FRASER BASIN COUNCIL

THOMPSON RIVER WATERSHED GEOHAZARD RISK PRIORITIZATION

FINAL
March 31, 2019

BGC Project No.:
0511002

Prepared by BGC Engineering Inc. for:
Fraser Basin Council

EXECUTIVE SUMMARY

A geohazard risk prioritization initiative for the entire Thompson River Watershed (TRW) was launched in February 2018 at a Community-to-Community Forum in Kamloops, British Columbia (BC), coordinated by Fraser Basin Council (FBC) with participation of local governments and First Nations.

FBC subsequently retained BGC Engineering Inc. (BGC) to carry out a clear-water flood, steep creek (debris flood and debris flow), and landslide-dam flood risk prioritization of the TRW with the support of Kerr Wood Leidal Associates (KWL), with funding provided by Emergency Management BC (EMBC) and Public Safety Canada under Stream 1 of the Natural Disaster Mitigation Program (NDMP, 2018).

The primary objective of this initiative is to characterize and prioritize flood, steep creek, landslide hazards in the TRW that might impact developed properties. The goal is to support decisions that prevent or reduce injury or loss of life, environmental damage, and economic loss due to geohazard events. Completion of this risk prioritization study is a step towards this goal.

This study provides the following outcomes across the TRW:

- Identification and prioritization of flood and steep creek geohazard areas based on the principles of risk assessment (i.e., consideration of both hazards and consequences)
- Web application to view prioritized geohazard areas and supporting information
- Evaluation of the relative sensitivity of geohazard áreas to climate change
- Gap identification and recommendations for further work.

These outcomes support FBC and stakeholders to:

- Continue operating under existing flood-related policies and bylaws, but based on improved geohazard information and information management tools
- Review and potentially revise Official Community Plans (OCPs) and related policies, bylaws, and land use and emergency management plans
- Undertake flood resiliency planning, i.e., the ability of an area "to prepare and plan for, [resist], recover from, and more successfully adapt to adverse events" (NRC, 2012)
- Develop a framework for geohazard risk management, including detailed hazard mapping, risk assessment, and mitigation planning
- Prepare funding applications to undertake additional work related to geohazard risk management within the TRW.

This study provides results in several ways:

- This **report** summarizes methods and results, with additional details in appendices.
- **Web application** displaying all geohazard areas on an online mapp. This application represents the main way to interact with study results. Users can see large areas at a glance or view results for a single site. Appendix H provides a guide to navigate Cambio Communities.

- **Geodatabase** with prioritized geohazard áreas.
- **Appendix J** provides an Excel spreadsheet with summary statistics of results and attributes of prioritized geohazard areas.

In total, BGC identified and prioritized 6225 geohazard areas encompassing over 4,000 km^2 (7%) of the TRW (Table E-1, Figure E-1). Compared to the entire TRW, about 30% of the Census population, 50% of assessed building values, 30% of business locations, and most of the major transportation routes are within or cross these areas.

Table E-2 lists the results worksheets, which are provided in Appendix J. These worksheets can be filtered and sorted to view ranked hazard areas by type and priority. Note that clear-water flood and landslide-dam flood geohazard areas substantially overlap and elements at risk statistics about these areas should not be summed.

There are additional factors for risk management and policy making that are outside the scope of this assessment that local authorities may consider when reviewing prioritization results. For example, additional factors include the level of risk reduction achieved by existing structural mitigation (dikes), comparison of the risk reduction benefit to the cost of new or upgraded flood risk reduction measures, and the level of flood resiliency in different areas.

Appendix I provides the example Risk Assessment Information Template (RAIT) form required by the National Disaster Mitigation Program (NDMP).

Table E-1. Number of prioritized areas in the TRW, by geohazard type.

Row Labels	Priority Level					Grand Total
	Very High	High	Moderate	Low	Very Low	
Clear-Water Floods		**344**	**609**	**3969**	**0**	**4922**
Waterbody (subtotal)		67	109	379	0	**555**
Watercourse (subtotal)		277	500	3590	0	**4367**
Landslide-Dam Floods		**23**	**57**	**52**	**14**	**146**
Steep Creeks	**10**	**99**	**280**	**564**	**204**	**1157**
Grand Total (Count)	**10**	**466**	**946**	**4585**	**218**	**6225**
Grand Total (%)	**0.16%**	**7.49%**	**15.20%**	**73.65%**	**3.50%**	**100%**

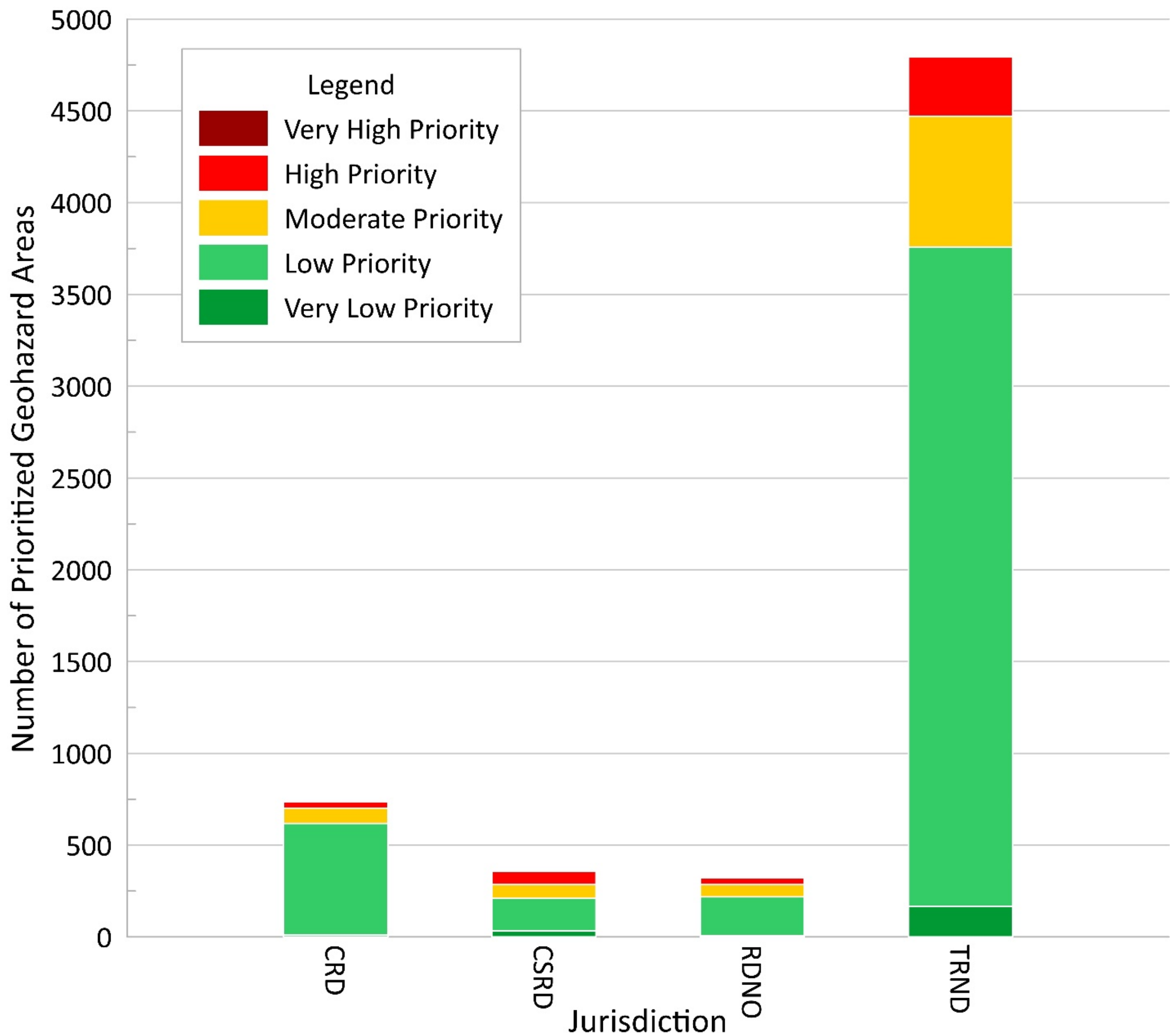

Figure E-1. Number of prioritized areas in within the TRW[1].

[1] List of abbreviations in figure: Cariboo Regional District (CRD); Columbia Shuswap Regional District (CSRD); Regional District of North Okanagan (RDNO); Thompson Nicola Regional District (TNRD)

Table E-2. Results worksheets provided in Appendix J.

Appendix J (Excel Worksheet Name)	Contents
Study Area Metrics	Summary statistics of select elements at risk (count of presence in geohazard areas)
Study Area Hazard Summary	Summary statistics of elements at risk, according to their presence in geohazard areas
Study Area Hazard Type Summary	Summary statistics of geohazard areas, according to the presence of elements at risk.
Priority by Jurisdiction	Summary statistics of prioritization results by jurisdiction.
Steep Creek Hazard Attributes	Attributes displayed in the information sidebar on Cambio Communities for all steep creek geohazard areas.
Clear-water Flood Hazard Attributes	Attributes displayed in the information sidebar on Cambio Communities for all clear-water flood geohazard areas.
Landslide-dam Flood Hazard Attributes	Attributes displayed in the information sidebar on Cambio Communities for all lanslide-dam flood geohazard areas.

BGC developed simplified evaluation methodologies based on readily available data at the regional scale to differentiate relative climate change sensitivity between hazard sites located within the major sub-basins of the TRW. For clear-water floods, regional, relative differences in hydro-climatic characteristics were used to characterize the relative sensitivity of flood hazard areas to changes in the timing and intensity of freshet floods, in response to region-wide projected declines in snowpack depth due to climate change as summarized in Appendix F. For steep creeks, watersheds were characterized as either sediment supply-limited or sediment supply-unlimited pertaining to the availability of readily available sediment for transport by debris flows and debris floods. Projected increases in extreme rainfall volumes and frequencies would impact the hazard frequency and magnitude of these two types of watersheds differently.

BGC also compared the current study and its recommendations to a 2017 province-wide review of government response to flood and wildfire events during the 2017 wildfire and freshet season (Abbott & Chapman, 2018). The Abbott-Chapman report included a total of 108 recommendations to assist the Province in improving its systems, processes and procedures for disaster risk management. Of these, BGC highlights 11 recommendations partially fulfilled by this study.

Gaps identified in this study can be categorized as those limiting the understanding of geohazards: in the characterizing of geohazard exposure (i.e., the built environment); and in the characterization of existing flood protection measures and flood conveyance infrastructure. In no case does this study replace site-specific geohazard risk assessments that aim to identify tolerable or acceptable risk or that support design of mitigative works. BGC also identified opportunities to improve geohazard information management and integrate risk-informed decision making into policy.

Table E-3 lists recommendations for consideration by FBC and local, regional, and provincial authorities. The rationale for each recommendation is described in more detail in the report. BGC encourages FBC and stakeholders to review this assessment and web tools from the perspective of supporting long-term geohazard risk and information management within the watershed. This effort would be greatly facilitated by provincial support and continued FBC coordination, to take advantage of efficiencies of scale.

Table E-3. List of recommendations.

