors (fish observations and drinking water wells, are high biodiversity areas).*	*Where these areas overlap with a buffered contaminant source, the receptor is contaminated.*
	**Culture** **Confidence Level: Moderate**	
Culturally important sites	*# of cultural sites (heritage, recreational, community, care, and educational centres/areas).*	*Cultural sites are representative community cultural elements.*
Syilx Okanagan and non-Syilx Okanagan archaeology	*# of sites.*	*Archeological sites are representative community cultural elements.*
	**Mortality** **Confidence Level: Low**	
Flood: Assume no mortality	*Not presented.*	*No mortality directly associated with flood hazard.*
Debris flow: Residential buildings, based on building footprints	*Estimated number of people in residential buildings.*	*People's locations overlap with hazard based on location of their homes.*
	**Affected People** **Confidence Level: Moderate**	
Census dissemination areas	*Number of people, based on population density of dissemination area. that is proportional to the size of the dissemination area that overlaps with the hazard.*	*The number of people is proportional to the area of census locations that overlap with hazard areas.*
	**Economy** **Confidence Level: Moderate**	
Flood: Building value	*Total improved value ($) for all buildings in flood extent.*	*Floods damage 100% of buildings that overlap hazard area, but not the land (conservative estimate).*
Debris Flow: Building and property value	*Total improved value ($) for all buildings in flood extent, and total land value ($).*	*Debris flows damage 100% of buildings that overlap the hazard area, as well as the proportion of the land parcel that overlaps the hazard area (conservative estimate).*

Indicator and Proxies	Quantitative Measure	Assumption
	**Disruption** **Confidence Level: Moderate**	
Roads and railways	*# of kilometres of affected highway, arterial, and collector roads. # of kilometers of affected rail.*	*Flood and debris flow hazards directly affect portions of road and rail.*
Utilities	*# of gas and electric structures.*	*Flood and debris flow hazards directly affect gas and electric structures.*

A variety of exposure datasets were used as proxies for the six exposure indicators. The data used were selected based on their availability, consistency across the project area, and relevance. Quantitative measures, and their assumptions, were developed to enable a comparison of consequences across hazard scenarios and watersheds.

5 Consequence Analysis

This Chapter discusses the results of the consequence analyses, by applying the quantitative measures summarized in Table 8. The tabular results for each indicator are discussed separately for flood and debris flow. The tabular results are relative to the totals for each watershed individually. For flood, the tables include results for the 3 scenarios. To simplify the discussion of consequences from flood, the map figures show only results for the moderate flood scenario.

In this section, comparisons are made between flood and debris flow hazard scenarios. However, since these two phenomena are distinct natural processes, they were modelled using different techniques. Due to these differences, the comparisons are made in *relative* terms to inform high-level discussions on prioritization of adaptation efforts.

Map figures at 1:400,000 scale are included in this section to comment on spatial patterns observed in the Okanagan and Similkameen watersheds. The figures also include smaller-scale subset areas (i.e., boxes 1 to 5, at 1:150,000 scale). These areas were selected to facilitate the discussion of consequences for locations of higher population, and that included *Syilx* Okanagan communities. However, these areas are not always those having the greatest consequences and the intent was not to draw undo attention to them relative to other areas. All the map figures shown in this Chapter are also found in the Map Book, which additionally contains the highest-resolution maps (1:50,000 scale) produced for this project.

The map figures presented are high-level representations of the exposure to flood and debris flow hazards. The mapped consequences correspond to the aggregated hazard areas across the Okanagan-Similkameen region, as if the hazards were happening simultaneously. In reality, the hazards are likely to occur in a fraction of the project area during one event. Therefore, the mapped consequences from individual events would be much lower than what is reported.

5.1 Environment

Consequences to the environment are widespread throughout both watersheds, and for both hazards. For both hazards, the consequence patterns follow population centres and riparian areas.

5.1.1 Flood

Table 9 provides a summary of the environment indicator consequences from flood hazards.

Table 9: Summary of environment indicator consequences from flood hazard.

Watershed	Scenario (Hazard Magnitude)	Contaminants		Receptors Affected					
				Drinking Water Wells		Fish Observation Locations		High Biodiversity Areas	
		No.	% of total	No.	% of total	No.	% of total	Ha.	% of total
Okanagan	High	1,838	35%	163	90%	8,635	59%	90,838	100%
	Moderate	1,061	20%	155	85%	6,766	46%	86,520	95%
	Low	652	12%	146	80%	6,186	42%	83,111	91%

Watershed	Scenario (Hazard Magnitude)	Contaminants		Receptors Affected					
				Drinking Water Wells		Fish Observation Locations		High Biodiversity Areas	
		No.	% of total	No.	% of total	No.	% of total	Ha.	% of total
Similkameen	High	428	71%	35	81%	2,803	38%	48,821	93%
	Moderate	296	49%	36	84%	2,759	37%	42,649	81%
	Low	102	17%	33	77%	2,417	32%	40,010	76%

Okanagan

There is a large potential for environmental consequences in the Okanagan watershed, including contamination of drinking water wells and high biodiversity areas. In particular, 80% of locations are potentially affected in even the low flood scenario (Table 9). This is due to the high number of potential contaminants within the hazard area. As discussed in Section 4.2, however, this is a conservative estimate and does not take into account the release and transport of these contaminants, or local protection measures (such as storing potential contaminating materials above flood levels). In terms of environmental receptors (also referred to as environmental assets), they are concentrated at the bottom of valleys, within the floodplain.

Table 9 shows that consequences are concentrated within the centre of the project area, following the lakes that run through the centre of the watershed. Unsurprisingly, contaminants are concentrated at the population centres such as Vernon, Kelowna, Penticton and Oliver, which appear as darker shades of red. While the receptors are generally evenly spread throughout the affected area, there are a large number of drinking water wells potentially affected around Vernon (Box 1) and the District of Lake Country (Box 2). Drinking water wells are important potential receptors and may warrant further investigation.

Similkameen

Consequences in the Similkameen are similar in relative magnitude to those in the Okanagan with a very high percentage of environmental assets potentially affected. As shown in Table 9, the two major population centres of Princeton and Keremeos are the locations having the main sources of contaminants. There are also significant sources located north of Princeton and along Highway 3 between Princeton and Keremeos. Apart from Copper Mountain Mine (active) and Headley Mine (decommissioned), the majority of contaminant sources outside of Princeton and Keremeos are septic tank systems.

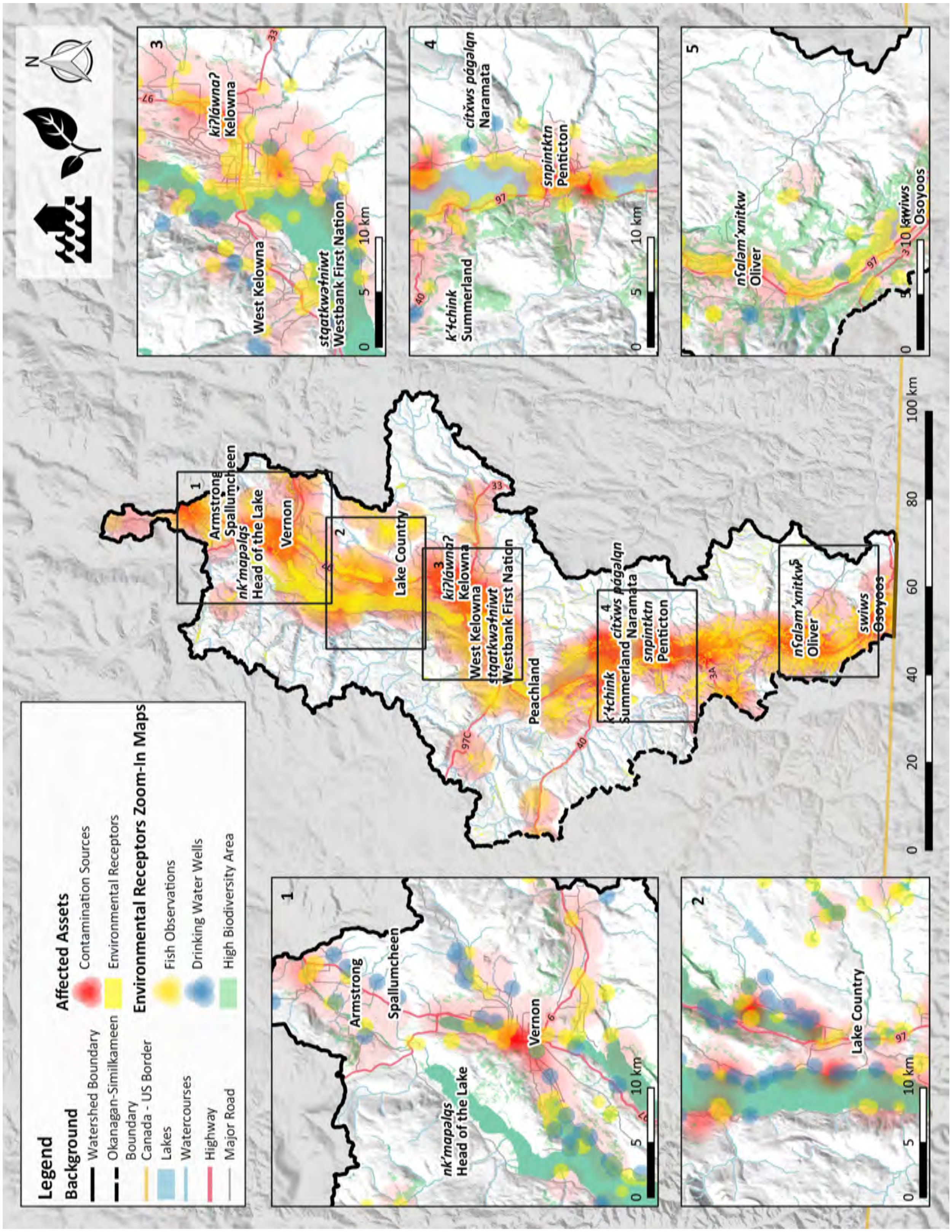


Figure 8: Environment indicator consequences from moderate flood hazard in the Okanagan.

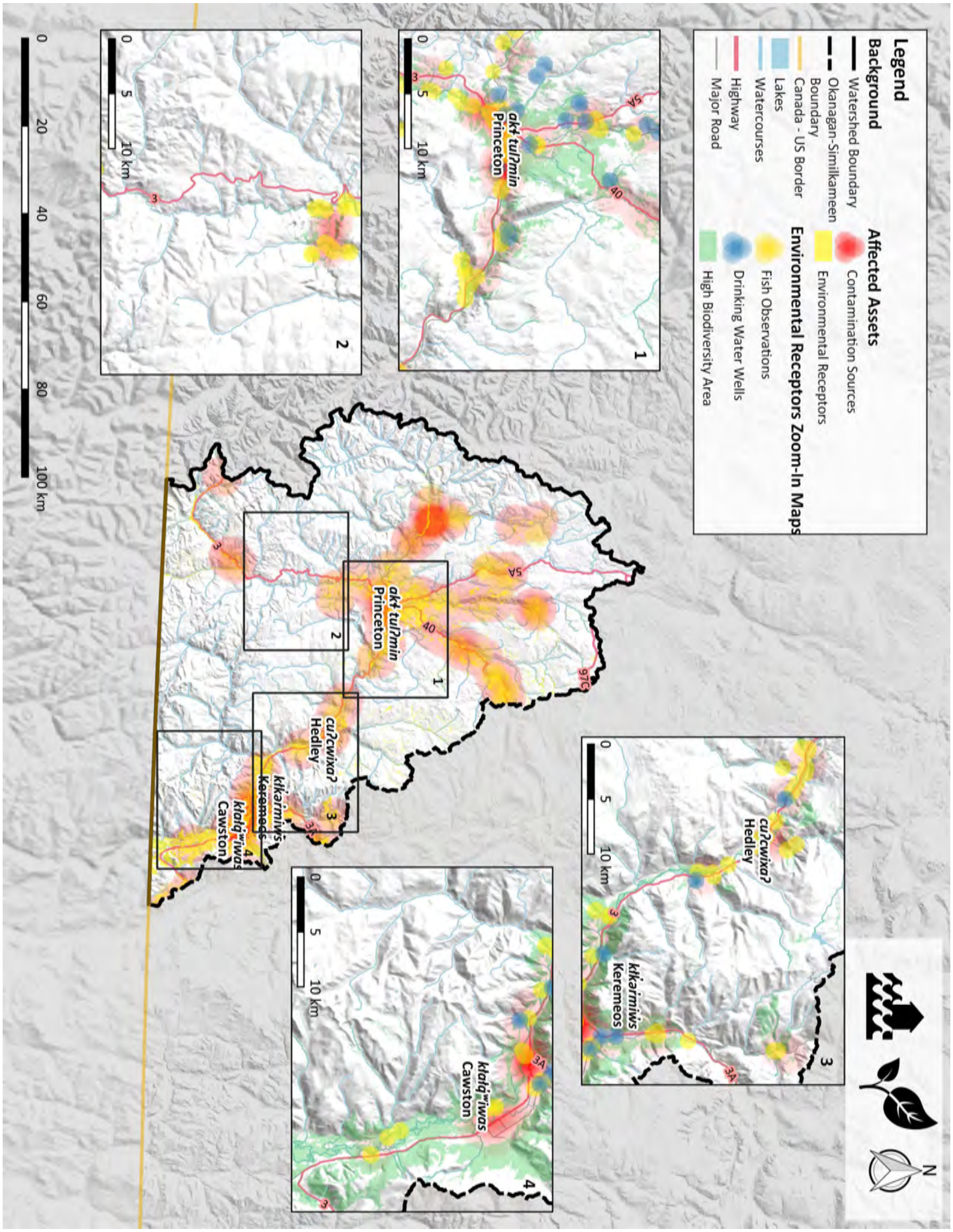


Figure 9: Environment indicator consequences from moderate flood hazard in the Similkameen.

5.1.2 Debris Flow

A summary of environment indicator consequences from debris flow is provided in Table 10. Consequences from debris flow are similar to that of the high flood scenario. While the number of contaminants and the consequences to fish are lower, all high biodiversity areas in both watersheds are affected as well as a greater number of drinking water wells in both watersheds, compared to the moderate flood scenario.

Table 10: Summary of environmental indicator consequences from debris flow hazard.

Watershed	Contaminants		Receptors Affected					
			Drinking Water Wells		Fish Observation Locations		High Biodiversity Areas	
	No.	% of total	No.	% of total	No.	% of total	Ha	% of total
Okanagan	1,751	33%	172	95%	6509	45%	90,838	100%
Similkameen	217	36%	366	84%	3298	44%	52,779	100%

Okanagan

The spatial distribution of consequences is also similar to those for flood. When comparing the consequence maps in Figure 8 to Figure 10 , the majority of the consequences occur within the centre of the watershed, along the mainstem lakes. However, there is a notably higher concentration of contaminants east of Vernon corresponding to debris flow compared to flood. This is due to the high number of septic systems in the area that are in the way of debris flow hazards, compared to flood hazards. Note that while debris flows may interact with surface components of septic systems, such as storage tanks, sub-surface components may be more vulnerable to flood hazards.

Similkameen

The number of contaminants within the debris flow hazard area (i.e. 217) in this watershed is much lower than that for the moderate flood scenario (i.e. 301). However, as shown in Figure 11, these contaminants cover a larger area, so the number of environmental receptors potentially affected is larger.

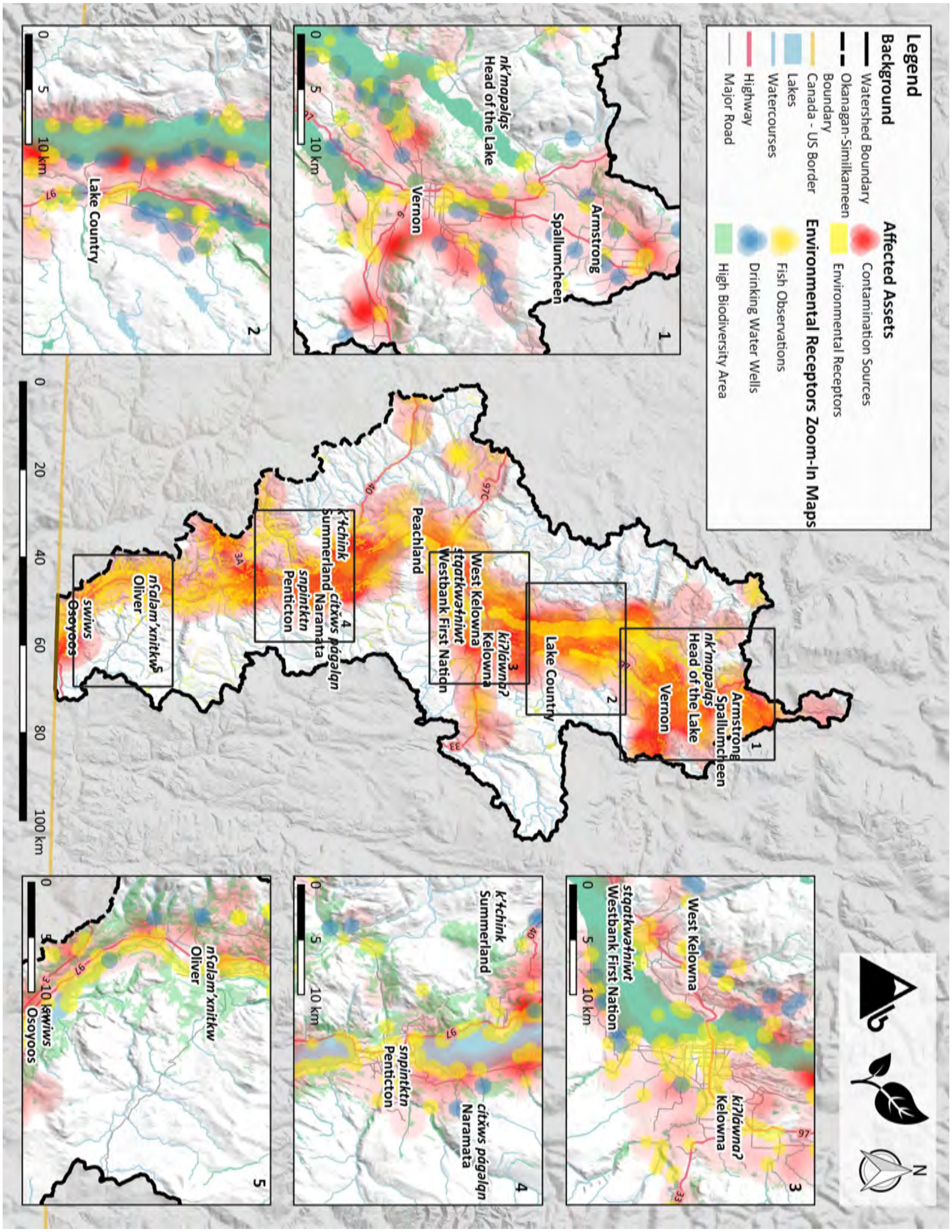


Figure 10: Environment indicator consequences from debris flow hazard in the Okanagan.