Type	Description
Data Gaps	• Develop a plan to resolve the baseline data gaps outlined in this study, including gaps related to baseline topographic, bathymetric and stream network data; geohazard sources, controls, and triggers; geohazard frequency- magnitude relationships, flood protection measures and flood conveyance infrastructure, and hazard exposure (elements at risk).
Further Geohazards Assessments	• Geohazard areas: complete more detailed assessments for areas chosen by FBC or stakeholders as top priority, following review of this assessment. • Out-of-Scope areas: review areas noted as potentially containing geohazards, but not further assessed in this study.
Geohazards Monitoring	• Add real-time stream flow and precipitation monitoring functions to geohazard web applications, to support emergency monitoring. • Develop criteria for hydroclimatic alert systems informing emergency response. • Develop capacity for the automated delivery of alerts and supporting information informing emergency response.
Policy Integration	• Review Development Permit Areas (DPAs) following review of geohazard areas defined by this study. • Review plans, policies and bylaws related to geohazards management, following review of the results of this study. • Develop risk evaluation criteria that allow consistent risk reduction decisions (i.e., that define the term "safe for the use intended" in geohazards assessments for development approval applications)
Information Management	• Review approaches to integrate and share asset data and geohazard information across functional groups in government, stakeholders, data providers and risk management specialists. Such an effort would assist long-term geohazard risk management, asset management, and emergency response planning. • Develop a maintenance plan to keep study results up to date as part of ongoing support for bylaw enforcement, asset management, and emergency response planning.
Training and Stakeholder Communication	• Provide training to stakeholders who may rely on study results, tools and data services. • Work with communities in the prioritized hazard areas to develop flood resiliency plans informed by stakeholder engagement.

TABLE OF REVISIONS

ISSUE	DATE	REV	REMARKS

LIMITATIONS

BGC Engineering Inc. (BGC) prepared this document for the account of Fraser Basin Council, which is coordinating the work described in this document on behalf of local governments and First Nations in the Thompson River Watershed (TRW). The material in it reflects the judgment of BGC staff in light of the information available to BGC at the time of document preparation. Any use which a third party makes of this document or any reliance on decisions to be based on it is the responsibility of such third parties. BGC accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this document.

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ACRONYMS AND ABBREVIATIONS

Acronyms and abbreviations used in this report:

AGS	Australian Geomechanics Society
BC	British Columbia
BGC	BGC Engineering Inc.
Canmore	Town of Canmore
CRD	Cariboo Regional District
CSA	Canadian Standards Association
CSRD	Columbia Shuswap Regional District
TNRD	Thompson Nicola Regional District
RDNO	Regional District of North Okanagan
DEM	digital elevation model
FEMA	Federal Emergency Management Agency
FFA	flood frequency analysis
F-M	frequency-magnitude
FBC	Fraser Basin Council
GCM	global climate model
GEO	Geotechnical Engineering Office
I_{DF}	intensity (debris flow)
ISO	International Organization for Standardization
Lidar	Light Detection and Ranging
MoTI	BC Ministry of Transportation and Infrastructure
NDMP	National Disaster Mitigation Program
PCIC	Pacific Climate Impact Consortium
QRA	quantitative risk assessment

RFP	request for proposal
SLRD	Squamish-Lillooet Regional District
TRW	Thompson River Watershed

Thompson - Fraser River Confluence at Lytton.
Photo: Picture BC/Province of British Columbia

1.0 INTRODUCTION

1. INTRODUCTION

1.1. Objectives

A geohazard risk prioritization initiative for the entire Thompson River watershed (TRW) (Figure 1-1) was launched in February 2018 at a Community-to-Community Forum in Kamloops, British Columbia (BC), coordinated by Fraser Basin Council (FBC) with participation of local governments and First Nations.

FBC subsequently retained BGC Engineering Inc. (BGC) to carry out a clear-water flood, steep creek (debris flood and debris flow), and landslide-dam flood risk prioritization study for the TRW with the support of Kerr Wood Leidal Associates (KWL). Funding was provided by Emergency Management BC (EMBC) and Public Safety Canada under Stream 1 of the Natural Disaster Mitigation Program (NDMP, 2018) for work carried out under the terms of an agreement between FBC and BGC dated April 2, 2018. The scope of work was described in BGC's March 9, 2018 proposal titled "Thompson Watershed Flood and Debris Flow Risk Assessment", which was authorized in an April 2, 2018 contract between FBC and BGC.

The primary objective of this initiative is to characterize and prioritize clear-water flood, steep creek (debris-flood and debris-flow) and landslide-dam flood hazards in the TRW that might impact developed properties. The goal is to support decisions that prevent or reduce injury or loss of life, environmental damage, and economic loss due to geohazard events. Completion of this risk prioritization study is a step towards this goal.

The regional study provides the following outcomes to FBC and authorities making geohazards management–related decisions within the TRW:

- Geohazard area identification and prioritization based on the principles of risk assessment (i.e., consideration of both hazards and consequences)
- Geospatial information[2] management for both geohazard areas and elements at risk
- Web application (Cambio Communities™) access to view prioritized geohazard areas and supporting information
- Evaluation of the relative sensitivity of geohazard áreas to climate change.
- Information gap identification and recommendations for further study and review of policy related to geohazards.

These outcomes provide a basis for:

- Geohazard risk-informed Official Community Plans (OCPs) and associated planning and land use management, bylaw development and implementation, and emergency response planning
- Flood resiliency planning, which speaks to the ability of an area "to prepare and plan for, [resist], recover from, and more successfully adapt to adverse events" (NRC, 2012)
- A framework for geohazard risk management, including detailed hazard mapping, risk assessment, and mitigation planning

[2] Geospatial information is data associated with a specific location.

- Funding applications to undertake additional work related to geohazard risk management.

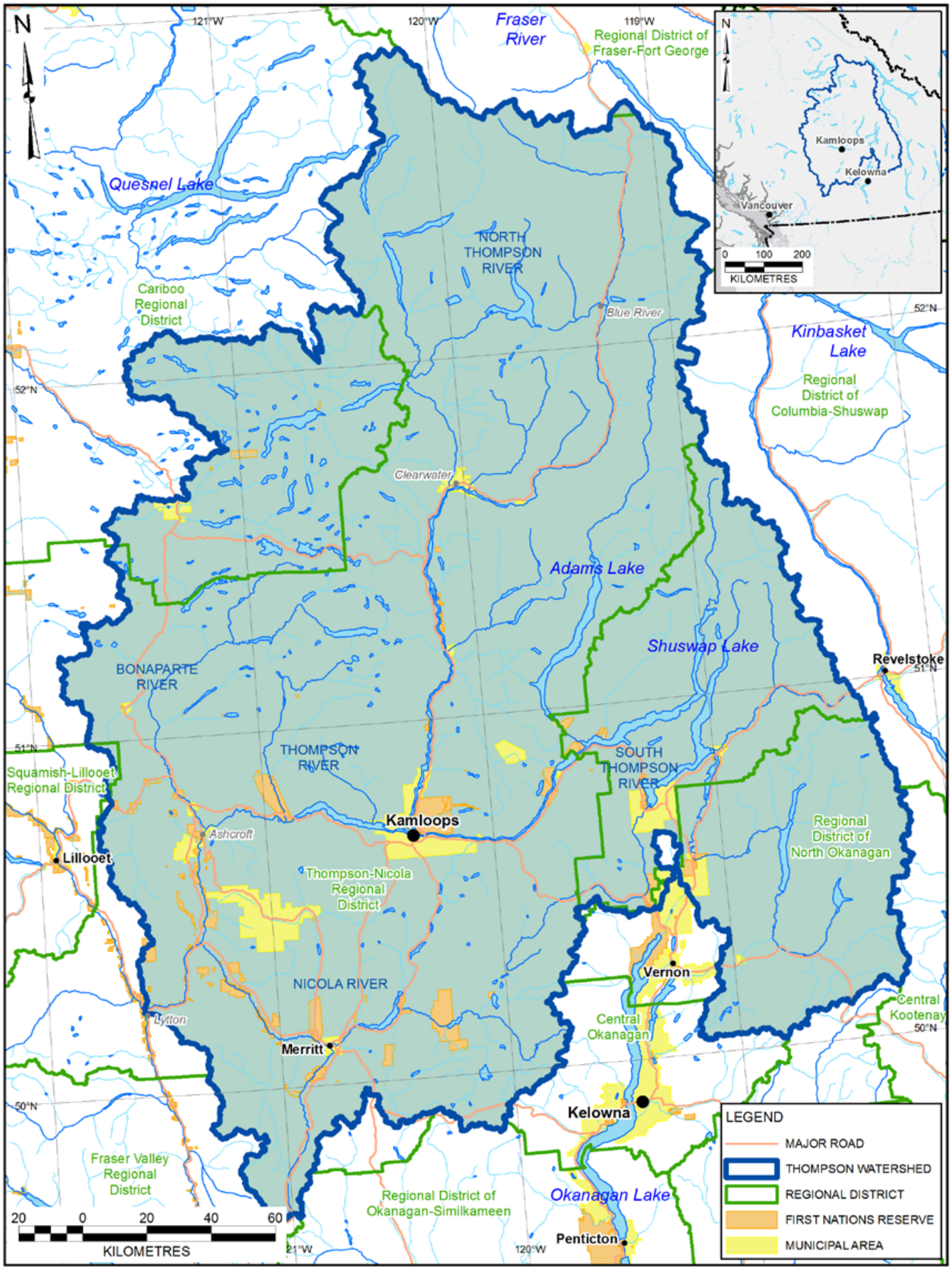

Figure 1-1. Thompson River Watershed.

The work considered the Engineers and Geoscientists BC (EGBC) Professional Practice guidelines for Legislated Flood Assessments in a Changing Climate in BC (EGBC, 2012), Flood Mapping in BC Professional Practice Guidelines (EGBC, 2017), as well as the Draft Alberta

Guidelines for Steep Creek Risk Assessments[3] (BGC, March 31, 2017). The study framework also considered the United Nations International Strategy for Disaster Reduction (UNISDR) Sendai Framework (UNISDR, 2015). Specifically, it focuses on the first UNISDR priority for action, understanding disaster risk, and is a starting point for the remaining priorities, which focus on strengthening disaster risk governance, improving resilience, and enhancing disaster preparedness.

1.2. Why This Study?

The TRW is a mountainous region frequently subject to potentially damaging floods that can result in property damage, loss of life, and the interruption of rail, highway, energy, and resource transportation corridors across BC. These events span the full spectrum of clear-water floods through steep creek processes containing high concentrations of mineral and organic debris. While such events have always occurred, the floods that occurred in the spring of 2017 and the post-wildfire steep creek flood events of 2018 have caused recent significant damages, including loss of life, that have brought these issues to the forefront of current public and political concern.