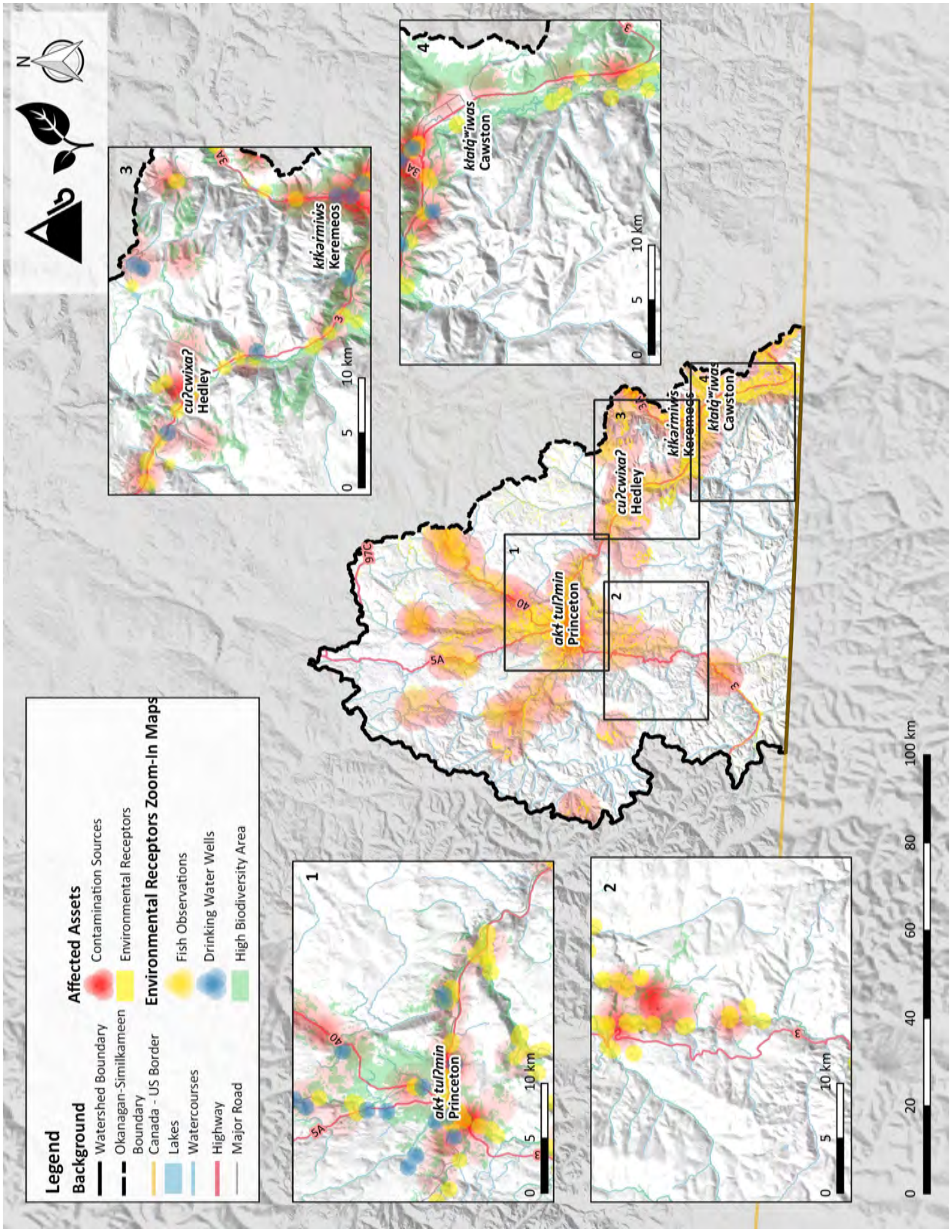


Figure 11: Environment indicator consequences from debris flow hazard in the Similkameen.

5.2 Culture

5.2.1 Flood

A summary of culture indicator consequences from flood is provided in Table 11.

Table 11: Summary of culture indicator consequences from flood hazard.

Watershed	Scenario (Hazard Magnitude)	*Syilx* Okanagan Archaeology		Non-*Syilx* Okanagan Archaeology		Cultural Amenities		Recreation Trails	
		No.	% of total	No.	% of total	No.	% of total	km	% of total
Okanagan	High	472	54%	254	64%	465	69%	137	11%
	Moderate	330	38%	158	40%	262	39%	64	5%
	Low	173	20%	66	17%	103	15%	27	2%
Similkameen	High	168	55%	90	63%	55	90%	104	13%
	Moderate	91	30%	41	29%	40	66%	55	7%
	Low	25	8%	12	8%	4	7%	12	1%

Okanagan

As presented in Table 11 and Figure 12 there are a large number of cultural sites within the flood hazard area across the Okanagan watershed. For the moderate flood scenario, approximately 40% of cultural sites are exposed. While cultural buildings are generally concentrated in the cities, archaeological sites are spread across the region. The consequence to trails is relatively low. However, should localised consequences cause a trail to close either in the short term or longer term, the local consequences would likely be much higher.

Similkameen

The relative consequences in the Similkameen are similar to those in the Okanagan. The principal difference is in the number of cultural buildings affected. As shown in Figure 13, the majority of these are in Princeton, Hedley, Keremeos, and Cawston. A flood in these areas could have a very large consequence on cultural amenities.

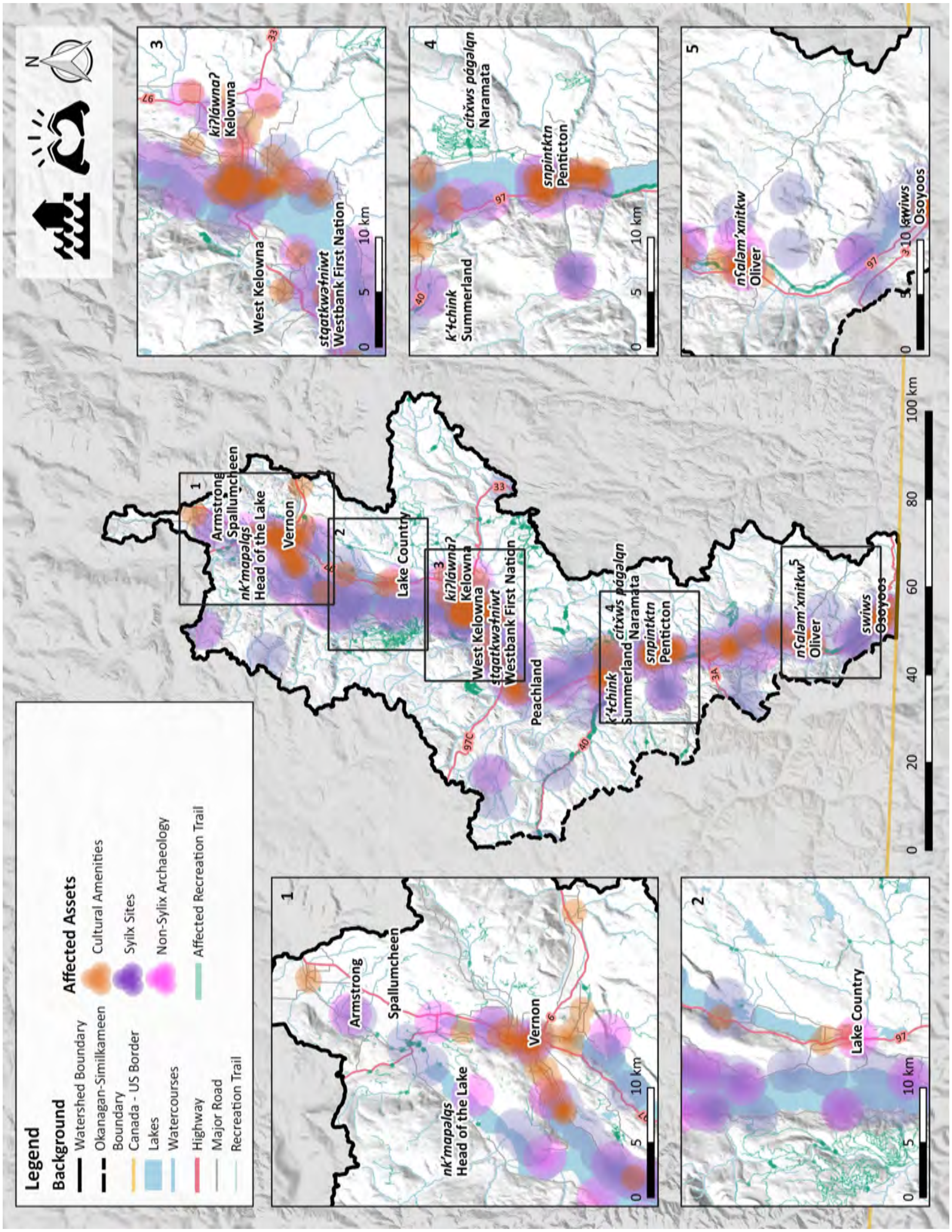


Figure 12: Culture indicator consequences from moderate flood hazard in the Okanagan.

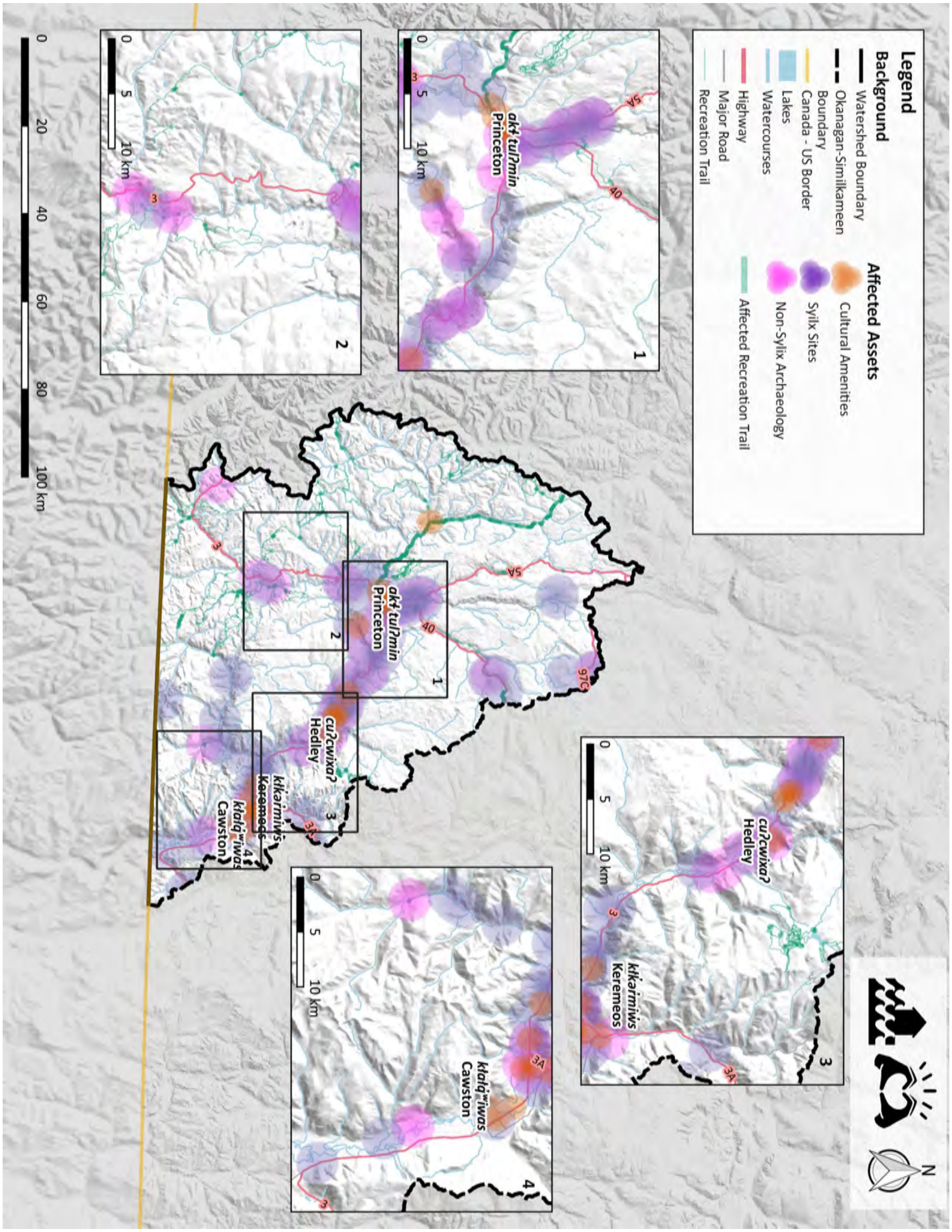


Figure 13: Culture indicator consequences from moderate flood hazard in the Similkameen.

5.2.2 Debris Flow

A summary of culture indicator consequences from debris flow is provided in Table 12.

Table 12: Summary of culture indicator consequences from debris flow hazard.

Watershed	*Syilx* Okanagan Archaeology		Non-*Syilx* Okanagan Archaeology		Cultural Amenities		Recreation Trails	
	No.	% of total	No.	% of total	No.	% of total	km	% of total
Okanagan	374	43%	135	34%	97	14%	249	19%
Similkameen	202	67%	90	63%	21	34%	253	31%

Okanagan

While the numbers of archaeology sites affected are similar to that for flood hazard as shown in Figure 12, the consequences from debris flow are distributed further, particularly in the southern half of the watershed (Figure 14). The majority of consequences, however, remain concentrated around the lakes. As mentioned in Section 4.2.2, this could be due to archaeology data being limited in the uplands. The consequences to cultural amenities are considerably lower than even the low flood scenario; this is due to a fewer number of cultural buildings being in the way of the debris flow hazards compared to flood hazards, especially in developed areas.

Similkameen

Effects to archaeological sites in the Similkameen watershed are high, and they are equal or greater than that of the high flood scenario. The consequence on walking trails is also significantly higher compared to flood. However, as in the Okanagan, the consequence on cultural amenities is significantly lower compared to flood. This is generally indicative of the spatial characteristics of the two hazards. Debris flow areas are more widespread across the project area, whereas floods are more limited to flat areas and river valleys that tend to be more developed. The culture indicator consequences due to debris flow hazard in the Similkameen are shown in Figure 15.

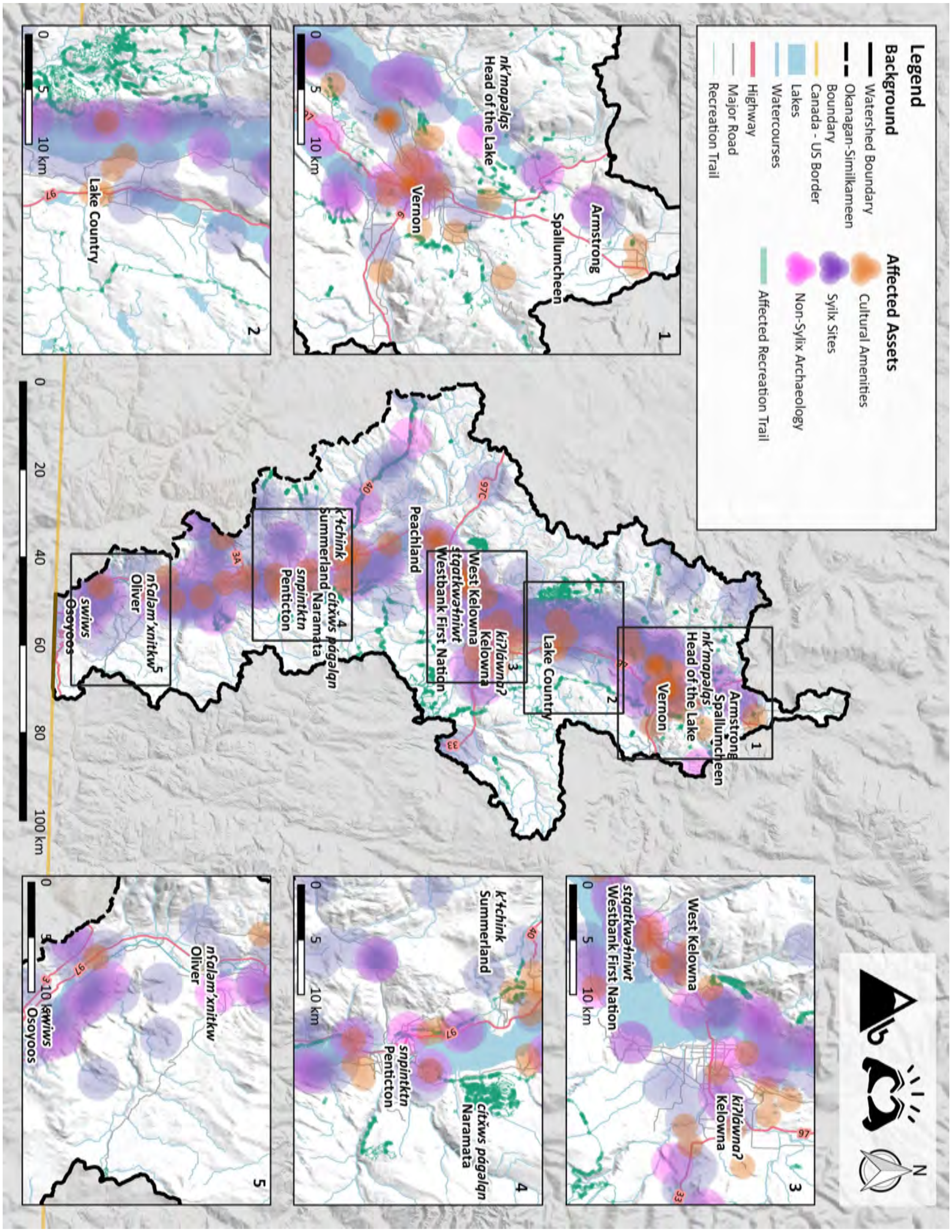


Figure 14: Culture indicator consequences from debris flow hazard in the Okanagan.

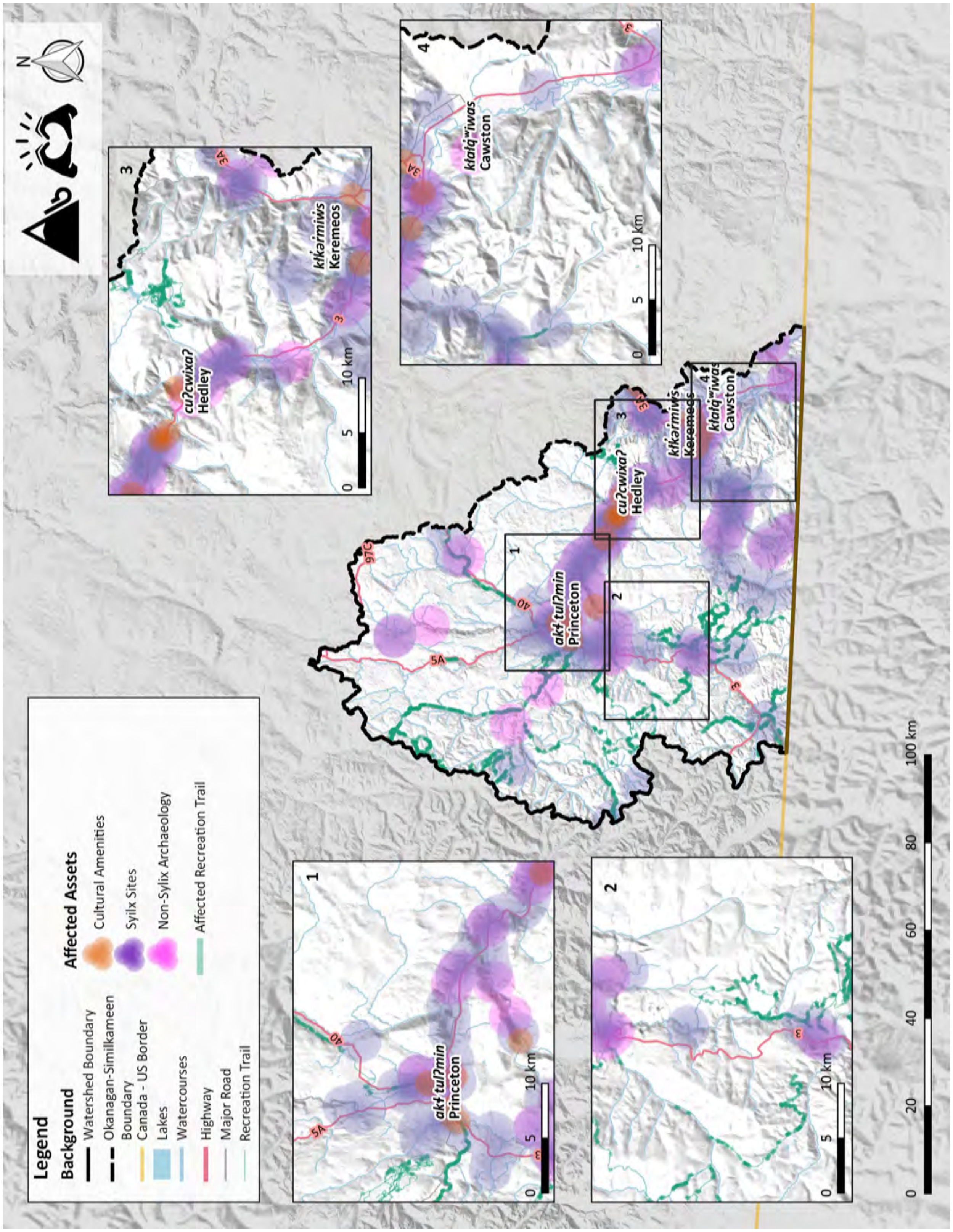


Figure 15: Culture indicator consequences from debris flow hazard in the Similkameen.

5.3 Mortality

The number of buildings in high hazard areas was used as a proxy for the mortality indicator; however, the indicator was only considered for debris flow hazard.

5.3.1 Debris Flow

In both watersheds, the number of exposed residential buildings was relatively high, and ranged from 20% to 29% of the total estimated number of residential buildings in the Okanagan and Similkameen watersheds, respectively (Table 13). The majority of residential buildings in the project area are in the Okanagan watershed.

Table 13: Summary of mortality indicator consequences from debris flow hazard.

Watershed	Exposed Residential Buildings (proxy for people)	Percentage of Total
Okanagan	30,352	20%
Similkameen	2,083	29%

The consequences are shown spatially in Figure 16 and Figure 17 with the use of two layers that are based on the same exposed residential buildings data. Building footprints density (appearing as hotspots in orange colour) shows the concentration of buildings located in debris flow hazard areas; this visual technique is useful to draw attention to areas of low building footprints density (e.g., large portions of the Similkameen watershed). Affected buildings, shown in red, show the actual building footprints that overlap the hazard areas.

Okanagan

The largest number of buildings (and therefore people) within the hazard areas are concentrated in population centres along the lakes that run through the centre of the watershed, including large parts of West Kelowna, Vernon, and the northern part of Kelowna (Figure 16). There are also smaller clusters and individual properties outside of these main development areas which are important to consider.

Similkameen

The largest number of buildings (therefore likely people) are along the main highways in the Similkameen and in the population centres of Princeton and Keremeos (Figure 17). There is also a significant concentration of buildings at a limited number of other locations including Tulameen and Missezula Lake; these areas can be more easily distinguished in the high-resolution results in the Map Book.

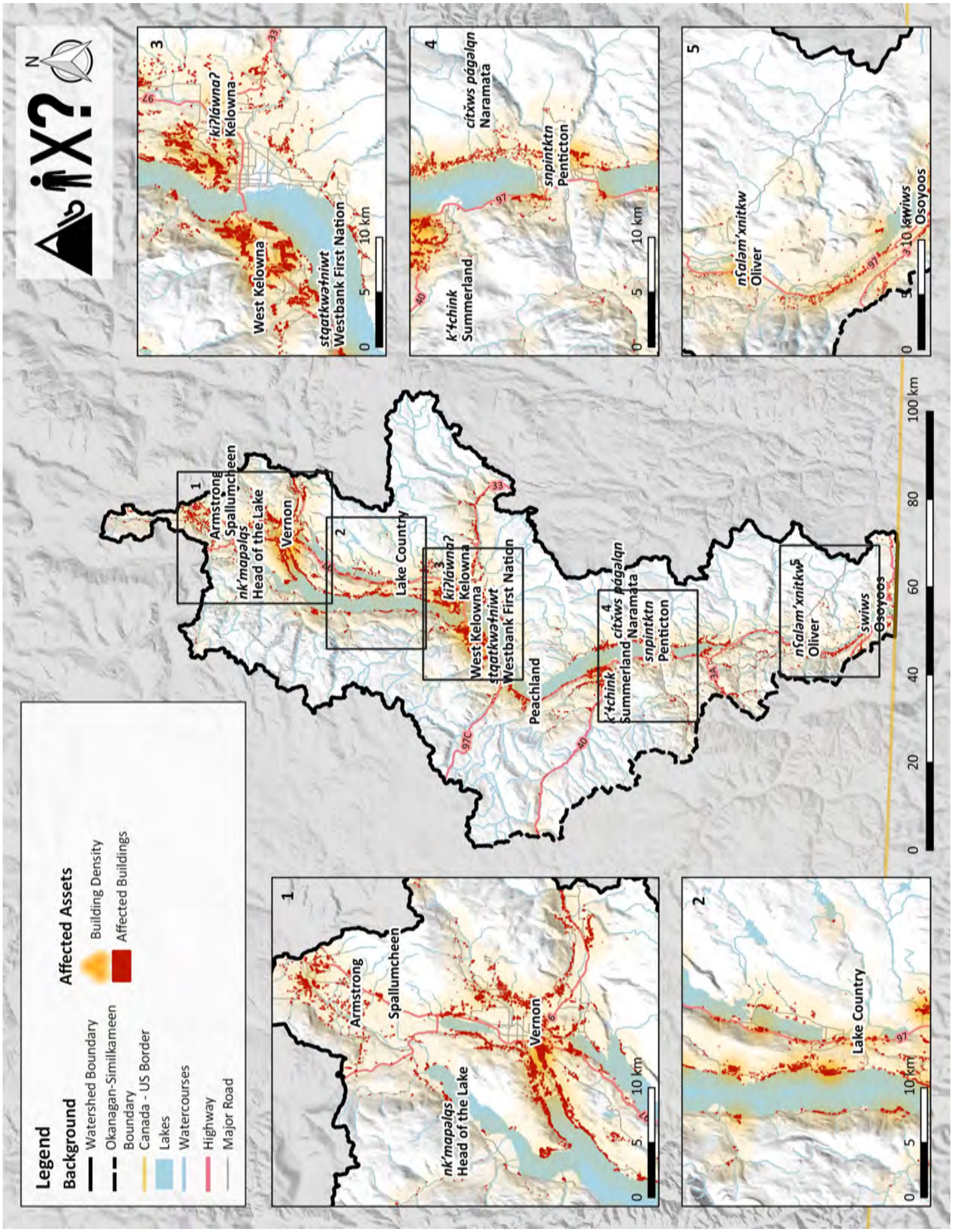


Figure 16: Exposed buildings in debris flow hazard areas in the Okanagan watershed.

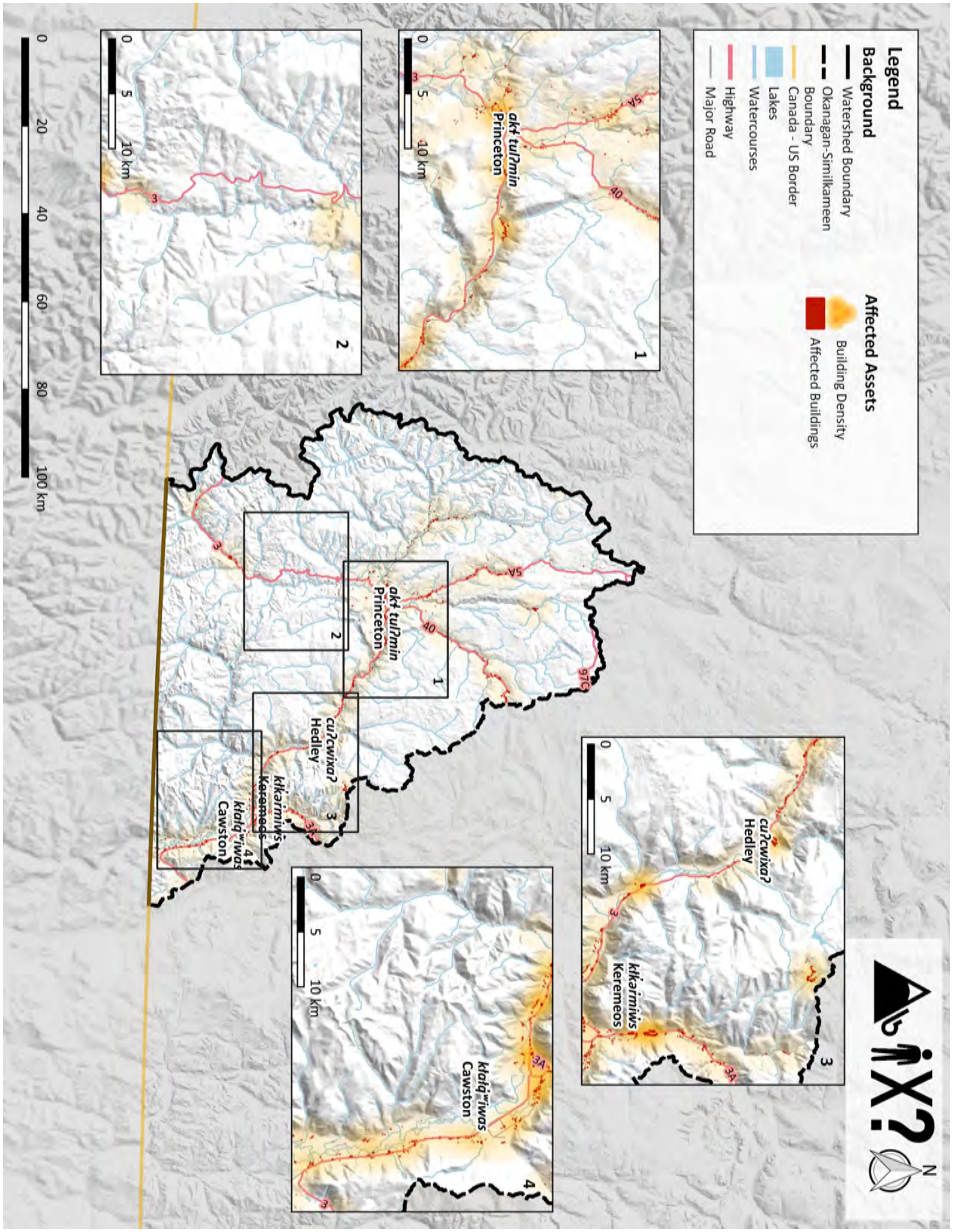


Figure 17: Exposed buildings in debris flow hazard areas in the Similkameen.

5.4 Affected People

Census data was the primary data source used for this indicator, and this was verified using residential buildings.

5.4.1 Flood

A summary of people affected by flood hazard is provided in Table 14.

Table 14: Summary of affected people indicator consequences from flood hazard.

Watershed	Scenario (Hazard Magnitude)	Census		Residential Buildings	
		Population Affected	Percentage of Total	Buildings Affected	Percentage of Total
Okanagan	High	140,493	42%	65,105	44%
	Moderate	64,943	19%	30,262	20%
	Low	22,480	7%	11,801	8%
Similkameen	High	3,663	40%	5,405	72%
	Moderate	2,107	23%	3,413	45%
	Low	478	5%	714	10%

Okanagan

A large proportion of the population in the Okanagan watershed could be potentially affected by flood(Table 14). This ranges from approximately 22,000 people in the low scenario to over 140,000 in the high scenario (and from 7% to 42% of the watershed population).

Comparing census population figures to residential buildings, the percentages of potentially affected people are similar between the two data sources across all scenarios. These results indicate that, on average, approximately 2 to 3 people live in each residential building. This result is reasonable, and the comparison validates the estimates calculated using the census data.

Figure 18 shows multiple areas of very high population density (over 1000 people per km^2) within the moderate flood hazard area in Kelowna (Box 3), Penticton (Box 4) and Vernon (Box 1) as well as high population densities in the south of the region in Oliver and Osoyoos (Box 5).

Similkameen

While the numbers of potentially affected people within the Similkameen are much lower than in the Okanagan, the percentage of potentially affected people (as shown by the Census data) is similar (5%–40%, depending on the scenario). It is interesting to note, however, that the percentages calculated based on the residential buildings proxy are much larger than those based on the census data. For example, under the moderate scenario, 23% of the census population is shown as potentially affected but 46% of residential buildings are shown as affected (Table 4). This indicates that residential buildings are disproportionately located in flood hazard areas compared to the census dissemination area. This means that the affected population could be much higher than indicated based strictly on the census data.

Figure 19 shows that the majority of the people potentially affected by flood are concentrated in the high population density areas of Princeton and Keremeos. However, there are people potentially affected all along the Similkameen River, particularly south of Keremeos where the hazard area is greatest.

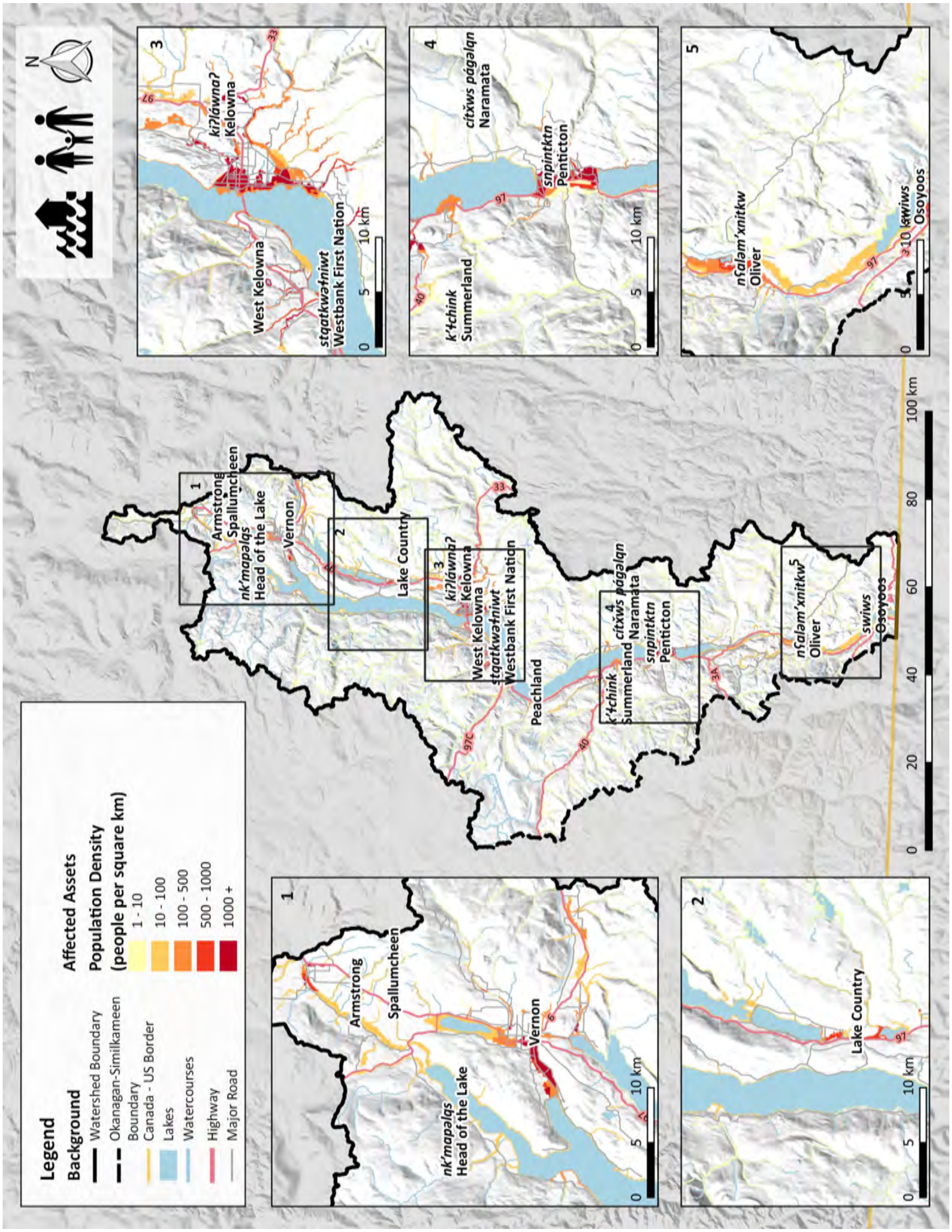


Figure 18: Affected people indicator consequences from moderate flood hazard in the Okanagan.

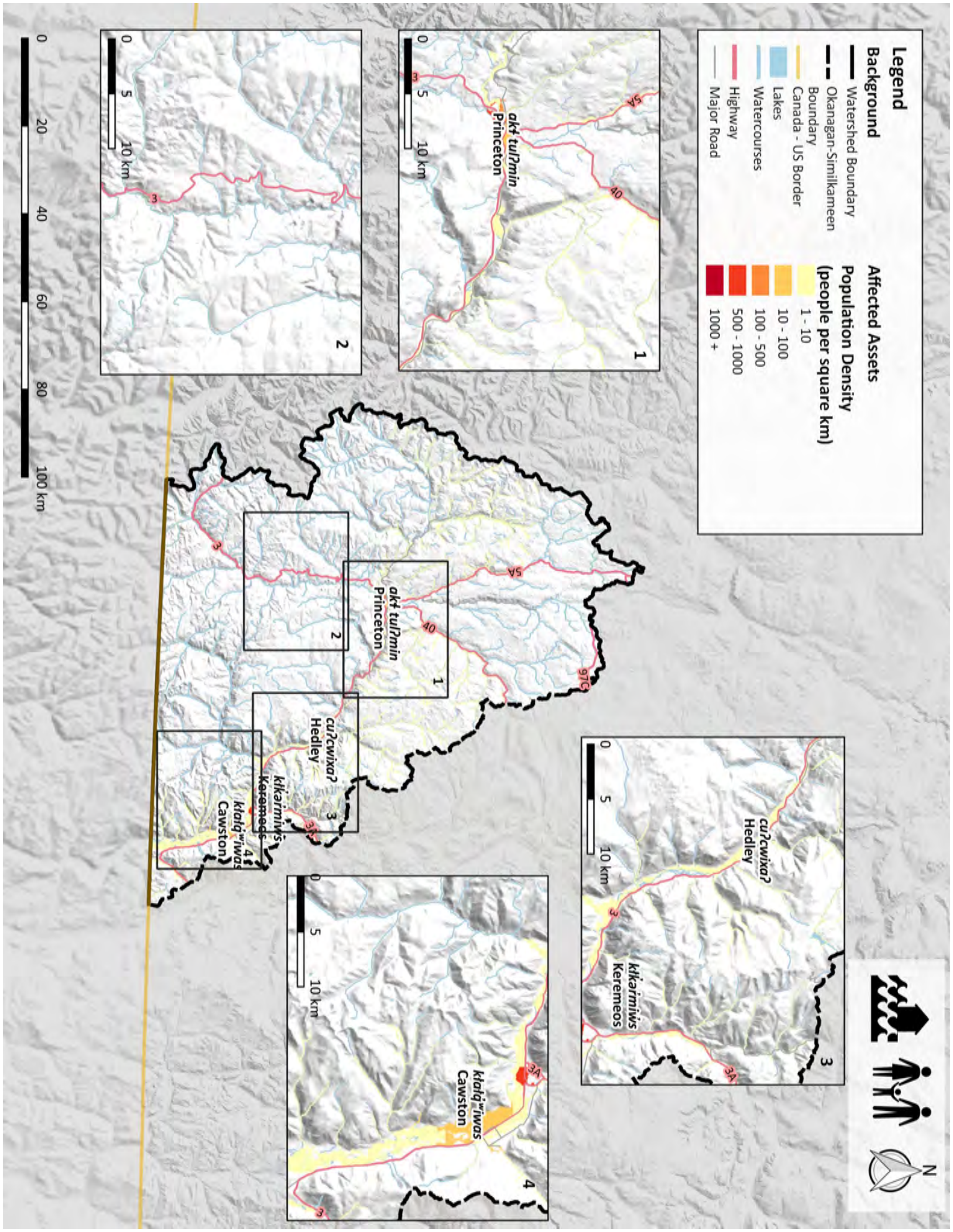


Figure 19: Affected people indicator consequences from moderate flood in the Similkameen.

5.4.2 Debris Flow

A summary of people affected by debris flow hazard is provided in Table 15. Note that the residential buildings data is the same as that used for the mortality indicator shown in Table 13.

Table 15: Summary of affected people indicator consequences from debris flow hazard.

Watershed	Census		Residential Buildings	
	Population Affected	Percentage of Total	Buildings Affected	Percentage of Total
Okanagan	44,144	13%	30,276	20%
Similkameen	2,444	26%	2,158	29%

Okanagan

The estimate based on the census data suggests that 13% of the population of the Okanagan watershed could be exposed or potentially affected by debris flow (Table 15). Comparing with the estimate of 20% based on the number of residential buildings suggests that using the census data may lead to an underestimation. There are limitations in both datasets that make direct comparison difficult, including the age of the data and the assumptions made in estimating how many of the total buildings are residential.

Figure 20 shows that the consequences are much more distributed compared to those for flood hazard. While there are some areas of very high population density affected in Kelowna (Box 3) and Vernon (Box 1), there are much larger areas of moderate population density (i.e. yellow-shaded areas) within the map figure.

Similkameen

While the numbers of potentially affected people within the Similkameen are much lower than in the Okanagan, the percentage potentially affected based on the census data in Table 10 is larger (26%). Figure 21 shows a similar pattern to the Okanagan in that the consequences are much more distributed over the watershed compared to those for flood. There are no consequences shown in the north or southwest of the watershed. This is due to the very low population density in these areas and the limitations of the census data. As shown in Figure 17 there are some properties in these areas where people could be potentially affected by debris flow hazard.