Representative harmful and recent events include:

- Debris floods at Sicamous and Hummingbird Creeks in June 2012, which caused damage to several houses at Swansea Point and Two Mile. The debris flood at Sicamous Creek is the subject of a lawsuit currently before the courts
- Flooding in Cache Creek in 2015, 2017 (Figure 1-2), and 2018, which includes the flood-related fatality of the Cache Creek fire chief in 2017
- Flooding in Cherry Creek south of Kamloops BC in 2017 and 2018 (Figure 1-4)
- Robinson Creek debris flow, near Paradise Point, in May 2017, which led to one fatality and destroyed at least two houses (Figure 1-5)
- Debris flows in July and August 2018 that blocked Highways 1 and 97 in more than 40 places between Ashcroft and Clinton, BC (Figure 1-5). The debris flows were sourced from areas burnt by the 2017 Elephant Hill wildfire. The debris flows caused one fatality and several houses were affected by debris.

[3] No equivalent guidelines have yet been prepared by the Engineers and Geoscientists BC or the Province of BC.

Figure 1-2. Preventative sandbagging in May 2017 near the Cache Creek Fire Hall (Global News, May 5, 2017).

Figure 1-3. Damage from flooding in Cherry Creek in May 2018 (CJFC Today, May 7, 2018).

Figure 1-4. Damaged buildings from the 2017 Robinson Creek debris flow. Photo: BGC, May 7, 2017.

Figure 1-5. Debris flow blocking Highway 97 south of Clinton, BC on July 31, 2018 (MOTI, 2018). This area was burned in 2017 by the Elephant Hill Wildfire.

Despite the high frequency of damaging floods, the TRW is a region with gaps in both the availability and quality of flood hazard information. Specific gaps include:

- **Incomplete extent:** many areas subject to direct and indirect flood hazards have not been identified, and relatively few floodplains have been mapped.
- **Inconsistent extent or versions**: some data are spatially overlapping and potentially inconsistent across different sources and scales of assessment. Some datasets merge static snapshots from different time periods with missing metadata or versioning, or that contain dated information.
- **Process range insufficiently identified:** flood processes are highly diverse. Particularly at high return periods (greater than 100 years), issues such as extensive bank erosion, landslide dam outbreak floods, debris flows and debris floods may dominate the flood hazard.
- **Inconsistent methods and scale:** flood hazards have not been assessed and/or mapped with consistent methods or level of detail.
- **Inconsistent data standards:** data reside in disconnected databases with inconsistent data fields and attributes.
- **Inconsistent hazard ratings:** prior to the current regional study, no region-wide, geospatial dataset exists with consistent ratings for flood geohazards type, likelihood, magnitude or intensity (destructive potential).
- **Incomplete metadata:** documentation is rarely sufficient to make informed decisions about the use and limitations of flood geohazards data.
- **Incomplete classification of elements at risk**: for example, building footprints that could be used to assess flood vulnerability are only available for select buildings in the study area, and some cadastral parcels contain residential buildings that have not been identified and included in BC Assessment data.
- **Inconvenient format:** substantial flood hazards data exist within pdf format reports that cannot easily be georeferenced and integrated together to build a common knowledge base.
- **Not risk-based:** prior to the current study, information has not been available region-wide to support flood management decisions based on systematic assessment of both flood hazards and consequences.
- **Limited to no consideration of climate change**: there is currently a lack of integration between climate change and geohazards-focused studies, and there is a lack of consideration of indirect effects (i.e., changes to watershed hydrology resulting from wildfires). This may result in inadequate design of structures or landuse planning.

These gaps are being partially addressed by this regional study and support the mandate of municipal and regional governments within the TRW to reduce or prevent injury, fatalities, and damages during flood events. The work partially fulfills the first recommendation of the Auditor General of British Columbia's February 2018 report, titled *Managing Climate Change Risks: An Independent Audit*, which is to "undertake a province-wide risk assessment that integrates existing risk assessment work and provides the public with an overview of key risks and priorities" (Auditor General, 2018).

1.3. Terminology

This report refers to the following key definitions[4]:

- **Asset:** anything of value, including both anthropogenic and natural assets[5], and items of economic or intangible value.
- **Annual Exceedance Probability (AEP):** chance that a flood magnitude is exceeded in any year. For example, a flood with a 0.5% AEP has a one in two hundred chance chance (i.e., 200-year return period) of being exceeded in any year. While both terms are used in this document, AEP is increasingly replacing the use of the term 'return period' to describe flood recurrence intervals.
- **Clear-water floods:** riverine and lake flooding resulting from inundation due to an excess of clear-water discharge in a watercourse or body of water such that land outside the natural or artificial banks which is not normally under water is submerged. While called "clear-water floods", such floods still transport sediment. This term merely serves to differentiat from other flood forms such as outbreak floods or debris floods.
- **Steep-creek processes:** rapid flow of water and debris in a steep channel, often associated with avulsions and strong bank erosion. Most stream channels within the TRW are tributary creeks subject to steep creek processes that carry larger volumetric concentrations of debris (i.e., debris floods and debris flows) than clear-water floods. Appendix C provides a more comprehensive description of steep creek processes.
- **Consequence:** the conditional probability that elements at risk will suffer some severity of damage or loss, given geohazard impact with a certain intensity (destructive potential). In this study, the term was simplified to reflect the level of detail of assessment. Consequence refers to the relative potential for loss between hazard areas, given hazard impact with a certain intensity, but not an absolute estimate of loss.
- **Elements at Risk:** assets exposed to potential consequences of geohazard events.
- **Exposure model:** organized geospatial data about the location and characteristics of elements at risk.
- **Flood Construction Level:** a designated flood level plus freeboard, or where a designated flood level cannot be determined, a specified height above a natural boundary, natural ground elevation, or any obstruction that could cause flooding.
- **Flood mapping:** delineation of flood lines and elevations on a base map, typically taking the form of flood lines on a map that show the area that will be covered by water, or the elevation that water would reach during a flood event. The data shown on the maps, for more complex scenarios, may also include flow velocities, depth, other hazard parameters, and vulnerabilities.
- **Flood setback:** the required minimum distance from the natural boundary of a watercourse or waterbody to maintain a floodway and allow for potential erosion.
- **Geohazard:** all geophysical processes with the potential to result in some undesirable outcome, including floods and other types of geohazards.

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[4] CSA (1997), EGBC (2012, 2017)

[5] Assets of the natural environment that consist of biological assets (produced or wild), land and water areas with their ecosystems, subsoil assets and air (Glossary of Environment Statistics, 1997).

- **Hazardous flood:** a flood that is a source of potential harm.
- **Resilience:** the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.
- **Risk**: a measure of the probability of a specific geohazard event occurring and the consequence of that event.
- **Strahler stream order:** is a classification of stream segments by its branching complexity within a drainage system and is an indication of the significance in size and water conveying capacity at points along a river (Figure 4-1).
- **Waterbody:** ponds, lakes and reservoirs.
- **Watercourse:** creeks, streams and rivers.

1.4. Scope of Work

1.4.1. Summary

This work is being carried out under the terms of an agreement between FBC and BGC dated April 2, 2018. The scope of work was described in BGC's March 9, 2018 proposal titled "Thompson Watershed Flood and Debris Flow Risk Assessment". The work was authorized in an April 2, 2018 contract between FBC and BGC.

This study assesses clear-water flood, landslide-dam flood and steep creek processes within 'settled' urban and rural areas of the TRW. The boundary between settled areas and wilderness is not always sharp. Prioritized geohazard areas typically include buildings improvements and adjacent development (i.e., transportation infrastructure, utilities, and agriculture). Although infrastructure in otherwise undeveloped areas (e.g., roads, pipelines, transmission lines, and highways) could be impacted by geohazards, these were not included. Hazards were also not mapped in areas that were undeveloped except for minor dwellings (i.e., backcountry cabins). Additional geohazard types exist within the TRW that are not included in the scope of work, including other flood-related geohazard types (see Section 1.4.2). Although this study was based on the best available information, it is not exhaustive. Clear-water flood, steep creek and landslide-dam geohazards still exist in developed areas that were not detected in this regional study.

Table 1-1 summarizes tasks for each project stage. The table presents the same scope described in the Contract, re-formatted to reflect the work flow of the assessment. The assessment was based on the existing elements at risk. Proposed or future development scenarios were not examined as those are largely unknown.

Outcomes of this study include both documentation (this report) and digital deliverables. Digital format results are provided through a BGC web application called *Cambio Communities™,* and via data download and services. Cambio Communities is intended to be the primary way for users to view the study results, with data download and services also available as required by geomatics and data specialists. The data provided as a download or web service from BGC will be provided until March 31, 2020 and thereafter hosted for a license fee if requested by FBC or on behalf of FBC by other agencies (i.e., local, regional, or provincial governments).

Information shown on Cambio Communities is organized in an ArcGIS SDE Geodatabase[6] stored in Microsoft SQL Server[7], and data sources are indicated with metadata. Information sources cited in this document are provided as references at the end of this report. Appendix A provides additional information on data sources.

[6] ArcGIS SDE Geodatabase is a data storage container that defines how data is stored, accessed, and managed by ArcGIS.
[7] Microsoft SQL Server is a relational database management system developed by Microsoft.

Table 1-1. Overview of project tasks.

Activity	Related Tasks	Deliverable(s)
1. Project Management	Meetings, project management, administration, budget and schedule control.	• Presentations and updates
2. Data Compilation and Review	Project initiation and study framework development; Compilation of basemap, hazards and elements at risk information.	• Study objectives, scope of work and study area. • Roles of the parties involved in the project. • Over-arching study framework. • Definition of the hazard types and damage mechanisms assessed. • Reviewed information on study area physiography, climate and climate change, hydrology, and flood history, with reference to floodplain management policies. • Compiled basemap and hazard data in geospatial format. • Compilation of elements at risk for vulnerability assessment, including critical infrastructure layer. • Compilation of hazards to be assessed and prioritized
3. Analysis	Geohazard Prioritization	• Characterization of elements considered vulnerable to geohazard impact. • Hazard characterization. • Assignment of geohazard, consequence and priority ratings for the relative likelihood that geohazards will occur and reach elements at risk vulnerable to some level of consequence. • Identify climate change considerations (inputs) and describe key mechanisms for hazard change due to climate change.
4. Report	Reporting and Documentation	• Description of methods, results, limitations, gaps, and considerations for future work. • Preparation of the Risk Assessment Information Template (RAIT).
5. Data	Web Application and Data Services	• Study results and supporting information displayed on Cambio Communities web map; data and web services for dissemination of study results.

1.4.2. Limitations of Geohazards Assessed

It is important to recognize that flood-related geohazards exist within the TRW that are not included in the scope of work. Geohazards specifically excluded from this assessment include:

- Channel encroachment due to bank erosion during high or low flows
- Shoreline erosion
- Wind-generated or landslide-generated waves in lakes/reservoirs
- Floods related to regulated flows
- Dam and dike/levee failure[8]
- Overland urban flooding[9]
- Sewer-related flooding[10]
- Ice jam flooding
- Landslides other than those considered as part of steep creek or landslide-dam flood geohazards assessments
- Landslide-dam floods other than those caused when landslides impact and temporarily dam major water courses (e.g., moraine-dam failures, glacial lake outburst floods, tailings dam or other human-caused dam failures, or secondary landslide/flood hazards such as landslide-triggered waves)
- Natural hazards other than those listed as being assessed (e.g., fire, seismic, volcanic).