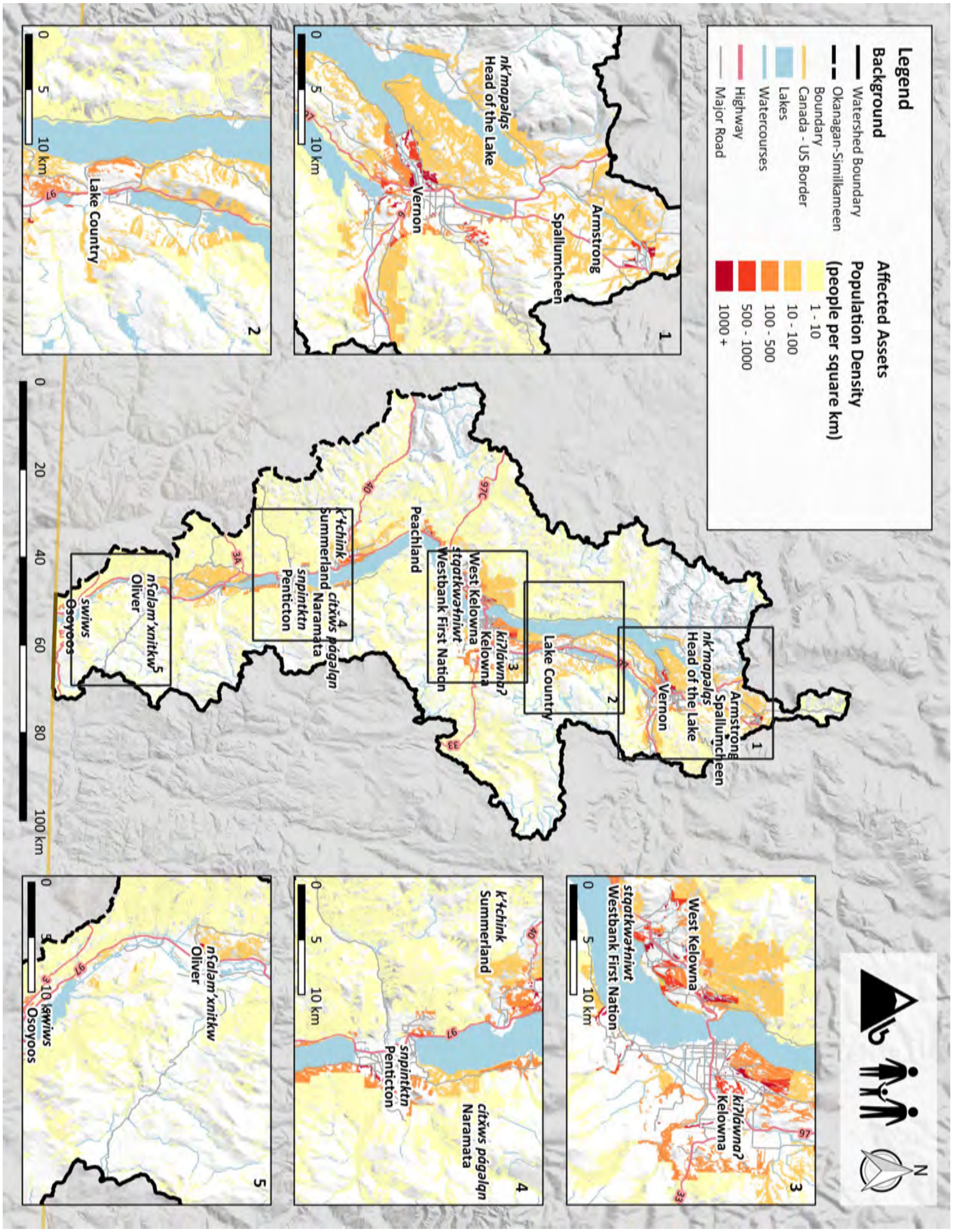


Figure 20: Affected people indicator consequences from debris flow hazard in the Okanagan.

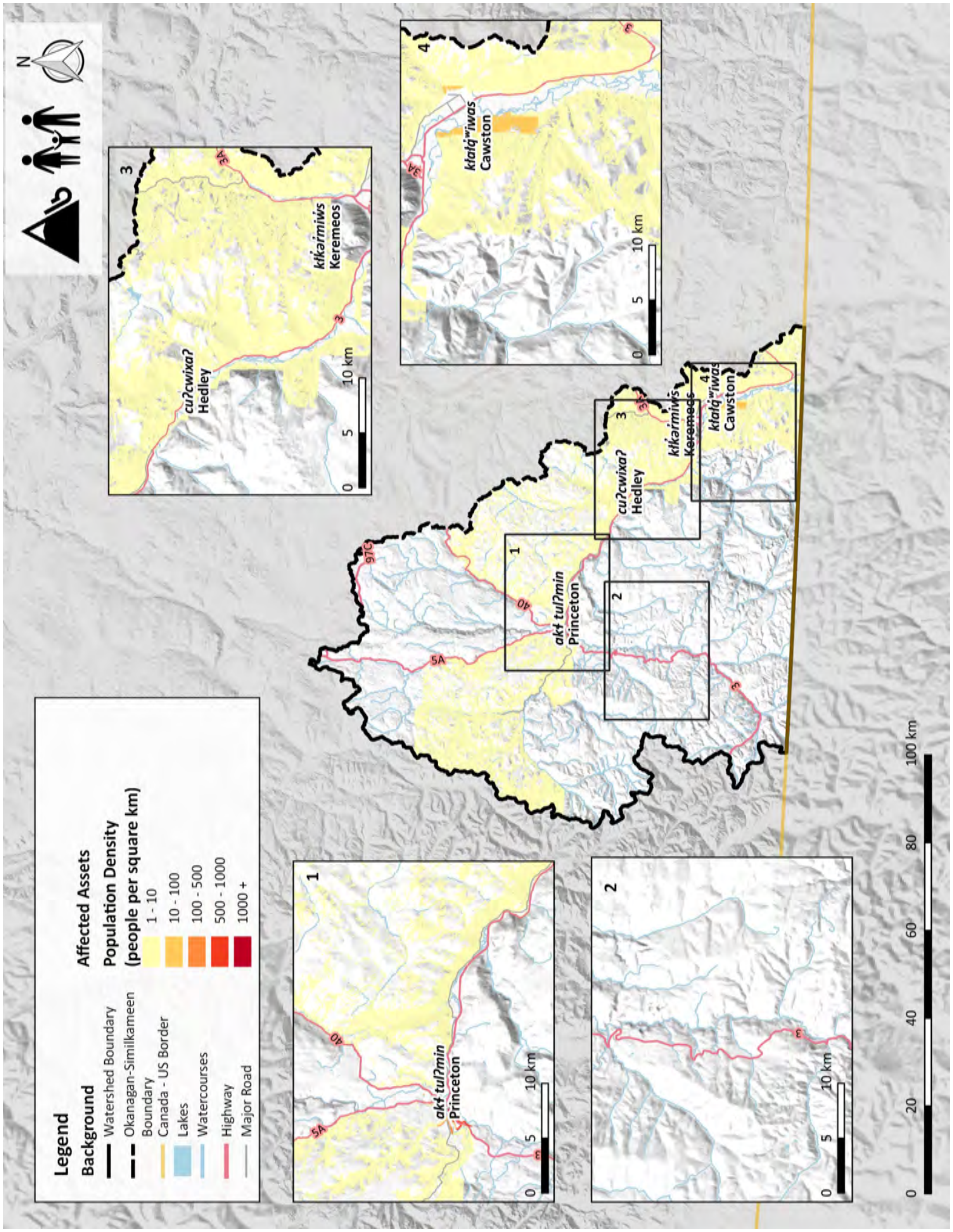


Figure 21: Affected people indicator consequences from debris flow hazard in the Similkameen.

5.5 Economy

To place the economic consequences in relative terms, a high-level estimate of the gross domestic product (GDP) for the Okanagan-Similkameen region was produced. The estimate scaled GDP estimates for BC using a factor derived from a GDP estimate for the technology sector in BC as well as the Okanagan region. The technology sector was considered to be relatively geography-independent, making it a reasonable proxy for the purposes of this estimate. The proportion of population as well as the proportion of technology business counts within BC and the Okanagan-Similkameen region validated the technology sector GDP proportion.

Based on this high-level approach, the GDP estimate for the project area was $23 billion. This estimate for the project area GDP was proportioned by watershed based on the estimated population proportions.

5.5.1 Flood

A summary of economic consequences from flood hazard is provided in Table 16. As discussed in Section 4.2.5, the whole building value proxy data used likely represents a conservative estimate of damages. In reality, building damages are likely to be a proportion of the total value. This is especially true for the low scenario. However, the value of buildings is only a part of the total economic consequences and factors such as loss of business have not been included in this study.

Furthermore, the reader is reminded that the estimate considers that the debris flow scenario would occur simultaneously throughout the project area, which is nearly impossible. Spatially, the estimate is therefore considered conservative in producing high damages.

Table 16: Summary of economy indicator consequences from flood hazard.

Watershed	Scenario (Hazard Magnitude)	Total Affected Building Value ($m)	Percentage of Watershed GDP
Okanagan	High	25,940	116%
	Moderate	15,533	69%
	Low	9,156	41%
Similkameen	High	1,012	166%
	Moderate	750	123%
	Low	378	62%

Okanagan

The potential economic consequences from flooding in the Okanagan ranges from $9,156 million for the low scenario to $25,940 million for the high scenario (Table 16). Therefore, consequences for the high scenario exceed the estimated GDP for the project area of $23,000 million (see Section 5.5).

As expected, Figure 22 demonstrates that the majority of the economic consequences from flooding are clustered around towns and cities. However, there are several very high value assets (greater than $2 million) outside of these areas (e.g. see Box 1 and Box 2).

Similkameen

The economic consequences from flooding in the Similkameen are also potentially very large compared to its estimated GDP and its proportion of the project area population of less than 5%. The high consequence is due to the high concentration of development in riverside locations such as Keremeos and Princeton. This indicator used land parcels rather than building footprints (used for the mortality indicator) to calculate the consequences in terms of proportional GDP for the watershed. In the Similkameen watershed, buildings are sparse while land parcels are larger. This explains why the consequences are relatively large for the economy indicator compared to the mortality indicator.

Figure 23 shows a similar distribution to the Okanagan with the majority of the consequences at the population centres of Princeton and Keremeos. However, there are some individual high-value assets such as Copper Mountain and Hedley mines, as well as consequences along the main highways.

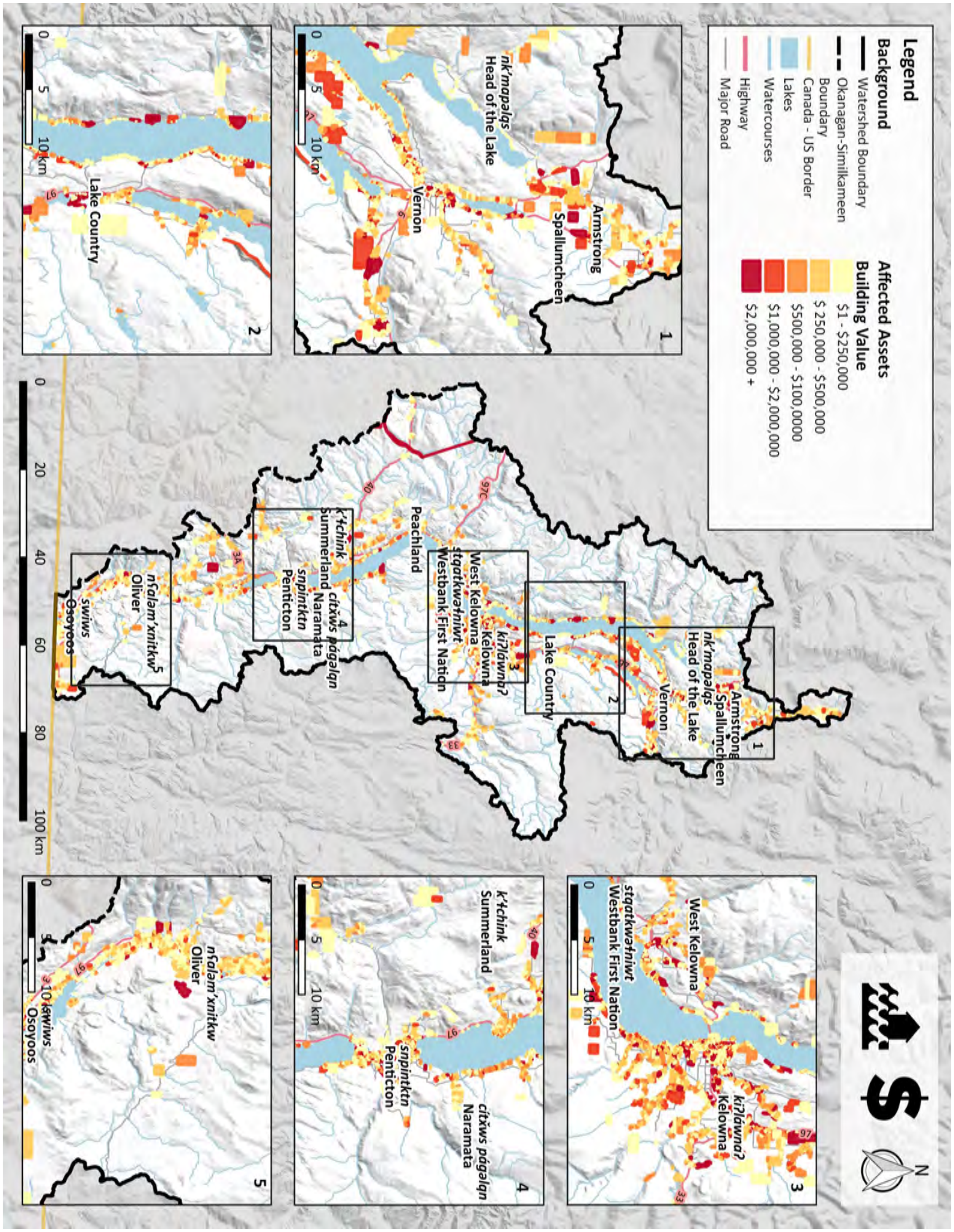


Figure 22: Economic indicator consequences from moderate flood hazard in the Okanagan.

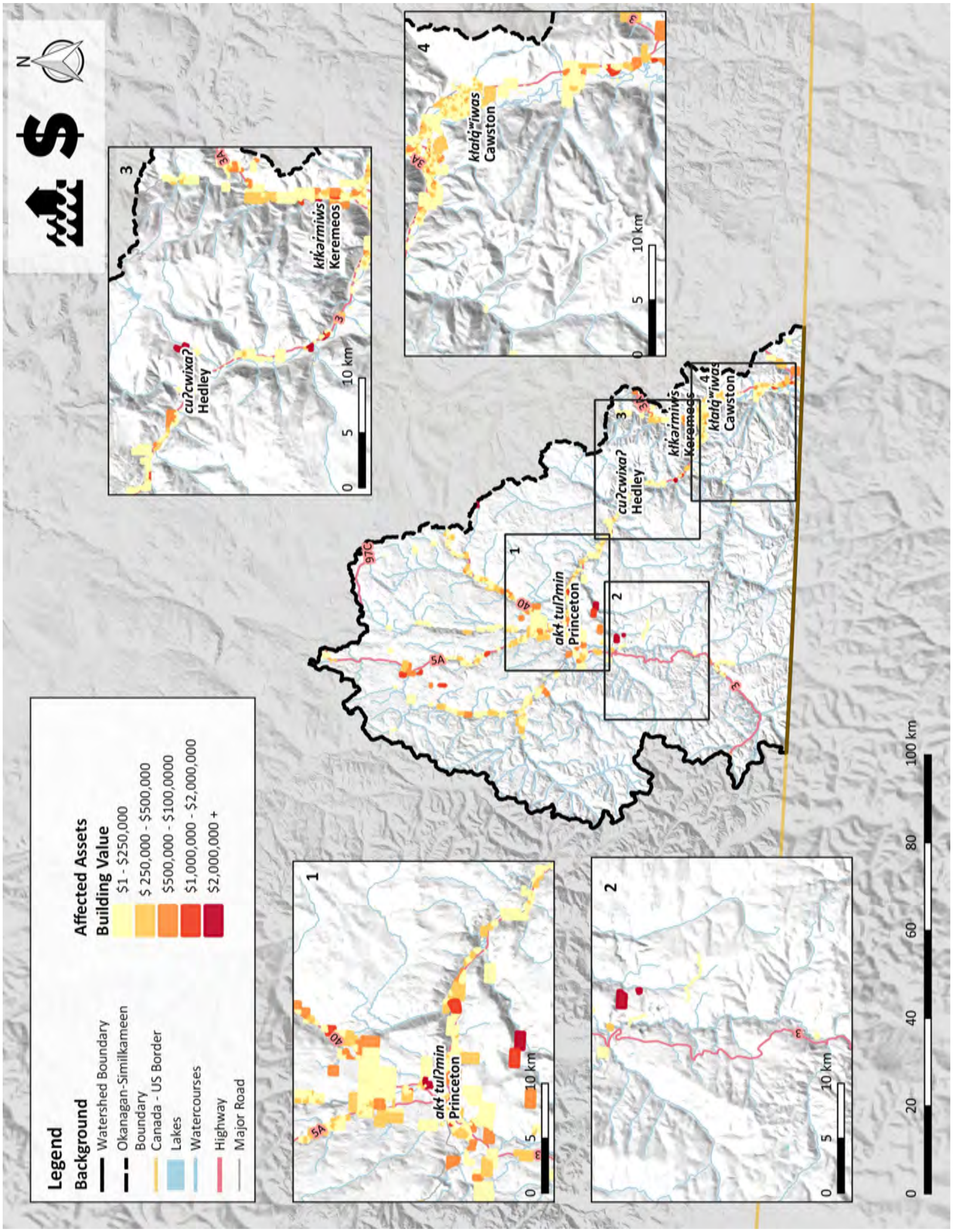


Figure 23: Economic indicator consequences from moderate flood hazard in the Similkameen.

5.5.2 Debris Flow

A summary of economic consequences from debris flow is provided in Table 17. Recall that the estimates represent the total land value and no function has been used that relates the hazard to the damage caused. Furthermore, the reader is reminded that the estimate considers that the debris flow scenario would occur simultaneously throughout the project area, which is nearly impossible. The estimate is therefore considered conservative in producing high damages.

Table 17: Summary of economy indicator consequences from debris flow hazard.

Watershed	Total Affected Land Value ($M)	Percentage of Watershed GDP
Okanagan	23,393	104%
Similkameen	802	131%

Okanagan

The economic consequences from debris flow were similar to that of the high flood scenario of $25,940 million. As discussed in Section 4.2.5, the total land value was used for debris flow as opposed to the building value as the debris flow is expected to be more damaging. This means that even fewer affected locations result in a higher total consequence cost.

While the distribution of consequences shown in Figure 24 appears very similar to that for flood (Figure 22), there is a slight shift of consequences away from the lake and towards the headlands. There are considerably more economic consequences from debris flow in the northern part of the watershed (see Armstrong and Vernon in Box 1) compared to flood. Debris flow consequences at Kelowna (Box 3) and Penticton (Box 4) are generally located on the outskirts of developed areas, whereas flood consequences generally occur in the centre of these cities. This means that despite the higher relative unit damage estimated for debris flow (due to land values used instead of building values), the total economic consequences are similar to those for flood, which affects more areas.

Similkameen

Economic consequences from debris flow are slightly higher than that of the moderate flood hazard, and they are similar in distribution. The main points of note in comparing Figure 23 and Figure 25 is the reduction of consequences in Keremeos, and the general increase in values (a change from yellow to orange), due to the use of land value rather than building value.

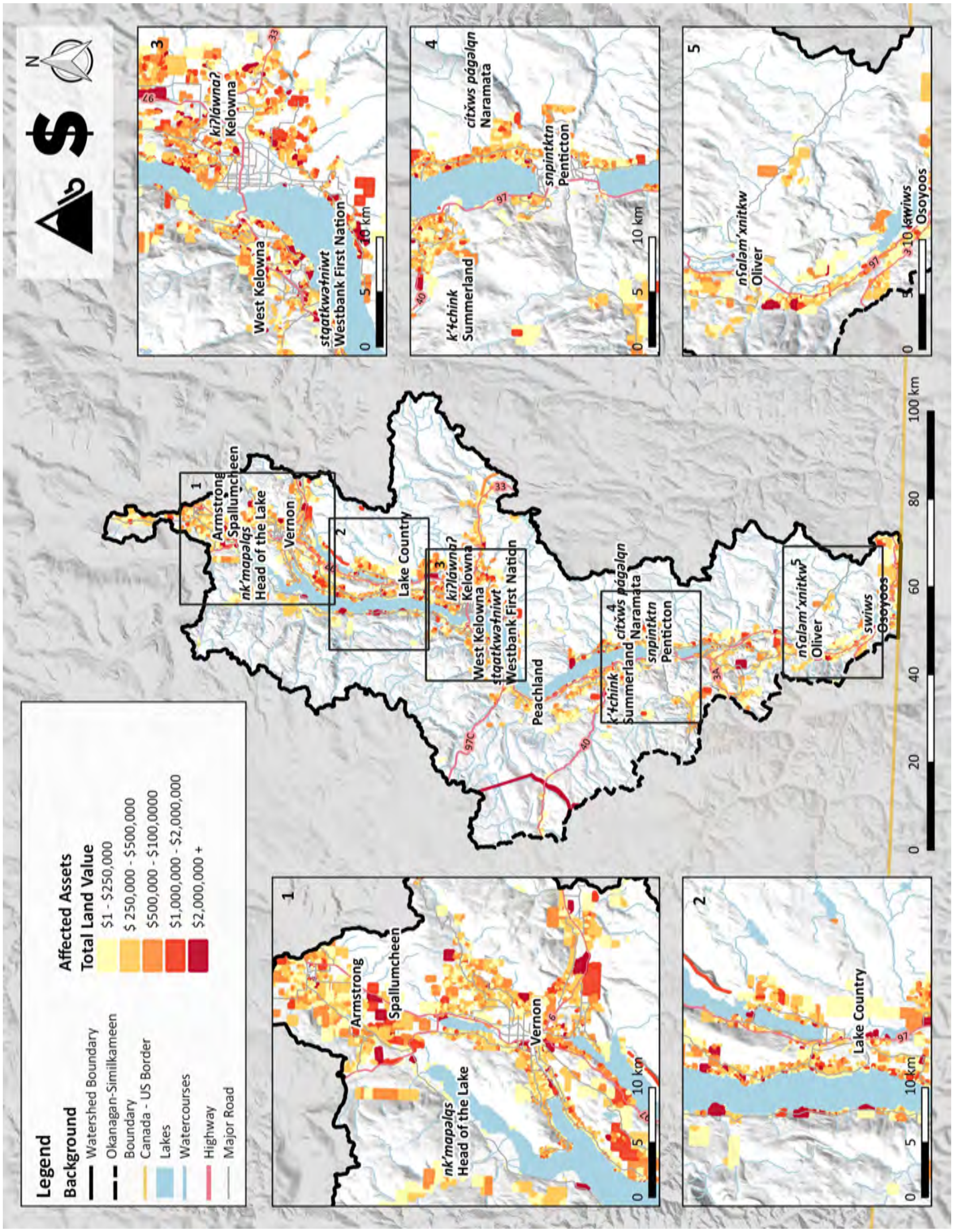


Figure 24: Economic indicator consequences from debris flow hazard in the Okanagan.

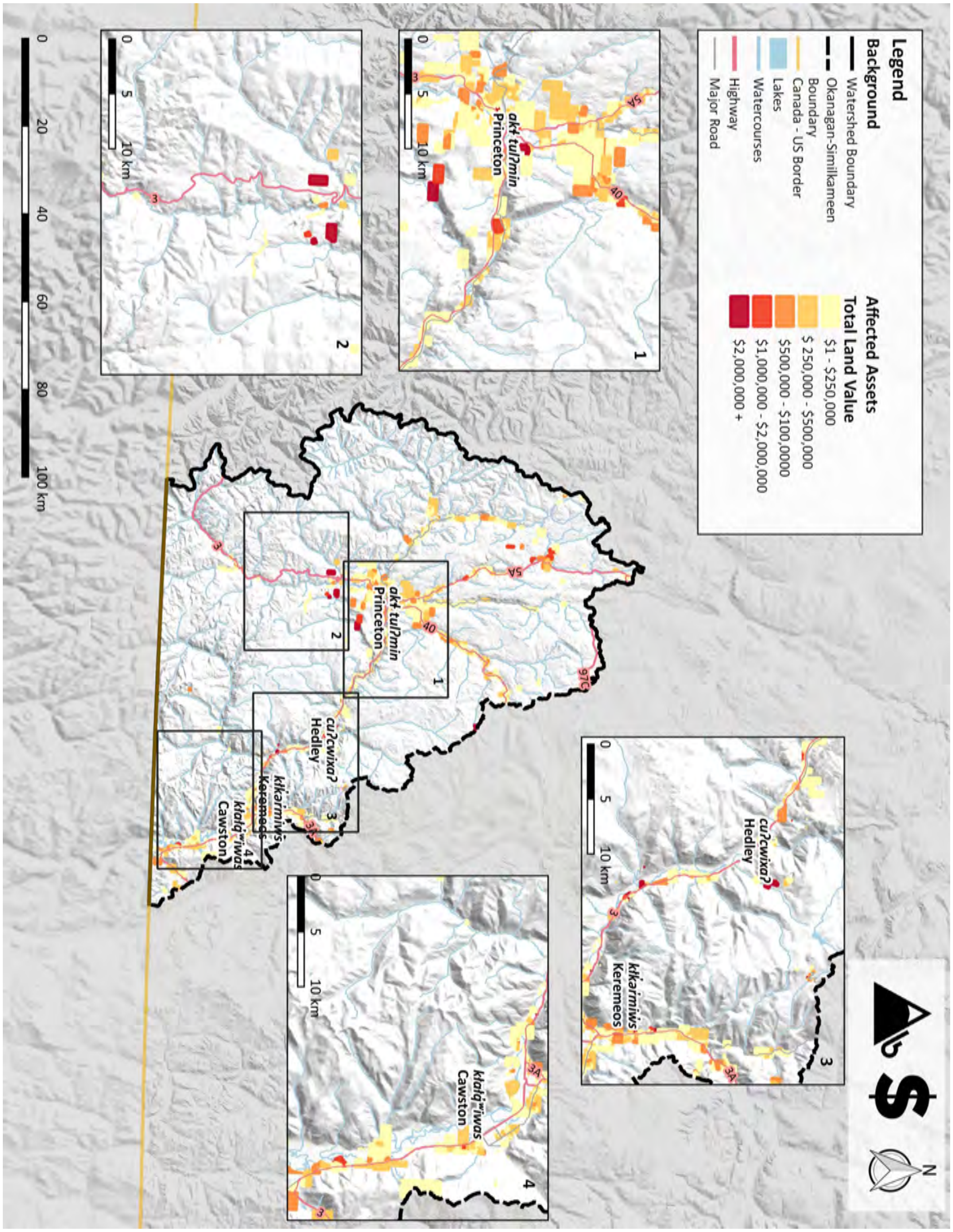


Figure 25: Economic indicator consequences from debris flow hazard in the Similkameen.

5.6 Disruption

5.6.1 Flood

The disruption indicator used transportation and utilities data proxies. A summary of transportation-related consequences from flood is provided in Table 18, and utility-related consequences are in Table 19.

Table 18: Summary of transport-related disruption indicator consequences from flood hazard.

Watershed	Scenario (Hazard Magnitude)	Roads				Rail	
		Affected Highway (km)	Affected Arterial (km)	Affected Collector (km)	Percentage of Total	Affected Rail (km)	Percentage of Total
Okanagan	High	110	151	323	41%	97	72%
	Moderate	39	87	121	17%	42	32%
	Low	14	38	31	6%	17	13%
Similkameen	High	174	22	123	63%	-	-
	Moderate	71	11	55	27%	-	-
	Low	13	2	9	5%	-	-

Table 19: Summary of utility-related disruption indicator consequences from flood hazard.

Watershed	Scenario (Hazard Magnitude)	Gas Structures	Electric Structures	Aggregated Percentage of Total for all Assets[1]
Okanagan	High	95	7	39%
	Moderate	52	5	21%
	Low	37	3	15%
Similkameen	High	39	-	71%
	Moderate	18	-	33%
	Low	12	-	22%

Note:

[1]In aggregate, rail assets were assigned a weighting of 0.25 to reflect their smaller disruptive influence within the project area compared to roads and utilities.

Okanagan

Disruption to transportation infrastructure in the Okanagan is relatively high (Table 18). This is as expected as many of the major transportation routes follow the lakes at the base of the mountains (Figure 26). As While the infrastructure sections of consequence usually cover short distances, in some areas there are few routes without any consequences. Considering the potential effects along the wider connected transportation network, consequences are likely to be larger than the numbers presented in Table 18 suggest. Similarly, with rail consequences the number and extent of disruption is likely to mean large-scale disruption and potential damage for the whole railway in this area.

The consequences on utilities is also high (Table 19). A large number of structures are affected, which represents a major disruption to the network. It is important to note that the moderate flood hazard area affects two electrical substations, and the high scenario flood area includes three substations. Consequences to these structures are likely to have far reaching implications for the network.

Similkameen

Consequences in the Similkameen are of a similar order to the Okanagan. Although the number of assets affected is lower, the percentage of the network affected is higher. This means that flooding is likely to have a larger relative effect in the Similkameen. A large proportion of the consequences are along Highways 3, which runs parallel to the Similkameen River between Princeton and Keremeos; and Old Hedley Road, which runs parallel to the river between Princeton and Hedley.

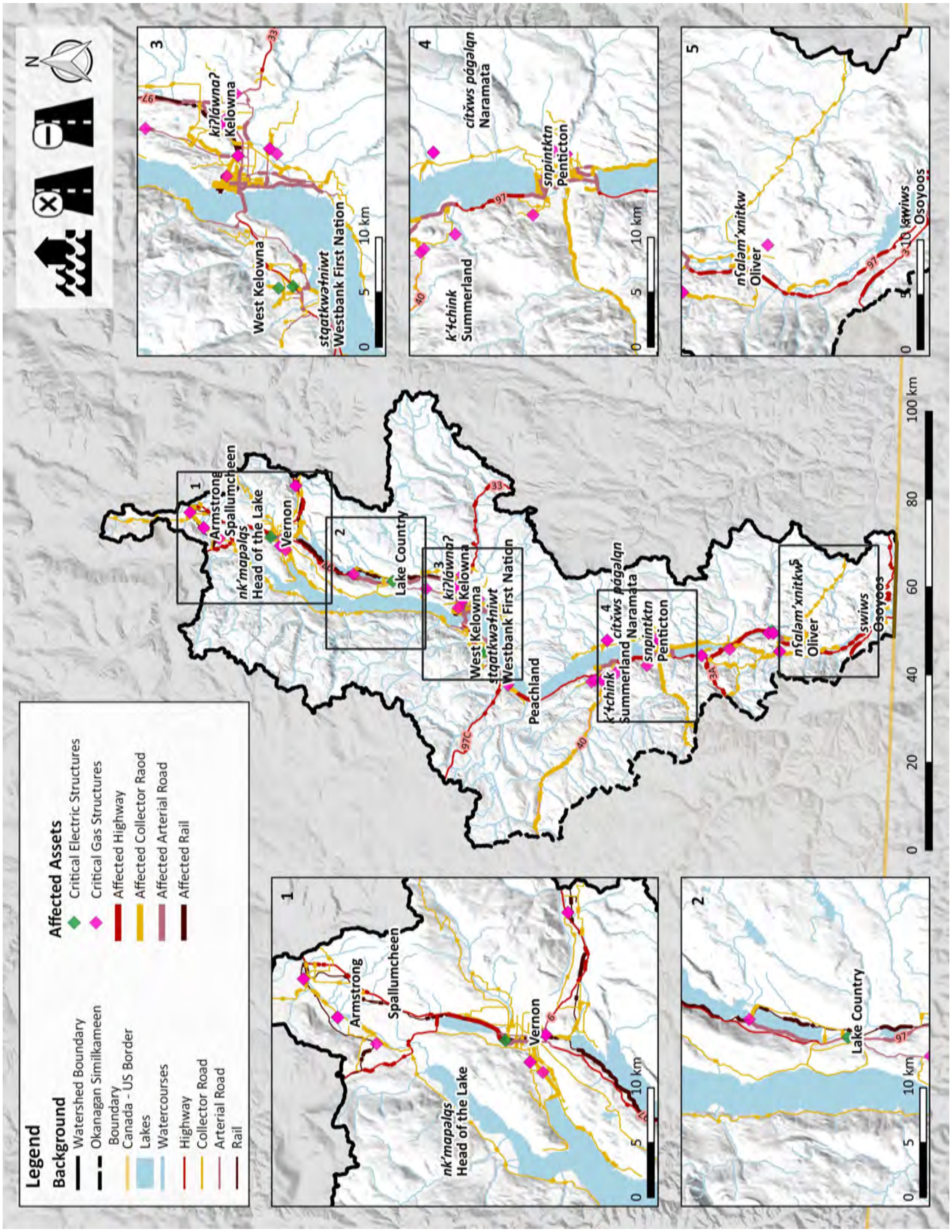


Figure 26: Disruption indicator consequences from moderate flood hazard in the Okanagan.

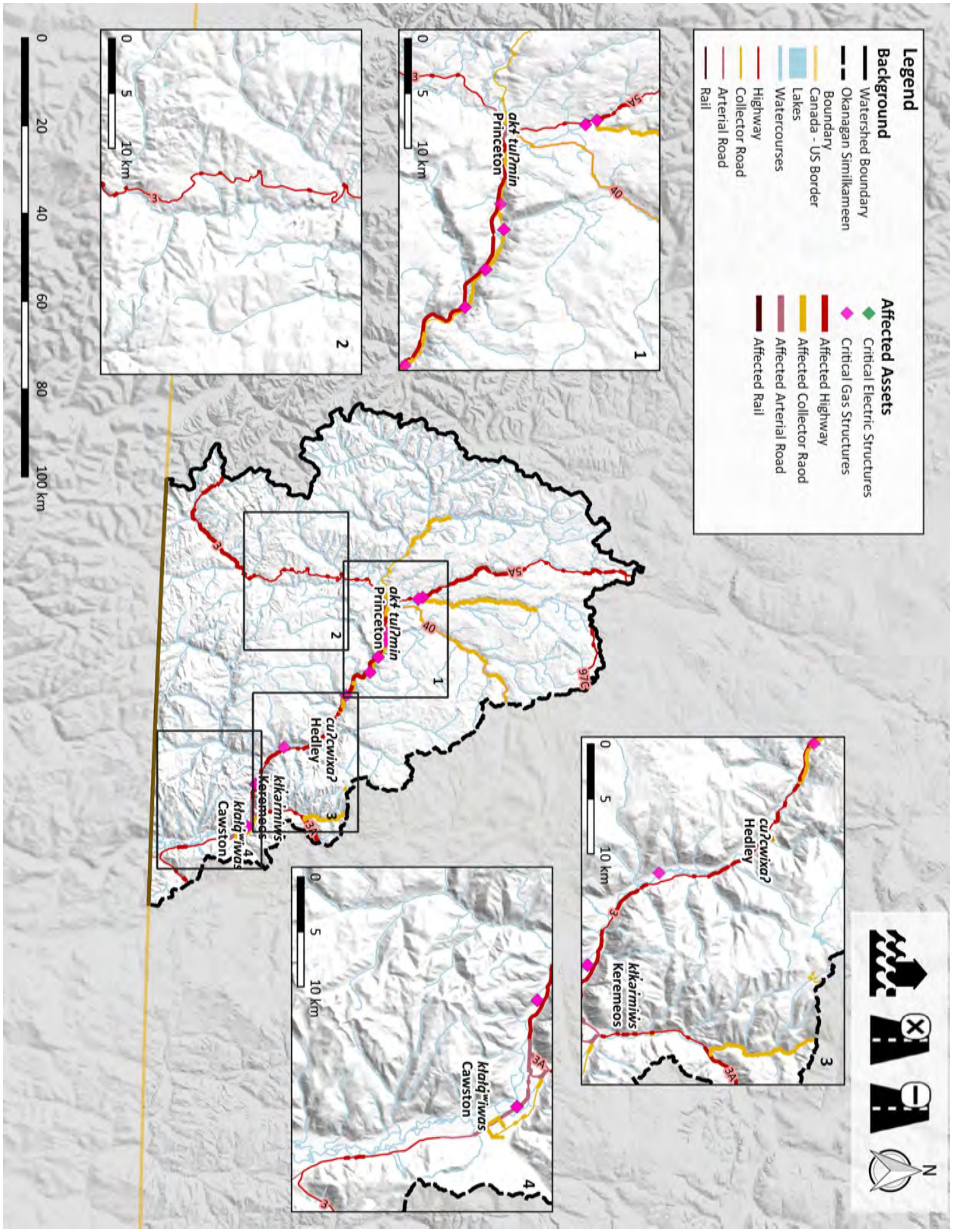


Figure 27: Disruption indicator consequences from moderate flood hazard in the Similkameen.

5.6.2 Debris Flow

A summary of transport-related consequences from debris flow is provided in Table 20 and utility-related consequences is provided in Table 21.

Table 20: Summary of transportation-related disruption consequences from debris flow hazard.

Watershed	Roads				Rail	
	Affected Highway (km)	Affected Arterial (km)	Affected Collector (km)	Percentage of Total	Affected Rail (km)	Percentage of Total
Okanagan	113	23	209	24%	43	32%
Similkameen	115	2	81	39%	-	-

Table 21: Summary of utility-related disruption consequences from debris flow hazard.

Watershed	Utility Structures			Powerline	
	Gas	Electric	Percentage of Total	Affected Powerline (km)	Percentage of Total
Okanagan	113	3	44%	797	19%
Similkameen	31	-	56%	319	32%

Okanagan

Disruption consequences from debris flow in the Okanagan are similar to that of flooding. The degree of disruption is equivalent to somewhere between the moderate and high flood scenarios. As discussed in Section 4.2, the consequences on powerlines have also been included in debris flow consequences due to the more damaging nature of debris flow. However, there are no substations within the debris flow hazard area.

As with flooding, the distribution of consequences is widespread and Figure 28 shows that there are few parts of the network which are outside of the debris flow hazard area. However, the majority of the consequence locations are not in the main population centres.

Similkameen

Disruption consequences within the debris flow hazard area are very high with almost 40% of road infrastructure affected, and a similar proportion of utilities. As with the Okanagan, the consequences are well distributed with no part of the network unaffected. However, the consequences are relatively low within the cities of Princeton (Box 1) and Keremeos (Box 4) as show in Figure 29.

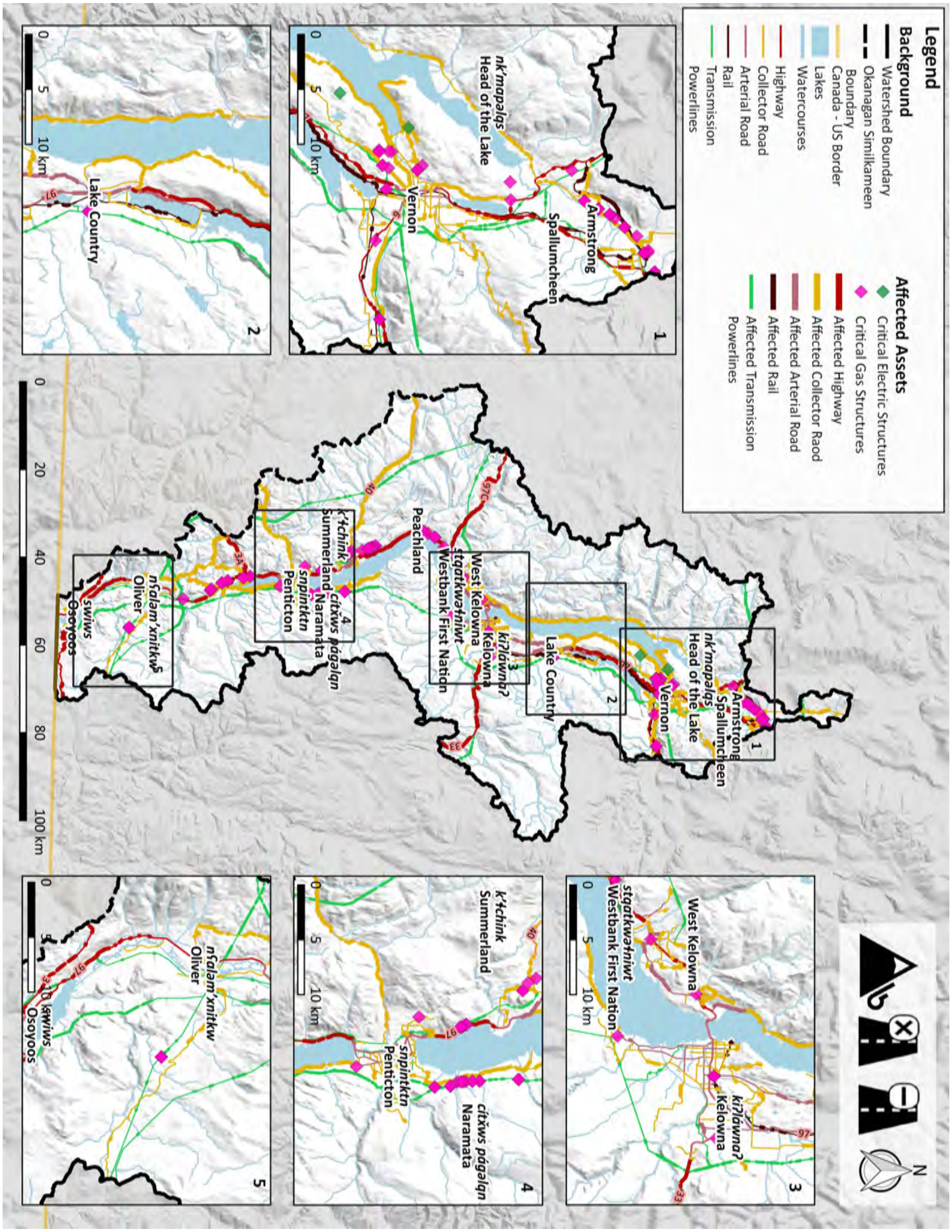


Figure 28: Disruption indicator consequences from debris flow in the Okanagan.