The delineated extent of geohazard areas prioritized in this study do not consider structural mitigation (i.e., dikes). As such, some areas could be identified as higher priority that already have some form of hazard reduction. In addition, more than one hazard type can potentially be present at a given location, such as a fan-delta (fan entering a lake) subject to both steep creek events and lake flooding. BGC displays hazards on the web application such that a user can identify overlapping hazards if present at a given location. However, prioritization is completed separately for each hazard type.

1.5. Deliverables

Outcomes of this study include documentation (this report) and digital deliverables provided as web maps and data services or downloads (geodatabase). This report summarizes each step of the study with more detailed information provided in appendices.

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8 A dynamic and rapid release of stored water due to the full or partial failure of a dam, dike, levee or other water retaining or diversion structure. The resulting floodwave may generate peak flows and velocities many orders of magnitude greater than typical design values. Consideration of these hazards requires detailed hazard scenario modelling. Under BC's Dam Safety Regulation, owners of select classes of dams are required to conduct dam failure hazard scenario modelling.

9 Due to drainage infrastructure such as storm sewers, catch basins, and stormwater management ponds being overwhelmed by a volume and rate of natural runoff that is greater than the infrastructure's capacity. Natural runoff can be triggered by hydro-meteorological events such as rainfall, snowmelt, freezing rain, etc.

10 Flooding within buildings due to sewer backups, issues related to sump pumps, sewer capacity reductions (tree roots, infiltration/inflow, etc.).

The prioritized hazard areas are presented on a secure web application, *Cambio Communities™* (Figure 1-6), at www.cambiocommunities.ca. Cambio Communities shows the following information:

1. Prioritized flood and steep creek hazard areas. These are the key outcome of this study. Clicking on a hazard area reveals priority ratings and supporting information.
2. Information provided by project stakeholders and referenced during the study, including:
    a. The built environment (elements at risk)
    b. Existing geohazard mapping.
3. Information generated by BGC during the study and provided for visual reference, including geohazard, hydrologic and topographic features (e.g., digital elevation model (DEM), watershed boundaries, and stream lines).

Note that the application should be viewed using Chrome or Firefox web browsers and is not designed for Microsoft Internet Explorer or Edge. Appendix H provides a more detailed description of Cambio Communities functionality.

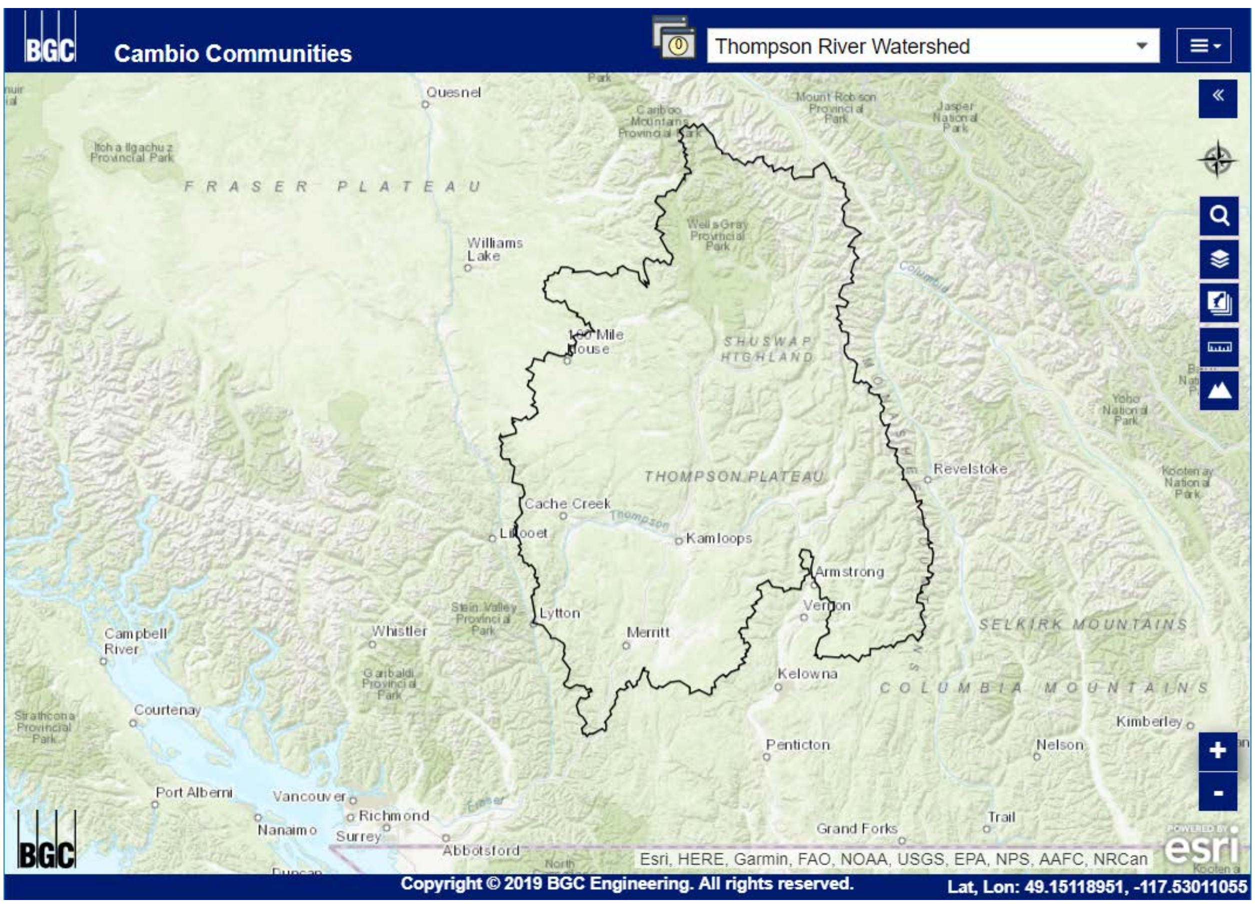


Figure 1-6. Example of Cambio Communities web application.

2. BACKGROUND

This section provides an overview description of the study area.

2.1. Administration

The TRW covers approximately 56,000 km^2 or 6% of the area of BC. The basin completely or partially encompasses 6 Regional Districts, 16 municipalities and 29 areas under First Nations governments. The Secwepemc, Nlaka'pamux, Syilx and St'at'imc nations assert title and rights over different parts of the TRW. The total Census population is approximately 195,000 people (Canadian Census, 2016), and the region contains an assessed $23.8 billion in building improvements (BC Assessment, 2016).

Table 2-1. Jurisdictions within the TRW.

Organization Type	Organization
Regional Governments	Regional District of North Okanagan
	Columbia Shuswap Regional District
	Thompson-Nicola Regional District
	Columbia Shuswap Regional District
	Cariboo Regional District
	Squamish-Lillooet Regional District[1]
First Nations Governments	T'kemlups te Secwepemc
	Whispering Pines/Clinton IB
	Simpcw FN
	Skeetchestn IB
	Bonaparte IB
	Splatsin FN
	Adams Lake IB
	Little Shuswap Lake IB
	Neskonlith IB
	Nlaka'pamux Nation Tribal Council
	Lytton FN
	Oregon Jack Creek Band
	Skuppah IB
	Kanaka Bar IB
	Boothroyd IB
	Boston Bar FN
	Ashcroft IB
	Nicola Tribal Association
	Cook's Ferry IB
	Shackan
	Nicomen
	Lower Nicola IB

Organization Type	Organization
	Upper Nicola IB
	Coldwater IB
	Nooaitch Band
	Siska IB
	Canim Lake Band
	Shuswap Nation Tribal Council
	Ts'kw'aylaxw First Nation
Municipal Government	Enderby
	Lumby
	Sicamous
	Salmon Arm
	Kamloops
	Chase
	Barriere
	Sun Peaks
	Merritt
	Logan Lake
	Cache Creek
	Clinton
	Clearwater
	Ashcroft
	Lytton
	100 Mile House

Note:

1. Only a very small, undeveloped part of the SLRD extends into the TRW.

2.2. Topography

Terrain models for the TRW were developed from high resolution (1 m or better) Lidar DEM, where available, and low resolution (approximately 20 m) Canadian Digital Elevation Model (CDEM) elsewhere[11]. Lidar does not penetrate water, and so underwater ground elevations were not surveyed. Cambio Communities shows Lidar data extents available to the study. Lidar data sources are included as metadata within the web application.

2.3. Physiography and Ecoregions

The TRW covers diverse physiographic area, encompassing highlands, a dissected plateau, and mountain ranges (Holland, 1976). As defined by DeMarchi (2011), the TRW encompasses six

[11] CDEM resolution varies according to geographic location. The base resolution is 0.75 arc second along a profile in the south-north direction and varies from 0.75 to 3 arc seconds in the east-west direction, depending on location. In the TRW, this corresponds to approximately 20 m grid cell resolution (Government of Canada, 2016).

ecoregions, which are areas of major physiographic[12] and minor climatic variation (Figure 2-1). Table 2-2 outlines the characteristics of each ecoregion and associated ecosection.

The largest ecoregion is the Thompson-Okanagan Plateau (TOP), an upland flat to rolling plateau that has been dissected by the largest river systems in the basin: North Thompson, South Thompson, Thompson, and Nicola Rivers. These rivers flow west into the Fraser River at Lytton, BC. East of the TOP lies the Columbia Highlands, a rolling to mountainous highland intersected by steep-sided valleys and large lakes, such as Shuswap, Mara, and Adams lakes. A section of the Fraser Plateau within the TRW is north of the TOP and comprises a rolling plateau with numerous small lakes and wetlands. On the western margin of the TOP, the plateau transitions to the mountainous Interior Transition Ranges and Northern Cascade Ranges, which are influenced by the rain shadow from the Cascade Range further south. The Columbia Highlands transitions eastward into the rugged Northern Columbia Mountains.

The topography in the watershed influences the distribution of population and hydrology in the watershed. In rugged areas, settled areas are restricted to flatter topography, primarily floodplains and alluvial fans in the valleys and on lakeshores. Steep creek hazards, such as debris flows and debris floods (Section 4.2), can be generated in the mountainous areas. Additionally, due to the dissection of the plateau and highlands ecoregions by streams and rivers, many of the watersheds in TRW display “gentle over steep” topography: their upland catchments are in broad areas of little elevation relief, whereas their lower reaches flow down steep valley sides to large rivers or lakes. This topographic setting influences the distribution of hydrogeomorphic hazards: the upper portion of the watershed is subject mainly to floods, whereas the lower portion can experience steep creek hazards. Debris flows and debris floods can be triggered by rainfall, as well as rain-on-snow events. As the streams transition from the mountains to the valleys, hydrologic processes transition into floods, which are typically controlled by snowmelt (Section 2.6).

[12] Referring to landforms and geology.