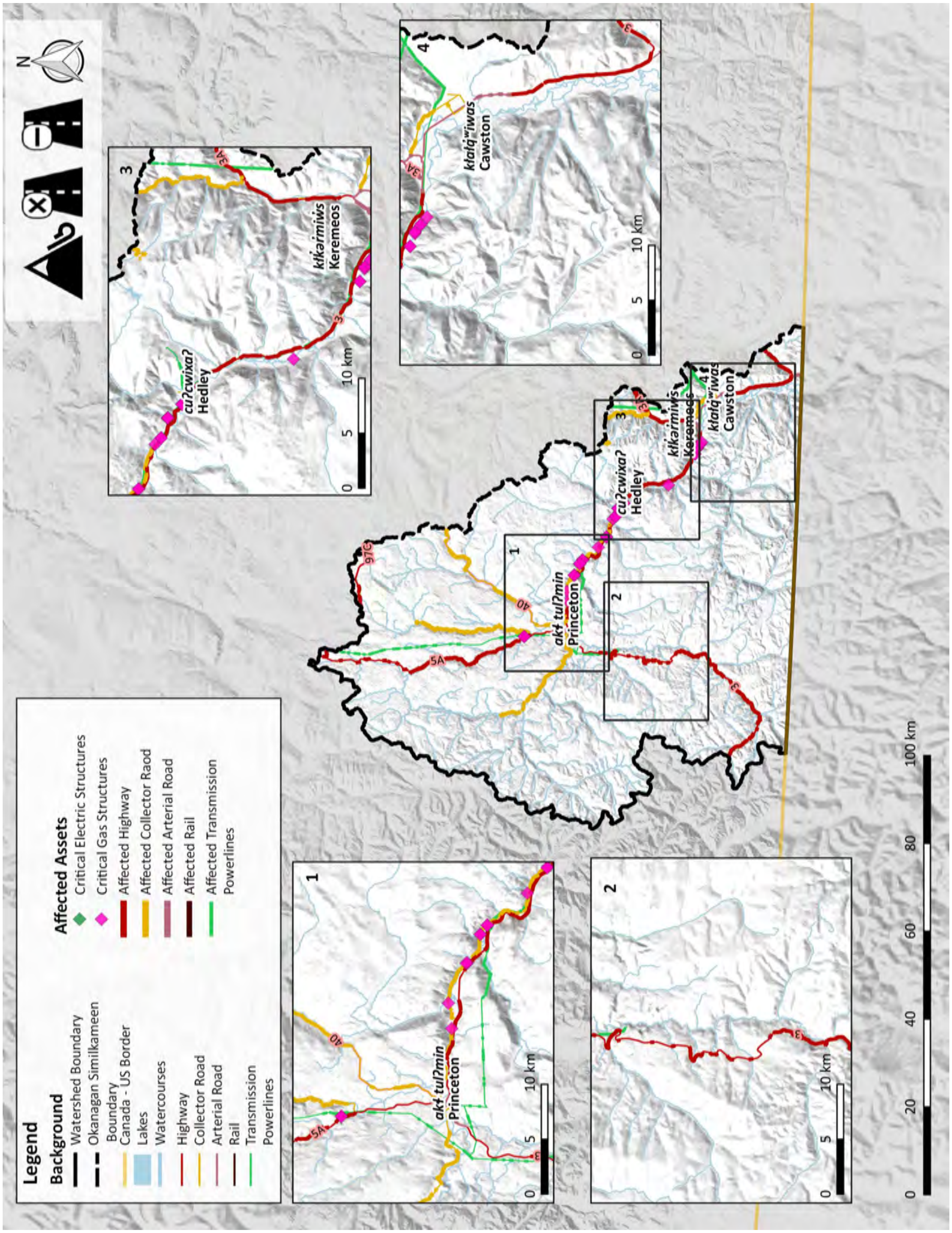


Figure 29: Disruption indicator consequences from debris flow in the Similkameen.

5.7 Summary of Consequences

The consequence map figures produced for each of the indicators and watershed paint a picture of where there are potential consequences from flood and debris flow hazards. However, the reader is reminded that flood and debris flows are different processes which were modelled using different approaches. The aggregated consequence data allows *relative* comparisons between the flood and debris flow scenarios that were developed for this project.

The consequence analyses provides a spatial context to think about where efforts need to be targeted in order to obtain the largest return on investment on adaptation measures.

Specific commentary based on the results follows:

- There are large consequences across all indicators for both flood and debris flow hazards.
- The number of potentially affected people from debris flow is similar to that of the low flood scenario; however, relative consequences from debris flow are higher for the other indicators, and typically fall between the medium and high flood scenarios.
- Generally, debris flow hazard is more widely spread and therefore has a greater influence on indicators affecting rural areas. In contrast, flood hazard areas are more constrained but often affect areas of high development.
- Within the Okanagan watershed, consequences are typically concentrated within 10-20 km of the lakes that run through the centre of the watershed, and around the major population centres. However, culture and disruption indicator consequences are more widespread.
- Within the Similkameen watershed, consequences are typically concentrated in the major population centres near Princeton, Keremeos, Tulameen, and Hedley. There are also significant consequences along the main highways.
- While the absolute number of consequences in the Similkameen watershed are generally lower than those in the Okanagan watershed, the relative consequences (expressed in percentages on a watershed basis) are often similar or even higher in the Similkameen.

Given the above, the following notes can inform adaptation efforts:

- All consequence categories should be considered important, and they should be addressed within any adaptation planning process.
- Flood and debris flow hazards are different in nature, leading to different consequences depending on the indicator and area. Floods tend to affect more highly-populated areas located close to large rivers and lakes.
- The geographically-dispersed nature of the consequences highlights the need to consider rural areas. The map figures highlight key transportation and utilities consequences that are likely to have a disproportionate consequence on these communities.

6 Risk Assessment

The quantitative aspects of a risk assessment include assessing the combination of a hazard's likelihood with the consequences of that hazard (see Section 1.5). As shown in Figure 4, a mapping technique was used to spatially assess risk. Likelihood was based on 3 flood scenarios and 1 debris flow scenario (see Chapter 3). Consequence was based on 5 exposure indicators for flood, and 6 indicators for debris flow (see Chapter 4).

The risk scoring 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 simplified approach to estimating risk using a matrix of scores that are easy to understand. Scores are assigned to likelihood and consequence, which are multiplied to provide a risk score.

6.1 Scoring Methods

Risk scoring is a quantitative exercise to obtain relative comparisons of consistent information. To do this, the consequence data is aggregated on a watershed basis (i.e., Okanagan and Similkameen) for each exposure indicator through classification. The benefit of this approach is that it allows risk to be scored on a larger scale of interest, and consequences to be assessed over time. These processes are explained below.

6.1.1 Flood Hazard Likelihood Scoring

The three flood scenarios that were used include both frequent events (low magnitude scenario), as well as rare events (high magnitude scenario). Table 22 was used to calculate likelihood scores for each of the flood scenarios. The likelihood score was based on a high-level interpretation of the event AEP, as described in Appendix B. The 5-point likelihood score scale (or 11-point scale, when using 0.5 denominations) is logarithmic. 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. & Ebbwater Consulting Inc., 2017) presented in the current National Disaster Mitigation Program (NDMP) Risk Assessment Information Template (RAIT).

Table 22: Likelihood rating for flood risk assessment.

Scenario	Likelihood Qualifier	Likelihood Score
-	Almost certain	5.0
Low	More Likely	4.0
Moderate	Unlikely	3.0
High	Less Likely	2.5
-	Rare	2.0
-	Very rare	1.0
-	Extremely Rare	0.0

6.1.2 Debris Flow Hazard Likelihood Scoring

The single debris flow scenario was based on locations with a high or very high susceptibility to debris flow initiation, along with generalized debris flow path modelling (see Section 3.2). Based on this process, a likelihood score of 3.5 was assigned to the debris flow hazard layer.

6.1.3 Consequence Scoring

Similar to the likelihood scores, the consequence scoring system was drawn from materials created to support program development at several federal agencies (Public Safety Canada, Natural Resources Canada, National Research Council) (AIDR, 2015; Stantec Consulting Ltd. & Ebbwater Consulting Inc., 2017) and summarized in Table 23. For each indicator, a score from 1 to 5 is assigned, where 1 demonstrates nuisance consequences, and 5 demonstrates catastrophic consequences. The quantitative measures are represented on a logarithmic scale and scores are considered relative to the whole Okanagan-Similkameen region.

Table 23: Quantitative scores and measures for consequence ratings.

Level	Score	Measure
Environment: 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.
Culture: 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.
Mortality: Number of deaths and/or missing persons attributed to disasters per population of interest		
Catastrophic	5	Deaths greater than 1 in 10 people in the project area
Major	4	Greater than 1 in 100 but less than 1 in 10 people in the project area
Moderate	3	Greater than 1 in 1,000 but less than 1 in 100 people in the project area
Minor	2	Greater than 1 in 10,000 but less than 1 in 1,000 people in the project area
Limited	1	Less than 1 in 10,000 people in the project area
Affected People: Number of directly affected people exposed to disasters, per population of interest		
Catastrophic	5	Affected people greater than 1 in 10 people in the project area
Major	4	Greater than 1 in 100 but less than 1 in 10 people in the project area
Moderate	3	Greater than 1 in 1,000 but less than 1 in 100 people in the project area
Minor	2	Greater than 1 in 10,000 but less than 1 in 1,000 people in the project area
Limited	1	Less than 1 in 10,000 people in the project area
Economy: Direct economic exposure attributed to disasters, relative to approx. GDP for region of interest		
Catastrophic	5	Direct economic exposure of 40% or more of GDP
Major	4	Direct economic exposure of 4% to 40% of GDP
Moderate	3	Direct economic exposure of 0.4% to 4% of GDP
Minor	2	Direct economic exposure of 0.04% to 0.4% of GDP
Limited	1	Direct economic exposure of <0.04% of GDP

Level	Score	Measure
Disruption: Critical infrastructure exposure attributed to disasters		
Catastrophic	5	Disruption is widespread and very long term (2 months +)
Major	4	Disruption is widespread and long term (3 weeks - 2 months) and/or localized and very long term
Moderate	3	Disruption is widespread and significant (2 days - 3 weeks) and/or localized and long term
Minor	2	Disruption is widespread but short term (>2 days) and/or localized and significant
Insignificant	1	Disruption is localized and short term (< 2 days)

6.1.4 Risk Scoring

Once likelihood and consequence scores are determined for each of the scenarios, the risk score is calculated as the product of likelihood and consequence. The resulting risk scores can be described as 'very low' to 'extreme' (Table 24) and can be represented graphically in a risk matrix for communication (Figure 30).

Table 24: Risk scoring descriptions.

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

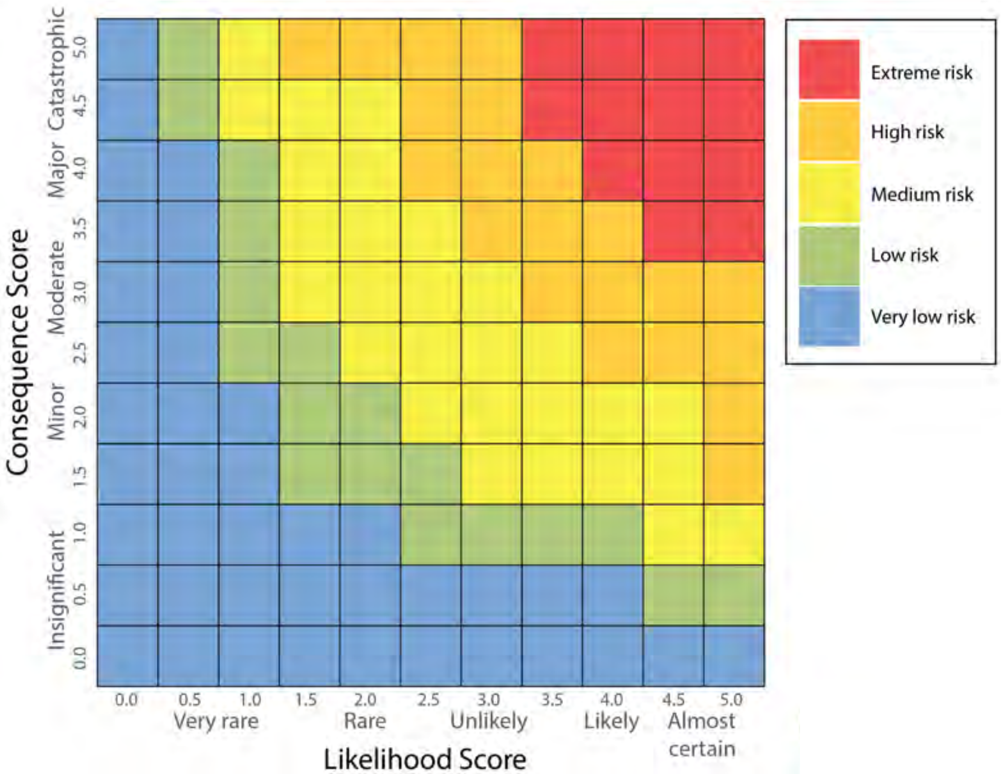


Figure 30: Example of a risk matrix. Based on AIDR (2015).

Considering the uncertainties of estimating and scoring consequences, confidence scores were also assigned to the final risk score for each indicator.

6.2 Results

The following sections present the results of the risk scoring for the project area for each indicator. The purpose of the scores is to provide a consistent comparison across the project area, and results can be compared between the Okanagan and Similkameen watersheds. In the risk matrices, they are distinguished by way of watershed icons. Further, the three flood scenarios can be compared, and in the risk figures they are distinguished by the letters "H", "M", and "L" to denote high, medium, and low scenarios. The risk confidence scores are determined by the individual confidence scores presented in Chapters 3 and 4 combined in accordance with Table 3.

6.2.1 Environment

Environmental consequences in this assessment focused on the negative consequences caused by the spread of human contaminants in the project area resulting from flood or debris flow. Environmental consequences were assessed semi-quantitively based on the number of contaminants affected and the number of fish, drinking water sources, and high biodiversity areas affected (Table 9 and Table 10). Professional judgement was then used to assess the likely spread and magnitude of consequences (see Table 23). The resulting scores are presented in Table 25 and Table 26 for flood and debris flow, respectively.

Table 25: Environment indicator scoring summary for flood.

Scenario	Likelihood Score	Consequence Score		Risk Score		Risk Confidence
		Okanagan	Similkameen	Okanagan	Similkameen	
High	2.5 (unlikely/rare)	5 (catastrophic)	4 (major)	12.5 (high)	10 (high)	Low
Moderate	3 (unlikely)	4 (major)	4 (major)	12 (high)	12 (high)	Moderate
Low	4 (likely)	4 (major)	3 (moderate)	16 (extreme)	12 (high)	Low

Table 26: Environment indicator scoring summary for debris flow.

Scenario	Likelihood Score	Consequence Score		Risk Score		Risk confidence
		Okanagan	Similkameen	Okanagan	Similkameen	
Debris Flow	2.5 (unlikely/rare)	5 (catastrophic)	4 (major)	17.5 (extreme)	10 (high)	Moderate

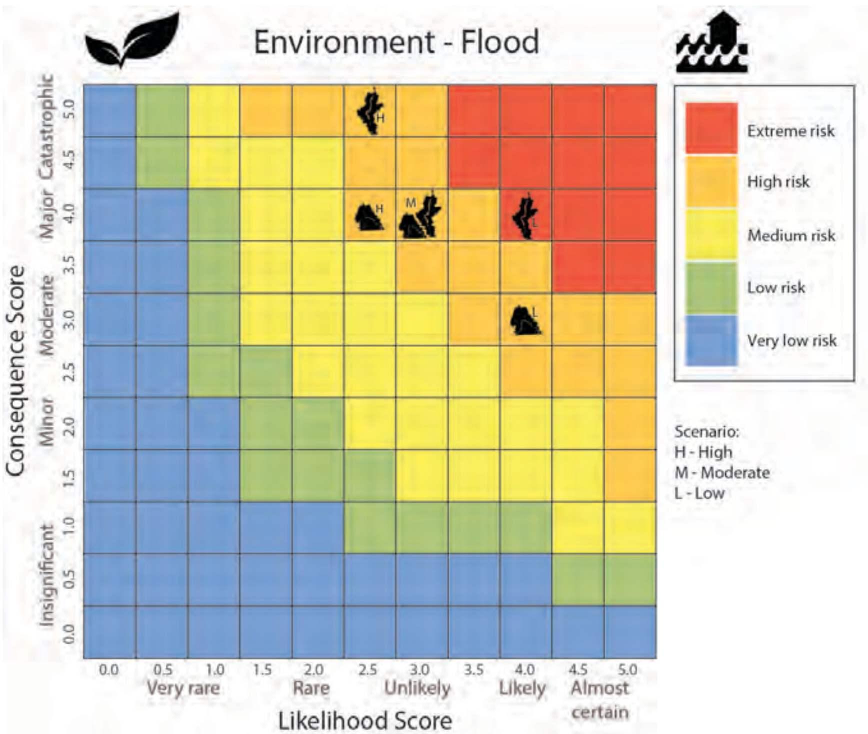


Figure 31: Risk matrix – environment – flood.

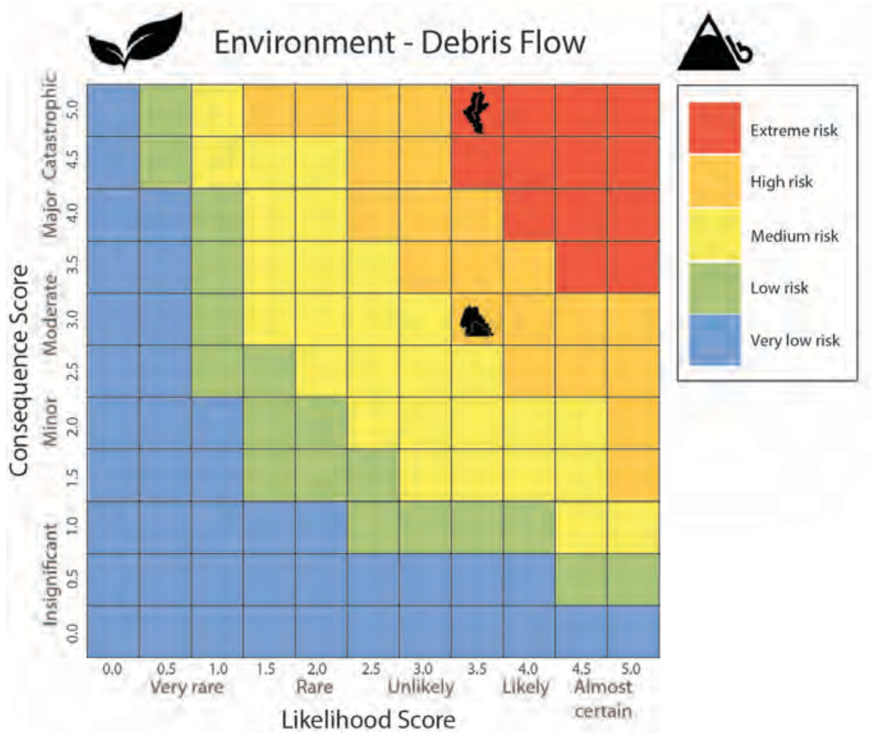


Figure 32: Risk matrix – environment – debris flow.

The confidence in this assessment is low. There may be other criteria that could be used to characterize potential environmental consequences due to flood and debris flow, both positive and negative, which could be included in the scope for future study. For example, a review of habitats which are dependent on these mechanisms could be conducted. In addition, a review of how potential contaminants are likely to spread and their likely consequence on sensitive ecosystems is important in building an understanding of this indicator. This could be done based on highly hazardous sites such as landfills or historic mining sites and/or areas with high concentrations of lesser contamination sources next to highly sensitive environments (for example, septic tanks near drinking water sources).

6.2.2 Culture

Culture represents a broad range of social and cultural factors which are likely to have a large influence on local communities beyond those captured in the other indicators. This study focused on historic and archaeological sites, amenities with a high social and cultural value, and recreational trails. While these assets are expected to have a high cultural value to communities in the area, this is a very limited view of cultural importance, in particular to the *Syilx* Okanagan people.

Cultural consequences were assessed semi-quantitively based on the assets affected (see section 5.2). Professional judgement was then used to assess the likely spread and magnitude of consequences (see Table 23). Out of all the proxies used, the historical and archaeological sites are perhaps the most vulnerable as damage to these sites is likely irreparable.

Table 27: Culture indicator scoring summary for flood.

Scenario	*Likelihood Score*	*Consequence Score*		*Risk Score*		*Risk confidence*
		Okanagan	*Similkameen*	*Okanagan*	*Similkameen*	
High	*2.5 (unlikely/rare)*	*5 (catastrophic)*	*3 (moderate)*	*12.5 (high)*	*7.5 (medium)*	*Moderate*
Moderate	*3 (unlikely)*	*4 (major)*	*3 (moderate)*	*12 (high)*	*9 (medium)*	*Moderate*
Low	*4 (likely)*	*3 (moderate)*	*2 (minor)*	*12 (high)*	*8 (medium)*	*Moderate*

Table 28: Culture indicator scoring summary for debris flow.

Scenario	*Likelihood Score*	*Consequence Score*		*Risk Score*		*Risk confidence*
		Okanagan	*Similkameen*	*Okanagan*	*Similkameen*	
Debris Flow	*3.5 (unlikely/rare)*	*5 (catastrophic)*	*4 (major)*	*17.5 (extreme)*	*14 (high)*	*Moderate*

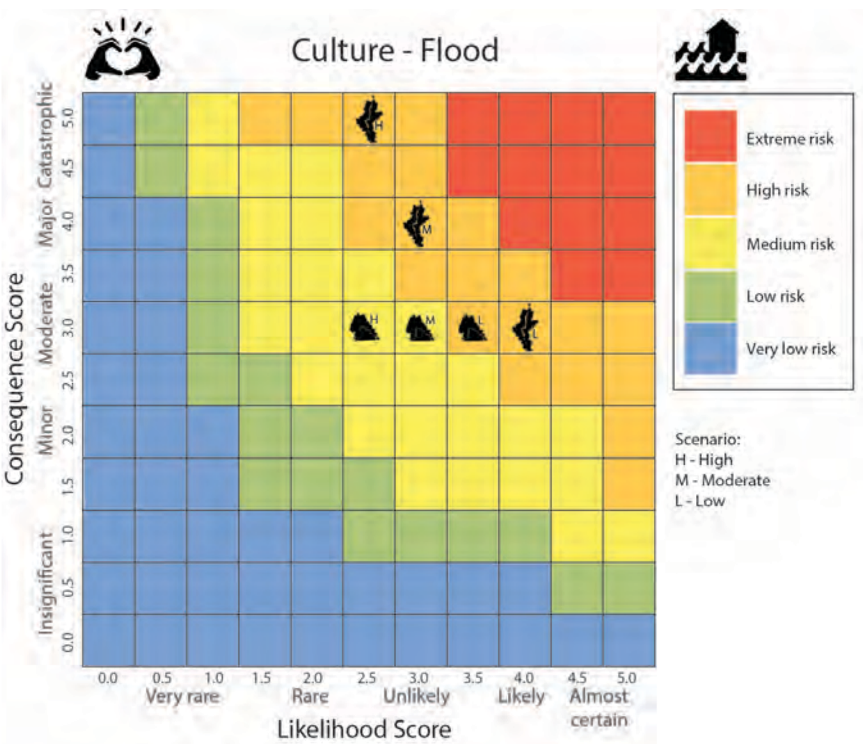


Figure 33: Risk matrix – culture – flood.

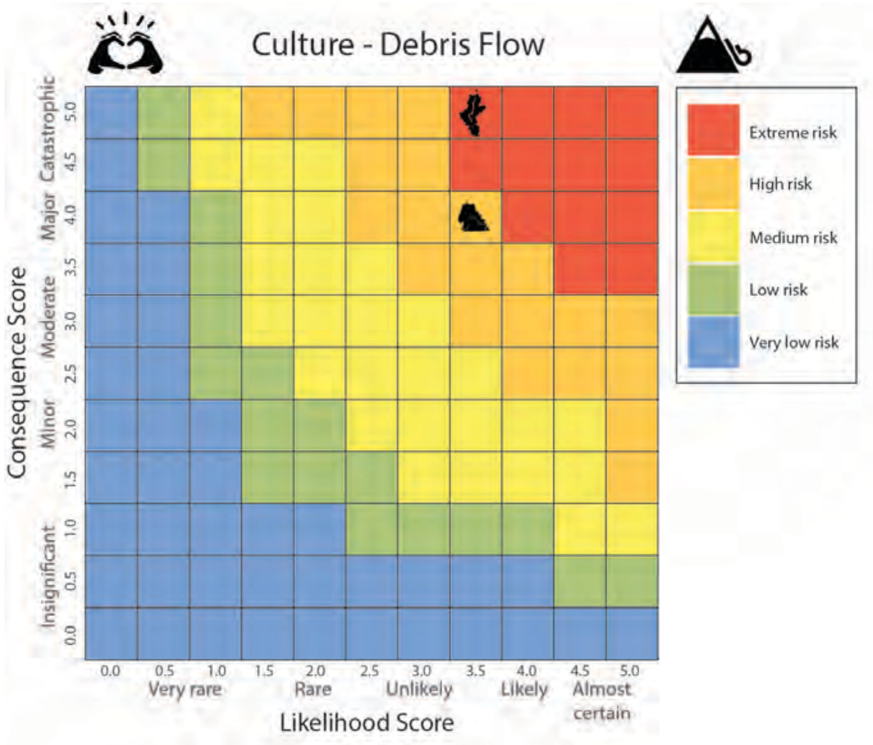


Figure 34: Risk matrix – culture – debris flow.

The confidence in this assessment is low. More direct input from communities in the project area would be required to appropriately capture potential culture indicator consequences based on community values. This assessment does, however, provide a good starting point for discussion and should ensure that culture is considered in the development of mitigation and adaptation solutions.

6.2.3 Mortality

Mortality consequence was scored using the building footprint figures presented in Table 13, relative to the total population of the Okanagan–Similkameen region. As discussed previously mortality was scored for debris flow only. The total population of the project area was based on the 2016 Census, and was estimated at 350,000. The population likely exceeds 360,000 today, but the census data was used as the best source of available spatial data. Using the rating methodology identified in Table 23, the resulting scores are summarised in Table 29 and Figure 35.

Table 29: Mortality indicator scoring summary for debris flow.

Scenario	*Likelihood Score*	*Consequence Score*		*Risk Score*		*Risk confidence*
		Okanagan	*Similkameen*	*Okanagan*	*Similkameen*	
Debris Flow	*3.5 (unlikely/rare)*	*5 (catastrophic)*	*3 (moderate)*	*17.5 (extreme)*	*10.5 (high)*	*Low*

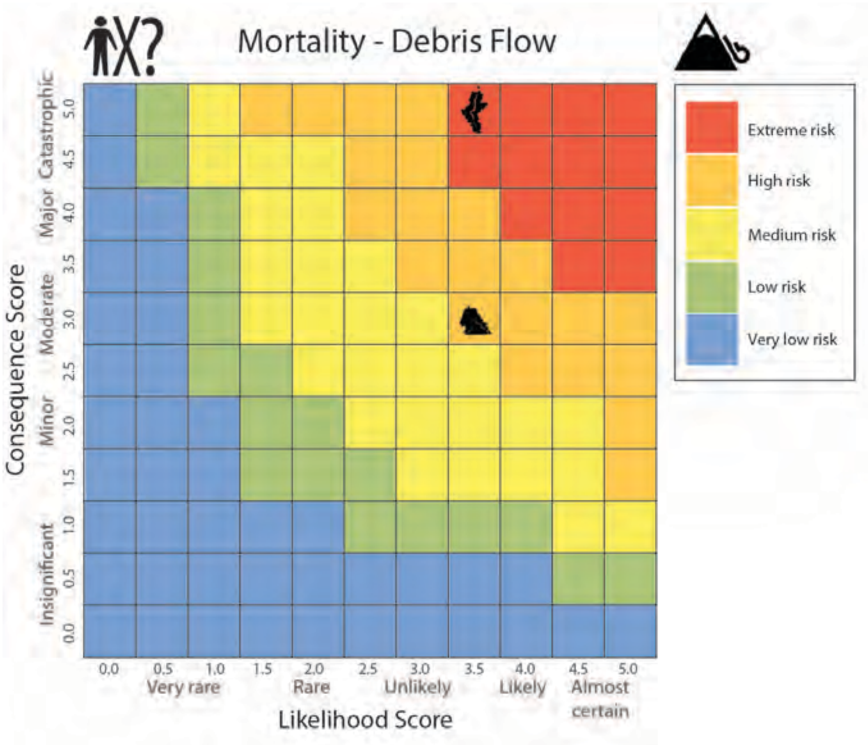


Figure 35: Risk matrix – mortality – debris flow.

The confidence in this assessment is low. This could be improved by more detailed investigations related to evacuation to link hazard and mortality rates. Investigations could improve understanding of the location of residential buildings, consider where people actually spend their time, evaluate hazard warning times and warning systems, and consider vulnerability factors such as demographics, accessibility, and evacuation routes.

6.2.4 Affected people

Consequence scores for affected people were produced using the census value from Table 14 and Table 15, scored relative to the total population of the project area. Using the rating methodology identified in Table 23, the resulting scores are presented in Table 30 for flood, and Table 31 for debris flow.

As discussed in Section 5.4, the census figures were compared to building footprints to validate the estimates. In general, the figures compared well. However, for the Similkameen watershed there was a significant discrepancy between the number of buildings and the census population exposed to flooding. For this reason, the confidence score for the affected people indicator was reduced to low in this watershed. Risk matrices for flood and debris flow are shown in Figure 36 and Figure 37, respectively.

Table 30: Affected people indicator scoring summary for flood.

Scenario	Likelihood Score	Consequence Score		Risk Score		Risk Confidence
		Okanagan	Similkameen	Okanagan	Similkameen	
High	2.5 (unlikely/rare)	5 (catastrophic)	4 (major)	12.5 (high)	10 (high)	Okanagan Moderate / Similkameen Low
Moderate	3 (unlikely)	5 (catastrophic)	3 (moderate)	15 (high)	9 (medium)	Moderate
Low	4 (likely)	5 (catastrophic)	3 (moderate)	20 (extreme)	12 (high)	Okanagan Moderate / Similkameen Low

Table 31: Affected people indicator scoring summary for debris flow.

Scenario	Likelihood Score	Consequence Score		Risk Score		Risk confidence
		Okanagan	Similkameen	Okanagan	Similkameen	
Debris Flow	3.5 (unlikely/rare)	5 (catastrophic)	3 (moderate)	17.5 (extreme)	10.5 (high)	Moderate

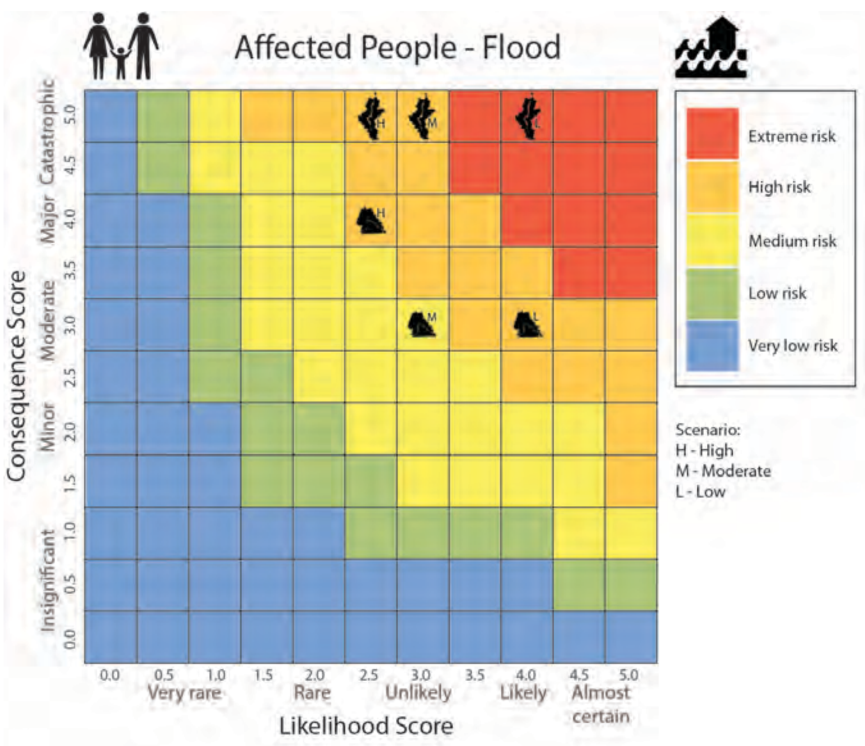


Figure 36: Risk matrix – affected people – flood.

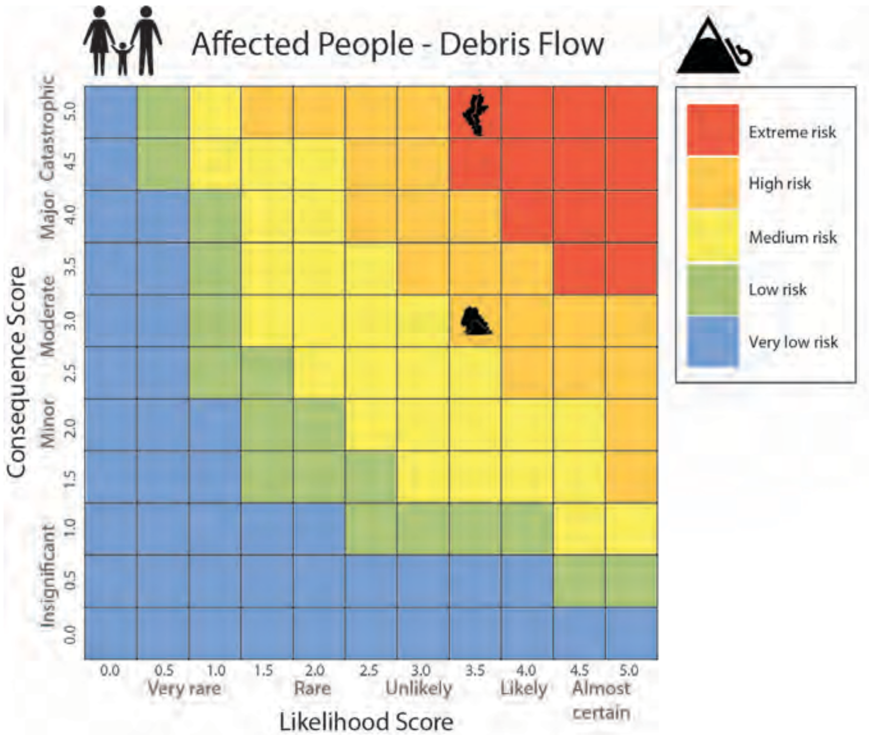


Figure 37: Risk matrix – affected people – debris flow.

Confidence in this assessment is moderate. This is largely because of the limitations in the census data and the lack of information on residential buildings. This could be improved with the completion of a specific study. This is particularly important for the Similkameen due to the discrepancy in the two data sources used to estimate consequences in this watershed.

6.2.5 Economy

Scores for the economy indicator consequences were produced using the buildings and land values from Table 16 and Table 17, scored relative to the total GDP of the project area ($23 billion). Using the rating methodology identified in Table 23, the resulting scores are presented in Table 32 and Figure 38 for flood, and Table 33 and Figure 39 for debris flow. The risk scores are very similar to those for the affected people indicator as the two indicators are highly linked.

Table 32: Economy indicator scoring summary for flood.

Scenario	*Likelihood Score*	*Consequence Score*		*Risk Score*		*Risk Consequence*
		Okanagan	*Similkameen*	*Okanagan*	*Similkameen*	
High	*2.5 (unlikely/ rare)*	*5 (catastrophic)*	*4 (major)*	*12.5 (high)*	*10 (high)*	*Low*
Moderate	*3 (unlikely)*	*5 (catastrophic)*	*3 (moderate)*	*15 (high)*	*9 (medium)*	*Moderate*
Low	*4 (likely)*	*5 (catastrophic)*	*3 (moderate)*	*20 (extreme)*	*12 (high)*	*Low*

Table 33: Economy indicator scoring summary for debris flow.

Scenario	Likelihood Score	Consequence Score		Risk Score		Risk confidence
		Okanagan	Similkameen	Okanagan	Similkameen	
Debris Flow	*3.5 (unlikely/rare)*	*5 (catastrophic)*	*3 (moderate)*	*17.5 (extreme)*	*10.5 (high)*	*Moderate*

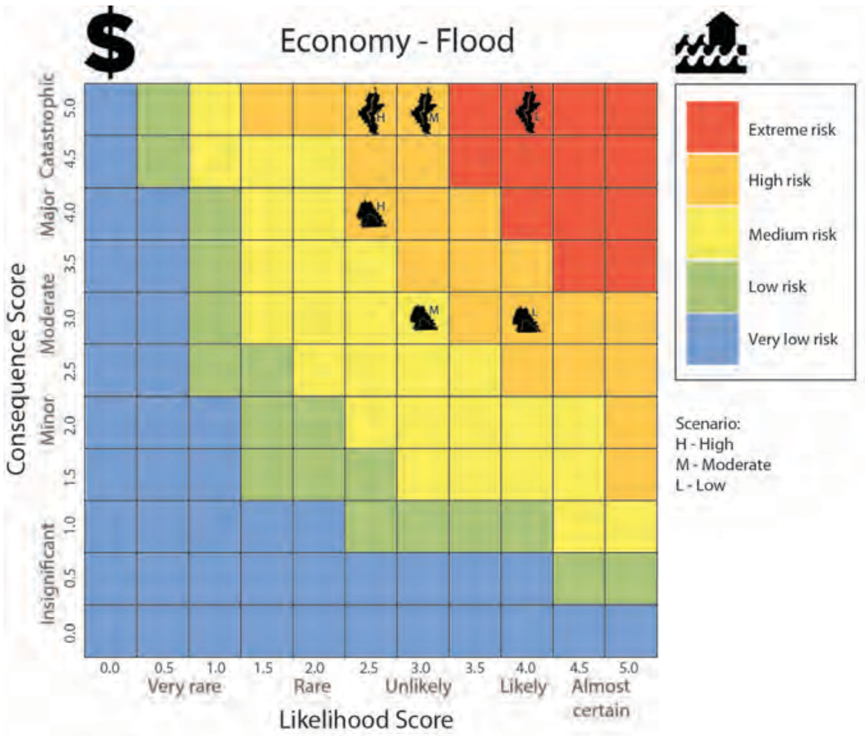


Figure 38: Risk matrix – economy consequences – flood.