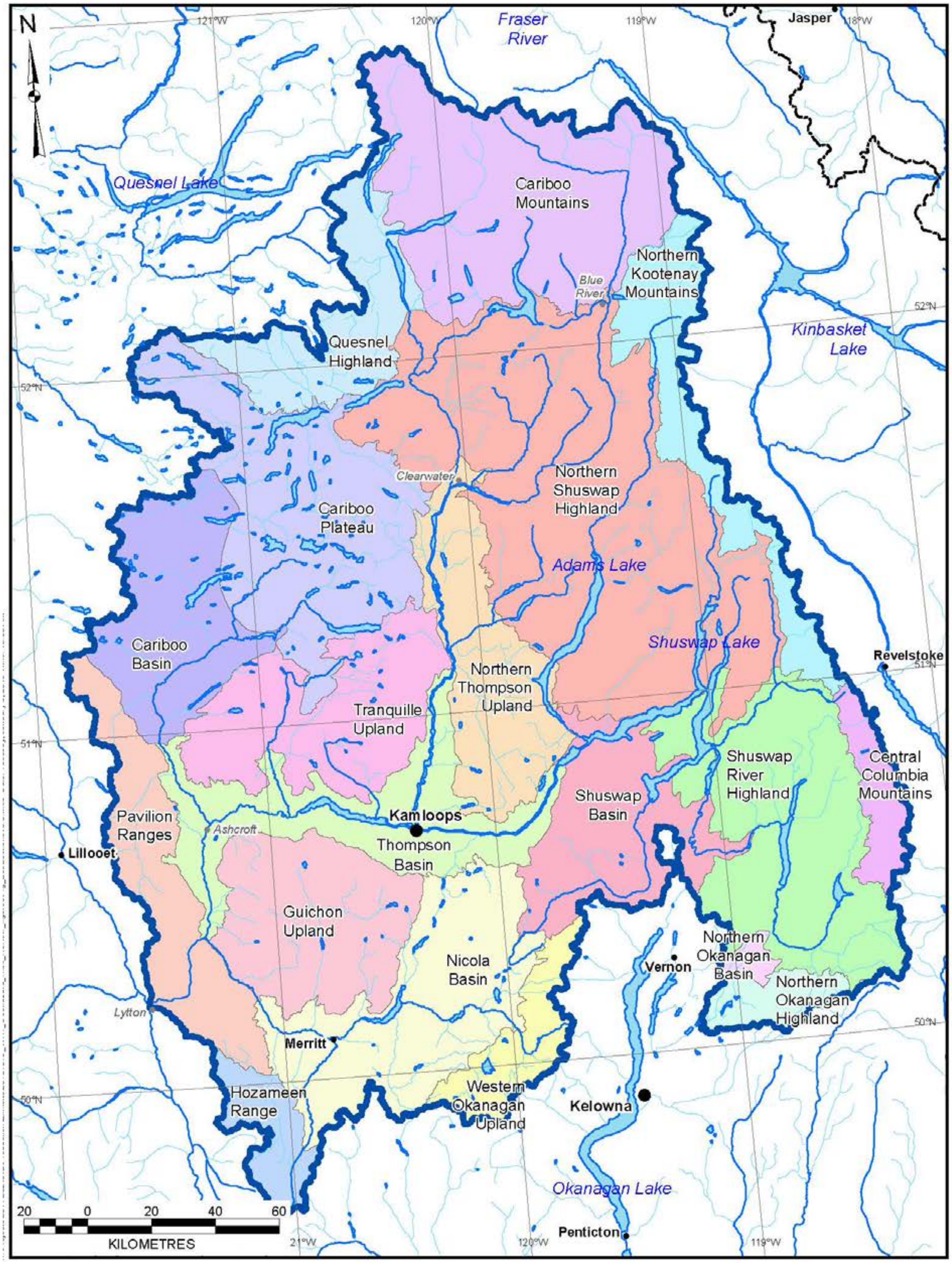


Figure 2-1. Ecosections in the Thompson River Watershed (Demarchi, 2011).

Table 2-2. Ecoregions and ecosections of the Thompson River Watershed (as defined by Demarchi, 2011).

Ecoregion	Ecosection	Area Within TRW (km^2)	Physiography	Climate	Major Watersheds	Vegetation
Northern Columbia Mountains	Northern Kootenay Mountains	2,100	High, rugged mountains. Sedimentary, volcanic, quartzite, and limestone rocks.	Summer – warm, potentially intense rainfall Winter – cold, potentially intense snowfall	Mud, upper Adams, upper Seymour, Crazy.	Interior Cedar-Hemlock, moist Engelmann Spruce.
	Cariboo Mountains	5,300	Rugged mountains and narrow valleys. Sedimentary, metamorphosed sedimentary, granitic rocks.	Summer – wet and humid, rainfall Winter – cold, potentially intense snow	Upper North Thompson, Lampiere, Blue, upper Murtle, Azure, Hobson, upper Clearwater.	Sub-Boreal Spruce, wet Interior Cedar-Hemlock, moist Engelmann Spruce.
	Central Columbia Mountains	700	High ridges and mountains, narrow valleys and trenches. Sedimentary, metamorphic, gneiss, granitic rocks.	Summer – high humidity, rainfall Winter – cold, deep snow	Sugar.	Interior Cedar-Hemlock, moist Engelmann Spruce-Subalpine Fir.
Columbia Highlands	Quesnel Highland	2,100	Transitional highland from plateau to mountainous. Sedimentary, volcanic, limestone, and quartz rocks	Intense precipitation common from fall to early spring Summer – warm, rainfall Winter – potentially intense cold, snowfall	Molybdenite, Canim, Spanish.	Wet Interior Cedar-Hemlock, Engelmann Spruce-Subalpine Fir.
	Northern Shuswap Highland	10,000	Gentle to moderately sloping highland, transitioning from plateau in the west to mountains on the east, steep valley sides. Metamorphic, intrusive, and sedimentary rocks.	Intense precipitation common from fall to early spring Summer – warm, potentially significant rainfall Winter – cold, potentially significant snowfall	Lower Clearwater, North Thompson, upper Adams, lower Seymour, lower Eagle, Raft, Mud, Barriere, Cayenne, Kwikoit.	Interior Cedar-Hemlock, Engelmann-Spruce Subalpine Fir.
	Shuswap River Highland	4,600	Steep-sided, gentle or moderate rolling uplands and ridges dissected by large rivers and lakes. Metamorphic and sedimentary rocks.	Intense precipitation common from fall to early spring Summer – warm, potentially heavy rainfall Winter – cold, potentially heavy snowfall	Eagle, lower Shuswap, Sicamous, Kingfisher, Tsuis.	Wet Interior Cedar-Hemlock, cold Engelmann Spruce-Subalpine Fir.
Fraser Plateau	Cariboo Basin	2,700	Rolling upland. Volcanic rocks.	Subcontinental climate Summer – warm, dry Winter – cool, moist.	Bonaparte, Deadman.	Interior Douglas-fir, Trembling Aspen, lodgepole pine.
	Cariboo Plateau	4,800	Rolling upland. Volcanic rocks.	Subcontinental climate Summer – warm, moist Winter – cool, moist.	Upper Bonaparte.	Sub-Boreal Pine-Spruce, lodgepole pine, trembling aspen, Sub-Boreal Spruce, white spruce, subalpine fir, lodgepole pine.
Thompson Okanagan Plateau	Tranquille Upland	3,000	Rolling upland with plateau-front and steep sides. Volcanic rocks and extensive glacial deposits.	Summer – warm, dry Winter – cool, moist	Upper Deadman, upper Tranquille, Criss, Watching, Jamieson, Whitewood, Peterson.	Interior Douglas-fir, Montane Spruce, Engelmann Spruce-Subalpine Fir, lodgepole pine.
	Northern Thompson Upland	2,700	Rolling upland dissected by North Thompson River, steep valley sides. Metamorphic, sedimentary, and intrusive rocks.	Transitional climate (continental to upland) Summers – warm, dry Winter – cool, wet with relatively high snowfall	North Thompson, McGillvray, Lewis, Nisconlith, Sinmax, Barrier, Chu Chua, Joseph.	Ponderosa Pine, meadow-steppe, Lodgepole Pine, Engelmann Spruce-Subalpine Fir.
	Shuswap Basin	2,700	Rolling plateau uplands, steep sided plateau walls, large inter-plateau lowlands. Metamorphic, sedimentary, and intrusive rocks.	Summer – warm, dry Winter – cool, moist	Salmon, Little Shuswap, upper Deep, Chase, upper Monte.	Sagebrush-steppe, Ponderosa Pine, meadow-steppe, Lodgepole Pine, Engelmann Spruce-Subalpine Fir.

Ecoregion	Ecosection	Area Within TRW (km^2)	Physiography	Climate	Major Watersheds	Vegetation
	Thompson Basin	3,100	Broad, low elevation basin. Extensive glacial deposits and volcanic rocks.	Summer – hot, dry Winter – cool, dry	North Thompson, South Thompson, Thompson, lower Bonaparte, lower Deadman, lower Venables, lower Carbine, lower Durrand, lower Tranquille, lower Cherry, lower Peterson, lower Heffley, lower Knouff, lower Monte.	Bunchgrass-steppe, sagbrush-steppe, meadow-steppe, Ponderosa Pine, Douglas Fir.
	Guichon Upland	2,900	Plateau with steep sides and rolling upland. Granitic and volcanic rocks.	Affected by rain shadow of Cascade Mountains. Summer – Hot, dry Winter – potentially cold Arctic air influence	Thompson, Durrand, Nicola, Droppingmore, Moore, Clapperton, Guichon, Skuhun.	Bunchgrass-steppe, Ponderosa Pine, montane and subalpine forests.
	Nicola Basin	3,700	Basin, valley, uplands. Volcanic rocks and extensive glacial lake deposits.	Affected by rain shadow of Cascade Mountains. Summer – Hot, dry Winter – Cool, dry	Nicola, Campbell, Stumplake, Wasley, Quilchena, Coldwater.	Sagebrush-steppe, bunchgrass-steppe, meadow-steppe, dry ponderosa pine, Douglas-fir.
	Northern Okanagan Basin	200	Wide trench and foothills between the Thompson Plateau and the Okanagan Highlands. Extensive glacial deposits.	Affected by the rain shadow of the Thompson Plateau. Summer – hot, dry Winter – cool, potential Arctic air influence	Deep.	Sagebrush-steppe, bunchgrass-steppe, meadow-steppe, dry ponderosa pine, Douglas-fir.
	Northern Okanagan Highland	600	Rolling upland. Gneiss rock.	Summer – warm, dry to moist Winter – cool, moist	Lawson, Creighton.	Douglas-fir, Montane Spruce, lodgepole pine, Engelmann-Spruce-Subalpine Fir, moist Interior Cedar-Hemlock.
	Western Okanagan Upland	1,000	Rounded upland. Granitic and volcanic rocks.	Summer – hot, dry Winter – cool, moist, potentially affected by cold Arctic air.	Upper Nicola, Quilchena, Pothole.	Douglas fir, Montane Spruce, Engelmann Spruce-Subalpine Fir, Interior Cedar-Hemlock.
Interior Transition Ranges	Pavilion Ranges	2,400	Mountainous upland. Limestone, volcanic, and metamorphosed sedimentary rocks.	Affected by rain shadow of Cascade Mountains. Summer – hot, dry Winter – cold, dry.	Thompson, Pavilion, Twaal.	Sagebursh-steppe, ponderosa pine, Interior Douglas-fir, Montane Spruce.
Northern Cascade Ranges	Hozameen Range	900	Rugged mountains. Metamorphosed sedimentary, volcanic, granitic rocks.	Transitional climate, affected by rain shadow of Cascade Mountains. Summer – dry and warm Winter – potentially high snowfall towards Coquihalla Summit	Coldwater, Prospect	Moist Douglas-fir, western Hemlock

2.4. Geological History

This section summarizes bedrock and surficial geology in the TRW to provide context on the fundamental earth processes that built the landscape assessed in this study.