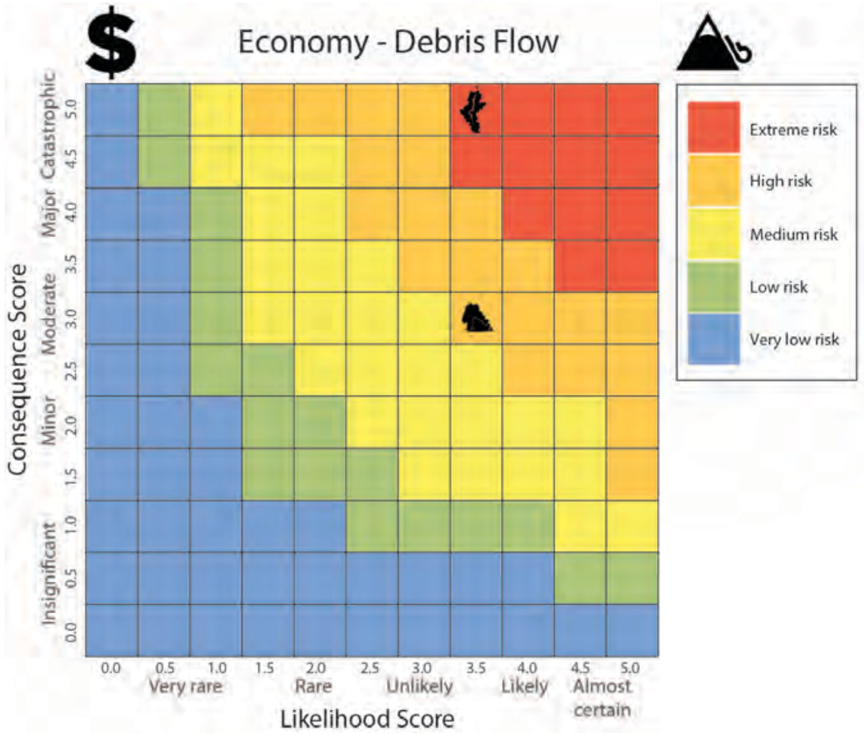


Figure 39: Risk matrix – economy consequences – debris flow.

The confidence in this assessment is low. This is largely due to the lack of consideration for the degree of damage caused by these hazards. A more detailed review including depths and velocity in priority areas would improve this confidence.

6.2.6 Disruption

Disruption represents the potential for widespread interruption of services, which can affect many other indicators (e.g., loss of power will affect businesses and residences). This assessment focused on disruption to transport and to utilities (see Table 18 to Table 21). Consequences were assed semi-quantitatively and by using professional judgement. The number and range of consequences were reviewed to determine how widely spread these consequences are likely to be, and the duration of disruption they are likely to cause (see Table 23). This included consideration of the relative damage likely to be caused by the different hazard scenarios.

The resulting scores are presented in Table 34 and Figure 40 for flood, and Table 35 and Figure 41 for debris flow.

Table 34: Disruption indicator risk scoring summary for flood.

Scenario	Likelihood Score	Consequence Score		Risk Score		Risk Confidence
		Okanagan	Similkameen	Okanagan	Similkameen	
High	*2.5 (unlikely/rare)*	*4 (major)*	*3 (moderate)*	*10 (high)*	*7.5 (medium)*	*Moderate*
Moderate	*3 (unlikely)*	*4 (major)*	*3 (moderate)*	*12 (high)*	*9 (medium)*	*Moderate*
Low	*4 (likely)*	*3 (moderate)*	*3 (moderate)*	*12 (high)*	*12 (high)*	*Moderate*

Table 35: Disruption indicator risk scoring summary for debris flow.

Scenario	Likelihood Score	Consequence Score		Risk Score		Risk confidence
		Okanagan	Similkameen	Okanagan	Similkameen	
Debris Flow	*3.5 (unlikely/rare)*	*5 (catastrophic)*	*4 (major)*	*17.5 (extreme)*	*14 (high)*	*Moderate*

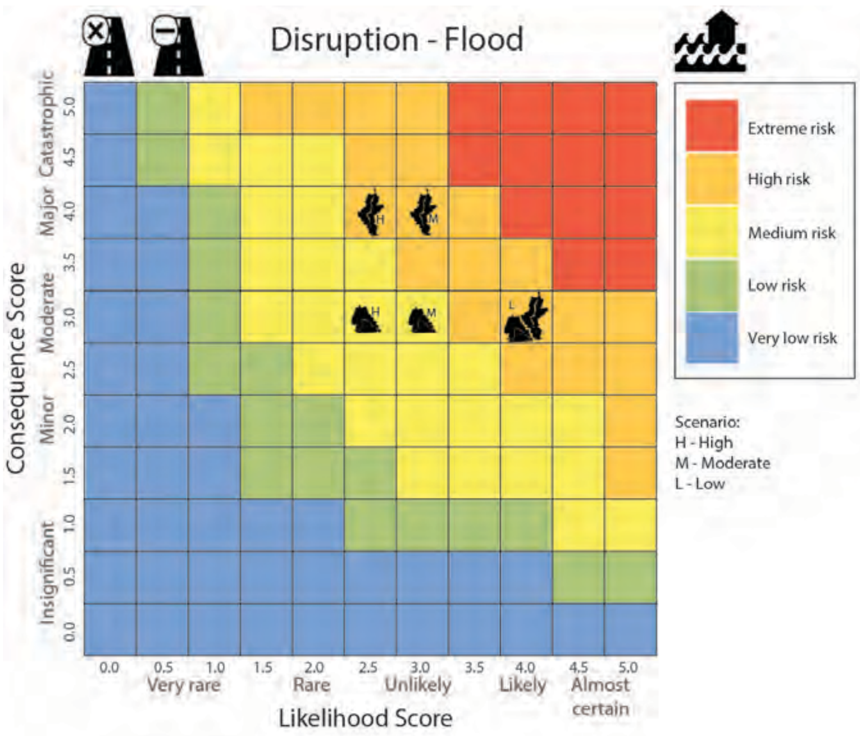


Figure 40: Risk matrix – disruption – flood.

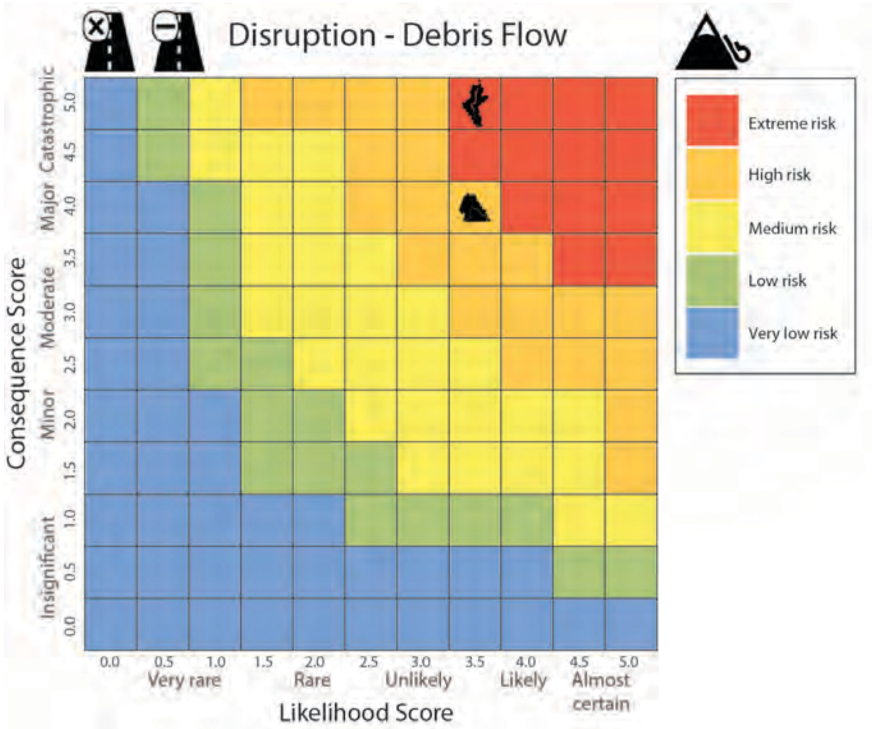


Figure 41: Risk matrix – disruption – debris flow.

Confidence in this assessment is moderate. This would be improved by a better understanding of the consequences of hazards on infrastructure in key locations and a thorough review of other critical infrastructure.

6.3 Summary of Risk Scoring and Discussion

The risk matrices in Section 6.2 show that the magnitude of risk from both flood and debris flow hazards, in both the Okanagan and Similkameen watersheds, ranges from medium to extreme across all indicators. This is shown in the risk summaries in Figure 42 and Figure 43 for flood and debris flow, respectively.

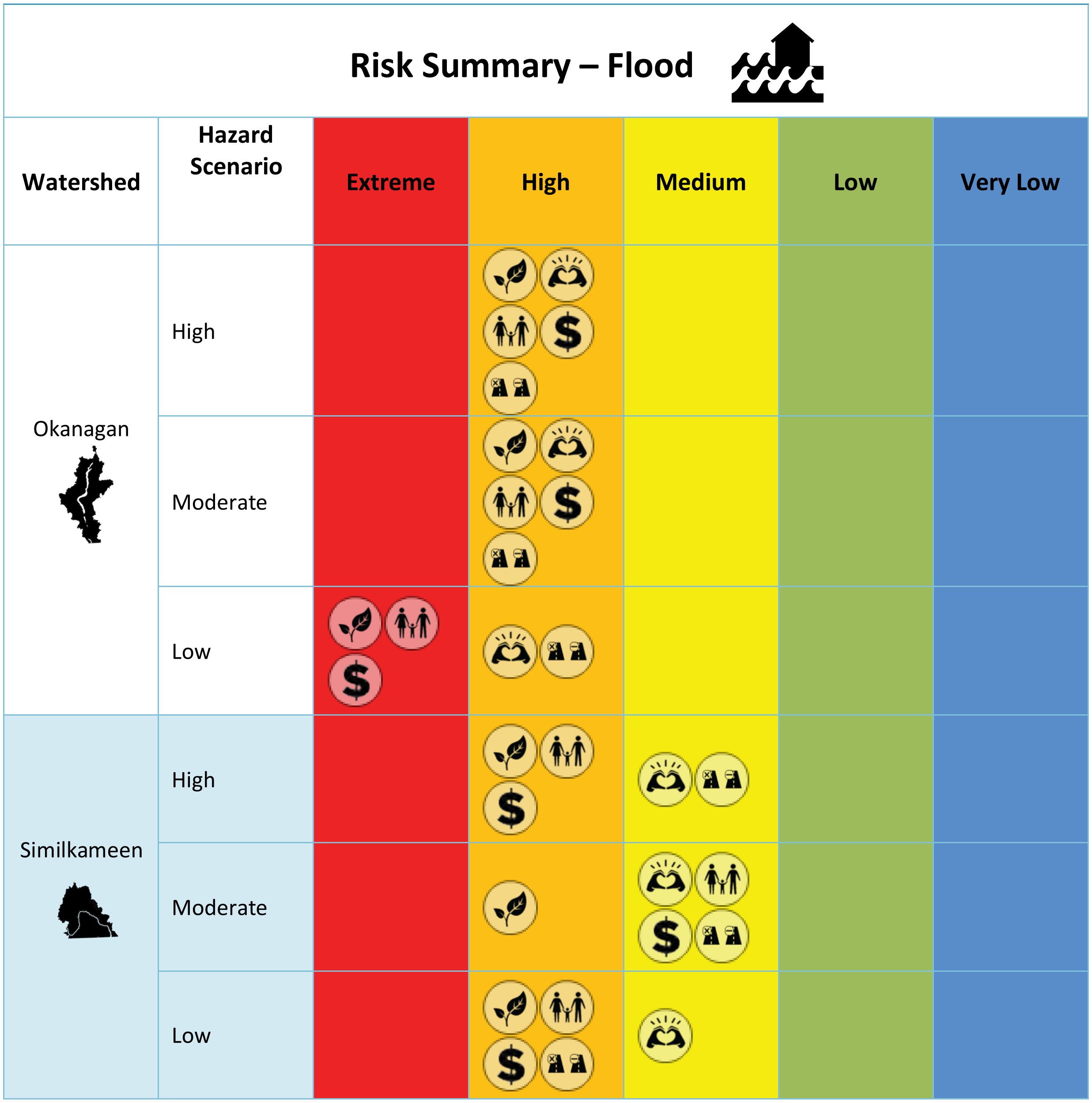


Figure 42: Summary of flood risk for all indicators.

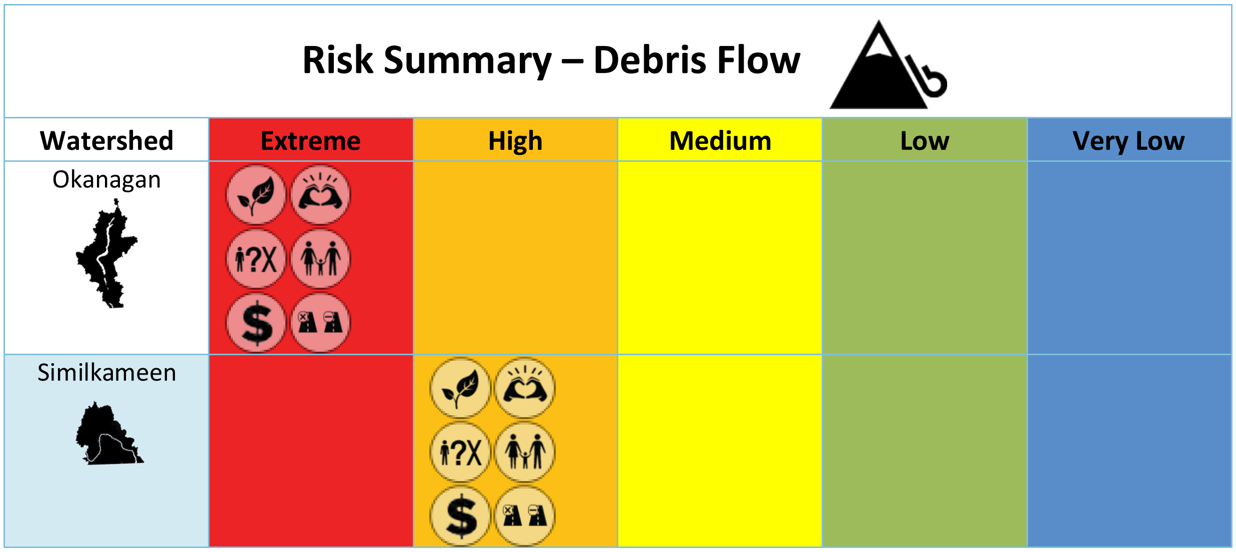


Figure 43: Summary of debris flow risk for all indicators.

Key takeaways from the risk summary figures are as follows:

- **Flood Risk:**
  - **Extreme** in the Okanagan watershed for the low scenario for the environment, affected people, and economy indicators. For these indicators, the more frequent but lower magnitude events result in higher risk compared to the less frequent but higher magnitude events.
  - High for many indicators including environment, affected people, and economy in both watersheds.
  - Medium for indicators such as culture and disruption in the Similkameen watershed.
  - Generally, it is higher in the Okanagan compared to the Similkameen watershed.
- **Debris flow Risk:**
  - **Extreme** in the Okanagan watershed for all indicators.
  - High in the Similkameen watershed for all indicators.

There is significant uncertainty in the definition of the low magnitude flood scenario due to a lack of flood mapping in the project area to calibrate this hazard layer (low confidence). However, the results highlight the importance of considering smaller, more frequent flood events in hazard risk assessments. Due to the difference in the nature of flood and debris flow hazards, the study results are not meant to directly compare risk results for the two hazards (some key differences are discussed in Section 6.3.1). However, the results do suggest that attention should be placed on reducing debris flow risk. Finally, risk is highest in the Okanagan watershed. However, considering that an excess of 95% of the project area population lives in the Okanagan, risk on a per capita basis is much higher in the Similkameen watershed. This suggests that similar attention to risk reduction should be applied to the Similkameen watershed.

6.3.1 Limitations

Quantitative risk assessment always has inherent limitations including the quality and quantity of hazard and exposure data, including the proxies developed and quantitative measures applied. A limitation in terms of the hazard data is that the layer was based on a representation of total hazard for the Okanagan-Similkameen region; risk scores for specific locations or events are likely to be lower, due to a reduced frequency of events at local scales. A limitation in terms of exposure is that indicators were defined with limited information. This should be taken into consideration for the next steps of the longer-term adaptation initiative. For example, better quantitative information and more community input is needed for the culture indicator.

The consulting team applied significant judgment in developing proxies and general assumptions (e.g., scaling the study to the whole of the project area when using dollar terms). This judgment was influential in the final risk scores and could have been different if different decisions had been made. However, where possible the consulting team used spatially consistent quantitative data and applied scoring methods based on international best practice. This included providing comments on confidence in data and decisions. Therefore, this study should be considered robust for the purposes of this project.

6.3.2 Considerations for Adaptation Planning

In Chapter 3, some of the differences in modelling and mapping of flood and debris flows were discussed, including their spatial extent. These hazards differ according to a few other key factors, which are part of the complex natural and human system that were not fully represented within this Quantitative Study. Key characteristics such as ecosystem benefits, time of onset, duration, spatial distribution, level of consequence, likelihood, and management systems are discussed in Table 36 to highlight further limitations of this study and to provide considerations for adaptation planning.

Table 36: Summary of key flood and debris flow characteristics and adaptation planning considerations.

Key Characteristic	Discussion	Adaptation Planning Considerations
Ecosystem Benefits	Viewed from the perspective of ecosystems, flood and debris flow phenomena can provide benefits including habitat diversity and nutrients.	This study considered flood and debris flow hazards in terms of their negative consequences. The positive benefits require consideration and are discussed in the Qualitative Study. Adaptation options should consider making room for water where possible, instead of “fighting nature”.
Cumulative Pressures	Pressures such as climate change, urban development, and industrial activity are causing flood and debris flow hazards to increase. Significant literature exists on these subjects, however, few analyses view natural hazards in terms of the cumulative pressures. This process is time and resource intensive.	Cumulative pressures on hazards were not considered in this Quantitative Study due to the effort required to model and map them. These important considerations are discussed in the Basis of Study based on literature review, and in the Qualitative Study based on participant input.

Key Characteristic	Discussion	Adaptation Planning Considerations
Time of Onset	While flood warning time can be short (e.g., in the case of dam breach), forecasting is generally well developed and flood mechanisms well understood; This leads to relatively to good warning times. In contrast, debris flows often occur quickly and with very little warning.	Results do not provide information that can be used to inform warning times. Lack of warning results in less time to prepare for and evacuate prior to an event, with potential consequences to many indicators. Greater warning times are likely to reduce the hazard's consequences.
Duration	Flood events can last for weeks whereas debris flow events are usually much shorter in duration. The cleanup from both of these events, however, can take much longer. The longer an event lasts, the greater are the potential indirect consequences through cascading effects.	Results do not provide information on event durations. This can affect the cultural and affected people indicators as life can take a long time to return to normal. "Downstream" disruptions can be important as consequences can occur outside of the hazard area.
Distribution	In general flood hazards are likely to be more widespread compared to debris flows. Debris flow hazards are likely to be less extensive (i.e. smaller number of locations for a given storm).	The distribution of hazard occurrence is not evenly distributed as the maps created in this study suggest. Forecasting the actual occurrence of events is dependent on more detailed geohazard studies, and environmental monitoring systems.
Level of Consequence	The level of consequence from a hazard event is dependent on various factors related to the hazard itself (e.g., depth and velocity), and to the vulnerability of the exposed asset. Due to the material entrained, debris flows can be much more destructive than floods.	The level of consequences was taken into account for several indicators. In general, the indicators used to analyze flood and debris flow were the same. However, comparing magnitudes and the consequences of flood and debris flow was outside of the scope of this study.
Likelihood	There are differences in the mechanisms that cause floods and debris flows; therefore, they have different likelihoods of occurrence.	The likelihood of an event has been included in this study to a degree in the use of three flood scenarios; however, the exact likelihood of each event was not been defined. The likelihood of debris flow events has also not been defined.
Management	There are multiple flood management systems in the project area including dikes and the regulation of mainstem lakes in Okanagan Lake; these reduce	Due to the high-level nature of the analysis, flood management systems were not included within the flood hazard areas.

Key Characteristic	Discussion	Adaptation Planning Considerations
	the consequences of flooding. There are no similar management systems in place for debris flows.	From this point-of-view, the delineated flood hazard areas are conservative.

7 Conclusion

This Quantitative Study has described the technical considerations and steps used to assess flood and debris flows, and to determine risk scores for each. This was achieved through a data gathering process, and detailed hazard assessments for flood and debris flow that were completed separately. Three flood hazard layers (scenarios) were produced based on different magnitudes. Exposure analyses were completed for 6 indicators, based on data proxies. The spatial hazard and exposure layers were overlaid in a GIS and the results were used to quantify the consequences for each indicator. Risk scores were then calculated based on the product of likelihood and consequence scores. The findings from this report provide a technical basis to complement findings from the Qualitative Study. The numerical results are supported by the spatial outputs presented in the Map Book. The findings from the Quantitative and Qualitative studies are integrated in the Synthesis and Recommendations report to provide next steps for priority-setting in the project area.

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Appendix A Data Summary

All appendices for this report are packaged as a separate document.

Appendix B Flood Hazard Assessment

All appendices for this report are packaged as a separate document.

Appendix C Debris Flow Hazard Assessment (Palmer)

All appendices for this report are packaged as a separate document.