2.4.1. Bedrock geology

The TRW lies within the Canadian Cordilleran Orogen, which contains distinct regions of different rock types. Much of what is now present as rock in the TRW began its geological history as islands, volcanoes, shallow oceans, and small continents in the Pacific Ocean. Between 200 to 60 million years ago, these terranes[13] were accreted onto the western margin of the North American continent. Each successive terrane accretion deformed and uplifted older terranes already joined onto North America. In places, these rocks were also intruded by magma, shown for example in the volcanic rocks of Wells Grey Provincial Park. Because of these different geological processes, the geological map of the Thompson River Basin resembles a patchwork of distinct units (Figure 2-2), with high variability in the spatial distribution of different rock types. This differs, for instance, from the Canadian Rockies, where rock types tend to be more consistent, due to its geologic origins as a large inland ocean. In general, the rocks in the TRW are oldest and most deformed in the eastern portion of the watershed, and youngest and less deformed in the western portion of the watershed.

Figure 2-2 shows the distribution of the following rock types:

- Sedimentary rocks, common throughout all ecoregions
- Volcanic rocks, extensive within Wells Grey Provincial Park, the Fraser Plateau ecoregion, and surrounding the Nicola River Basin
- Metamorphic rocks, extensive in the Columbia Highlands ecoregion and scattered throughout other ecoregions
- Intrusive rocks, common throughout all ecoregions.

[13] Terranes are regions of distinct rock formations that are typically bounded by fault structures.

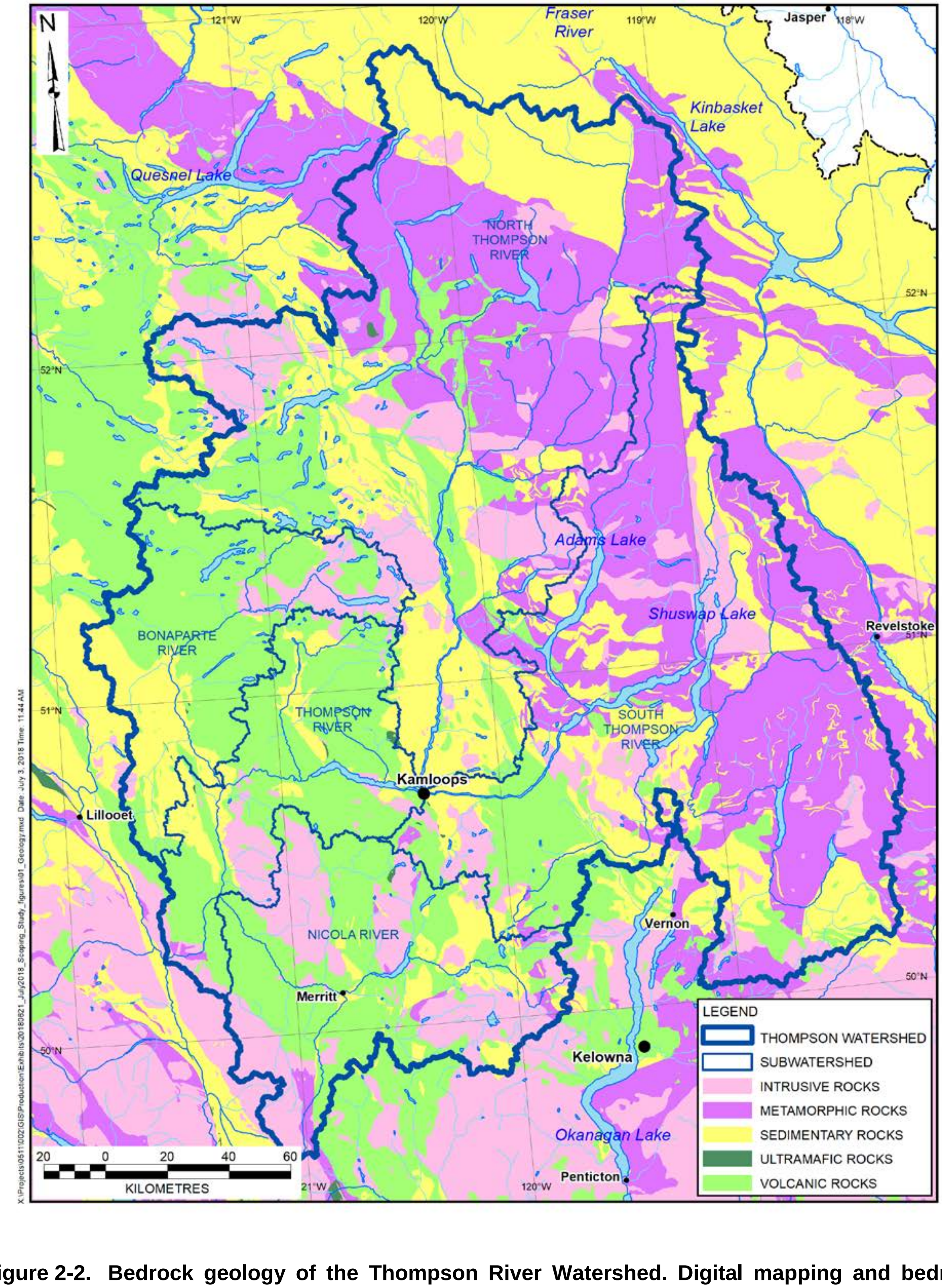


Figure 2-2. Bedrock geology of the Thompson River Watershed. Digital mapping and bedrock classes from Cui et al. (2015).

2.4.2. Surficial Geology

While the geologic history of the region is the basis for the landscape observed within TRW, the present-day surficial material and topography is a mainly a result of glacial activity during the Holocene and post glacial processes since deglaciation. Surficial material and topography are summarized here as they strongly influence the geohazard processes assessed in this study.

The Late Pleistocene (approximately 126,000 to 11,700 years before present) represents a time of repeated advances and retreats of glaciers across North America. During the most recent glaciation, which began approximately 25,000 years ago and ended approximately 10,000 years ago, thick glaciers covered the TRW and generally flowed southward (Holland, 1976; Church & Ryder, 2010; Clague & Ward, 2011). As these glaciers flowed across the landscape, they sculpted the bedrock and deposited sediment, creating many of the landforms that are seen today. Remnant glacial landforms in the TRW include "U"-shaped valleys, steep mountains with sharp faces, drumlins, and the "gentle-over-steep" topography discussed in Section 2.3. Glacial sediment is found as till blanketed onto slopes and filling valley bottoms. Across the TRW, but particularly demonstrated in the Thompson Plateau ecosection, glacial features such as drumlins, glacial striae, and eskers created the unique topography on the top of the plateau (Ryder, Fulton & Clague, 1991). At lower elevations, evidence of glaciers is found in the form of large sediment deposits, such as elevated glaciofluvial and glaciolactustrine terraces (Ryder, 1981; Ryder et al., 1991).

As the glaciers covering BC began to melt, extensive glacial lakes were formed throughout the TRW. The largest lakes filled the major river valleys in the TRW and deposited sediment, primarily silt, sand, and clay into these glacial lakes (Fulton, 1965; Ryder, 1981; Ryder et al., 1991; Clague & Evans, 2003; Johnsen & Brennand, 2004). In some locations, these sediments were deposited on top of older glacial sediments that were not eroded as the glaciers flowed across the valley floors (Clague & Evans, 2002).

Post-glacial streams and rivers eroded into the extensive glacial deposits, transporting sediment from the debris-covered slopes. Some of this debris created alluvial fans atop the glaciolacutrine sediments and adjacent to floodplains, creating paraglacial fans (Ryder, 1971a; Ryder, 1971b; Church & Ryder, 1972). These paraglacial fans reflect environmental and geological processes that are conditioned by the presence of glaciers and represent a transition from glacial to non-glacial conditions. Over a gradual time, as the climate warmed and the slopes began to re-vegetate, the influence of the sediment supply began to wane, and the streams and rivers began to downcut through the glacial and paraglacial deposits (Church & Ryder, 1972). This resulted in "stranded" paraglacial fans that are higher elevation than presently active fans. Stranded paraglacial fans are landforms that are entirely removed, due to stream incision, from active fluvial and steep creek processes and are therefore classified as "inactive" alluvial fans (Kellerhals & Church, 1990; Lau, 2017; Section 4.2).

River incision into the valley-filling glacial and post-glacial sediments also created terraces that are common throughout the TRW. These terraces expose sequences of the valley-filling sediments, which include fluvial, till, glaciolacustrine, and glaciofluvial deposits. Along the Thompson River south of Ashcroft to Lytton, these terraces expose laminated silt and clay deposits from glaciolacustrine deposits. Rapid landslides failing on these layers have produced landslide dams along the Thompson River, and the landslide masses continue to slowly move in response to the Thompson River levels (Ryder, 1981; Porter, Savigny, Keegan, Bunce, & MacKay, 2002; Clague & Evans, 2002; Eshraghian, Martin, & Cruden, 2007; Journault, Macciotta, Hendry, Charbonneau, Huntley, & Bobrowsky, 2018; Section 4.3).

Although relatively rare across the watershed, alpine permafrost features exist in some of the highest mountains of the TRW, particularly in the Northern Kootenay Mountain ecosection. Permafrost features include rock glaciers, solifluction slopes, and frost-shattered bedrock. While the presence of such features may not typically influence watershed hydrology, permafrost degradation can destabilize mountainous slopes and contribute to landslides, steep creek hazards, and increased sediment availability (e.g., Gruber & Haeberli, 2007; Stoffel & Huggel, 2012).

The glacial and post-glacial sediment common throughout the TRW supplies sediment for streams and rivers at a higher rate than sediment derived from bedrock weathering. This sediment is delivered to floodplains and alluvial fans, before being ultimately deposited into the large lake basins or carried further downstream by large rivers. Therefore, the location, grain size, and overall stability of the glacial landforms has a significant influence on the volume of sediment transported during flood and steep creek events.

2.5. Climate

In this section, three topics on regional climate are discussed:

- How global air circulation patterns and local physiography influence the climate of the TRW
- Precipitation and temperature normals for the TRW derived from 40-years of historical climate data
- Overview of projected climate change.

2.5.1. Regional-Scale Climate Factors

The distinct climate patterns found across the province reflect the interaction between regional-scale weather systems with topography that varies with elevation, distance from the coast, prevailing winds and season. Large-scale airflows moving in from the coast bring moist, marine air from west to east. Mountain ranges which lie perpendicular to the prevailing winds largely determine the distribution of precipitation and temperatures within the distinct climatic regions found across BC (Figure 2-3). The mountains force air to rise, where it cools and condenses, resulting in more frequent and higher volumes of precipitation on the west side than on the lee side (orographic effect). Low-lying areas, such as valleys, tend to allow cold air to drain into them, creating higher occurrences of frost and fog.

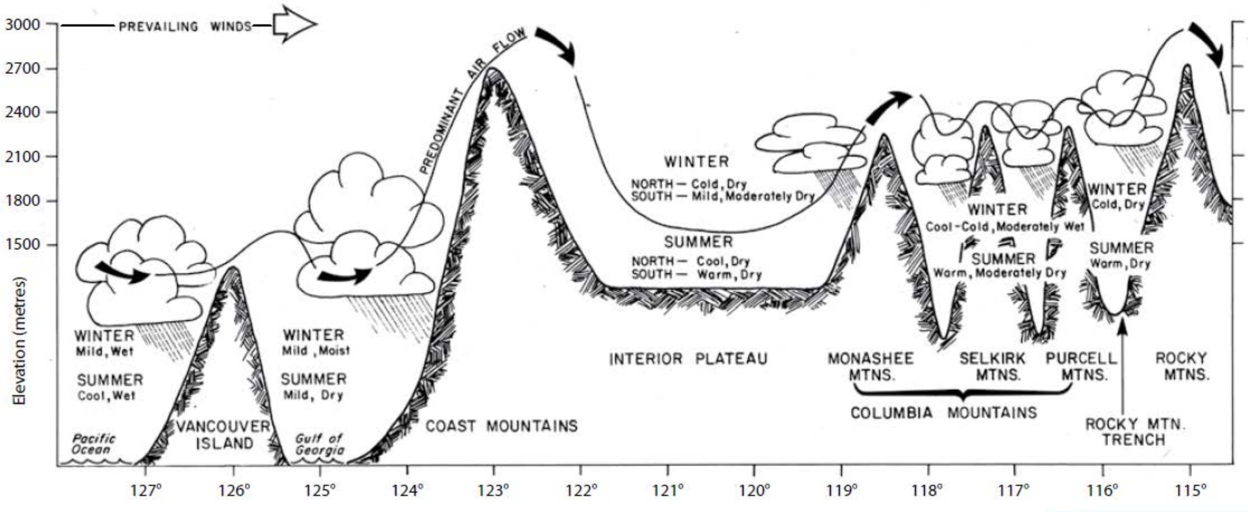


Figure 2-3. Latitudinal cross-section through southern BC depicting physiographic diversity and resulting climatic regimes. The TRW is associated with the Interior Plateau regime. (From Moore et al., 2008).

Located within the rain shadow of the Coast Mountains, the climate of the TRW is characteristic of the semi-arid plateau region of the BC Interior with warm, dry summers and cool winters. The region experiences a range of climatic conditions due to the physiographic variability found throughout the TRW as described in Section 2.3. For example, the semi-arid steppe climate around Kamloops is characterized by low total precipitation and high rates of evapotransporation resulting in water deficit conditions. Whereas, the northern portion of the watershed, such as the area around Blue River, experiences relatively colder temperatures and wetter conditions than the southern portion of the watershed.

2.5.2. Temperature and Precipitation Normals

Regional-scale factors affect temperature and precipitation patterns, as do local factors such as altitude, wind, and proximity to lakes. The extreme differences in elevation between the tops of the mountains and the troughs of the valleys results in pronounced differences in temperature and precipitation across the region. Table 2-3 provides a summary of climate normals for the period of 1981 to 2010 in the TRW. Results are averaged from 21 Environment and Climate Change Canada (ECCC) stations in the TRW as shown on Figure 2-4.

In the TRW, precipitation occurs primarily as snowfall from November to February, and as rain throughout the remainder of the year. Convective storm cell events are frequent in the summer months, and as a result precipitation is generally highest in June and July, and in winter from December and January as a mix of rain and snow as displayed on Figure 2-5 and Figure 2-6 as snow water equivalent (SWE). As a result, the regional hydrology is characterized by a mixed-precipitation hydrologic regime where peak flows and significant floods can be triggered by snowmelt in the spring, rainfall in the autumn or rain-on-snow events in the winter.

Table 2-3. Summary of 1981 to 2010 climate normals for the TRW.

Variable	Units	Average	Range	
			Minimum	Maximum
Mean Annual Precipitation	mm	512	264	1024
Mean Summer Precipitation (May to September)	mm	238	131	436
Total Snowfall	cm	153	30	404
Mean Annual Temperature	ºC	6.1	3.2	10.1
Mean Coldest Month Temperature (January)	ºC	-5.0	-7.8	-2.4
Mean Warmest Month Temperature (July)	ºC	17.4	13.8	22.1
Extreme Minimum Temperature	ºC	-37.3	-46.1	-25.5
Frost-free Period	days	111	83	188

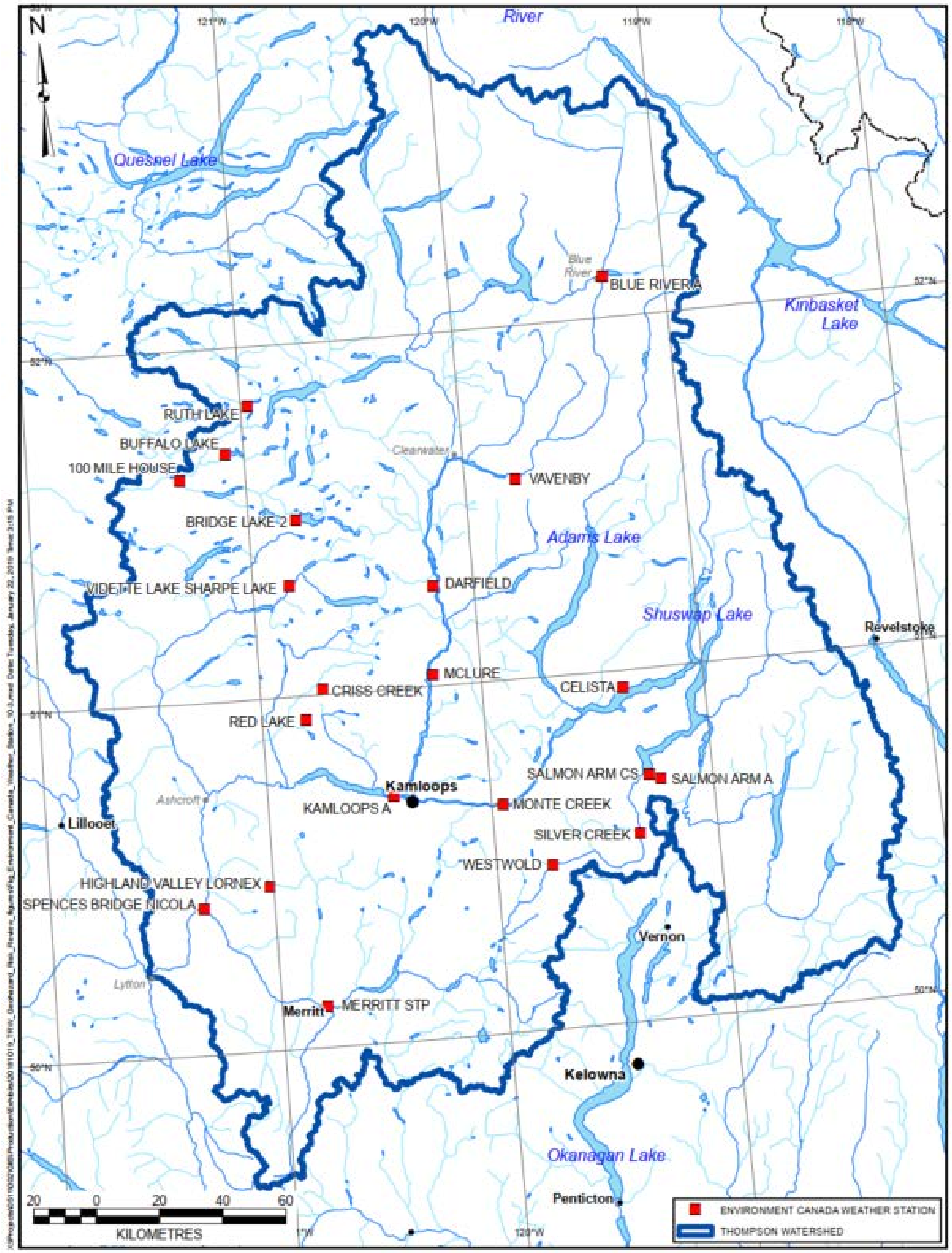


Figure 2-4. ECCC climate stations with 1981 to 2010 climate normals within the TRW. Stations are represented by a red square.

Table 2-4 shows climate normals at two ECCC stations: *Kamloops A** climate station (ID 1163780, 50°42'08.000" N, 120°26'31.000" W, 345.3 masl) and the *Blue River A** climate station (ID 1160899, 52°07'44.5" N, 119°17'22.300" W, 690.4 masl). Climate data from the two stations highlight the range of variability in air temperature and precipitation observed in the watershed.

Table 2-4. 1981 to 2010 climate normals at the ECCC *Kamloops A and *Blue River A** stations.**

Variable	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kamloops A[1] (ID 1163780)												
Temperature (°C)	-3	-1	4	8	13	17	20	19	14	7	2	-3
Rainfall (mm)	9	10	17	28	39	46	37	32	32	29	24	8
Snowfall (mm)	22	9	5	1	1	0	0	0	1	0	12	25
Precipitation[2] (mm)	31	19	22	29	40	46	37	32	32	29	37	33
Blue River A (ID 1160899)*												
Temperature (°C)	-7	-4	1	5	10	14	16	16	11	5	-2	-7
Rainfall (mm)	21	18	36	53	76	99	107	82	71	94	50	14
Snowfall (mm)	84	36	29	6	0	0	0	0	0	9	66	75
Precipitation[2] (mm)	105	54	65	59	76	99	107	82	71	103	115	88

[1] Climate station meets the World Meteorological Organization (WMO) standards for temperature and precipitation and the “A” stands for the WMO "3 and 5 rule" (i.e., no more than 3 consecutive and no more than 5 total missing for either temperature or precipitation)

[2] Precipitation is a combination of rainfall and snowfall amounts

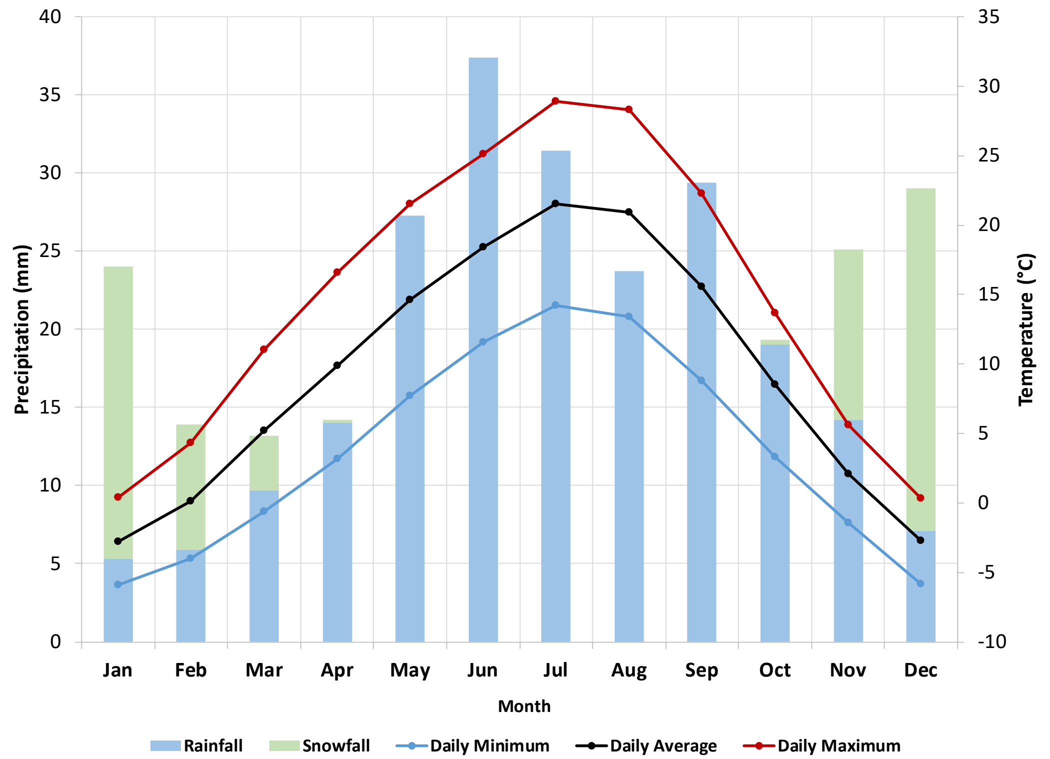


Figure 2-5. Climate normals at the ECCC Kamloops A* climate station for 1981 to 2010.

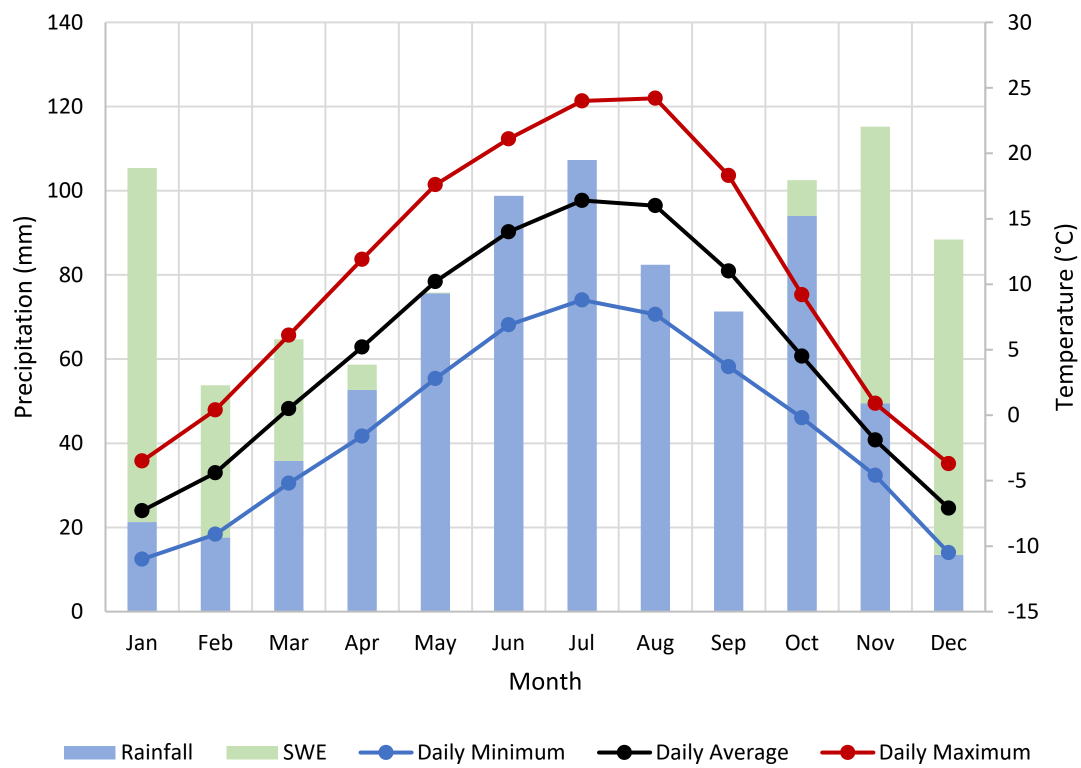


Figure 2-6. Climate normals at the ECCC Blue River A* climate station for 1981 to 2010.

2.5.3. Projected Climate Change

A number of temperature, precipitation, and hydrologic climate change impact studies have been completed for the TRW region, including reports from the Pacific Climate Impacts Consortium (PCIC) that have looked at wide-scale changes in the Fraser River basin, of which the Thompson Rivers are tributaries. For example, modelling done by Shrestha et al. (2012) and Islam et al., (2017, 2019) projected that the Fraser River basin may transition from a snow-dominated regime to a hybrid (pluvial/nival) river system with the interior plateau of the TRW becoming a rainfall-dominated system due to climate change. Islam et al. (2017) projected a decrease in SWE and a greater loss of snow cover from low to mid-elevations than in high elevations, where temperatures are projected to be cold enough for precipitation to fall as snow. Projected changes in average climate variables across the TRW (PCIC, 2012) show that there is likely to be:

- A net increase in precipitation (i.e., rain and/or snow), including a decrease in summer precipitation and an increase in winter precipitation.
- A net decrease in snowfall, including a smaller decrease in winter and a larger decrease in spring snowfall (due to a projected increase in temperature).
- On average, there is likely to be a reduction in snowpack depth, an increase in winter rainfall, and higher freezing levels.

Historical data from the region shows that average annual temperatures and total annual precipitation have increased 1.0°C and 17%, respectively between the period of 1900 to 2013 (MOE, 2016). In general, northern and interior regions of BC have warmed more rapidly than coastal regions. Trends suggest that the interior region of BC is getting warmer and wetter, with increasing minimum temperatures and number of frost-free days. Climate change is discussed in more detail in Appendix F.

2.6. Hydrology (Watercourse Characterization)

We define three general categories of watercourses that are differentiated by scale and physiography as per Table 2-5, and described in the following sections.

Table 2-5. Physiographic characterization of watercourses.

Category	Watershed Area Range	Strahler Order[1]	Example Watersheds
Major Valley Systems	>1,000 km^2	6+	Bonaparte River, Nicola River, North Thompson River, South Thompson River, Thompson River
Minor Valley Systems	200 - 1000 km^2	4 to 6	Clearwater River, Guichon Creek, Louis Creek, Mud Creek, Scotch Creek
Tributary Creeks	<200 km^2	1 to 3	Finn Creek, Heffley Creek, Hummingbird Creek, Silver Creek

Note:

1. Strahler stream order classification system (Strahler, 1952) was applied to all the stream reaches within the TRW. The stream order hierarchy is a method to define the relative size of a perennial stream with a stream network. A first order stream corresponds to the headwaters, while a higher order stream indicates a larger channel.

Major Valley Systems (Rivers and Lakes):

Major valley bottoms are characterized by wide, U-shaped valley bottoms, which feature large rivers and lakes that are the backbone of the region's physical and human geographies. Catchment areas are in excess of 1,000 km^2. These areas are where most people live and work, and where transportation and linear infrastructure is generally located.

Minor Valley Systems (Rivers and Lakes):

Minor valley bottoms are characterized by U-shaped valley bottoms that form major tributaries to the major valleys. They typically bisect mountain ranges and have catchment areas around 200-1,000 km^2.

These areas contain farms and lower density residential development and provide access to forestry operations. Transportation and linear infrastructure follow some of the larger valleys as they connect major valley bottoms. Where minor valleys terminate in a fan, these fans are typically more densely populated with urban development.

Tributary Creeks:

Tributary creeks are typically mountain streams that have headwaters at high elevation and follow a less circuitous path down the mountainside. They are typically in V-shaped valleys with Strahler stream order between 1 and 3. Catchment areas are typically less than 200 km^2 with many of the tributary creeks terminating at fans where they enter larger and lower-gradient valley bottoms.

Many tributary creeks are subject to steep creek processes (debris floods and debris flows with the latter occurring, typically in watersheds of < 10 km^2). Methods to identify creeks subject to steep creek processes are provided in Section 4.2.

2.7. Dams

Within the TRW, there are currently 453 dams out of the 1,965 inventoried dams in BC that are regulated under the *Water Sustainability Act* (SBC, 2014). Most of these dams are situated on smaller watercourses within the TRW and flows are generally unregulated. Although flow regulation due to the occurrence of dams has an impact on flood hydrology by potentially reducing the magnitude of a flood event, the impact of regulation on flows is outside the scope of this study. The web map displays all the inventoried dams in the TRW to support subsequent detailed flood hazard studies within the TRW. Additional discussion on dams is provided in Appendix B.

2.8. Historical Event Inventory

BGC reviewed several data sources to compile a historical flood, steep creek, and landslide dam inventory across the watershed (Appendix G). Data bias is typically inherent in historical accounts of past events due to gaps in recorded storms or geohazard events. Reasons include bias in media reports that tend to generalize effects of large region-wide events (e.g., 1948 region-wide floods) rather than smaller and more localized impacts, inaccurate or outdated reported data (e.g., stream names, locations, names of historical residences), changes in media coverage, and increasing population base in hazardous areas.

Somewhat unique to the TRW, in comparison to other large watersheds in BC, is the historical accounts of large landslide dams and associated flooding on the Thompson River near Ashcroft and Spences Bridge in the late 1800s and early 1900s (e.g., Clague & Evans, 2003). These landslides have either fully or partially dammed the Thompson River for several hours, resulting in widespread upstream flooding prior to dam overtopping and incision. Some of these dams required human intervention to create a spillway through the dam to lessen the flooding effects. During the 1905 Spences Bridge landslide-dam flood event, at least 15 people were killed because of the landslide and flooding (Walkern, 2015).

Large region-wide data sources of historical events include:

- A text compilation of media reports of flooding, landslide, and avalanche events from 1808 to 2006 (Septer, 2007)
- Historical DriveBC numbered highway incident database, which includes incidents and closures related to flooding, "mudslides" and washouts (typically debris flows and debris floods), rockslides, and debris on road (MOTI, n.d.)
- The Canadian Disaster Database (Public Safety Canada, n.d.)
- Media and social media reports of freshet-related flooding and landslides across the watershed, compiled by BGC from March to May 2018
- Reports from the Water Stewardship Information Sources database for the Thompson-Okanagan area (MFLRNO, n.d.)
- Sites identified in the Community to Community Forum between FBC and the TRW stakeholders (Fraser Basin Council, February 14, 2018).

This historical event inventory is assumed to be incomplete, but the information contained within it can be used to identify the location of past geohazards events and associated consequences of these events. BGC digitized the locations of historical events from the Septer (2007), DriveBC (MOTI, n.d.), and 2018 freshet-related floods and landslides. These locations were referenced during geohazard identification. Recorded events at steep creek fans are listed in supporting information for a given site on Cambio Communities.

3. EXPOSURE ASSESSMENT METHODS

This section summarizes the elements at risk considered in this study, and how exposure ratings were assigned to a given area. Appendix E describes methods to compile and organize elements at risk data. Section 5 describes how exposure ratings were used as inputs for risk prioritization.

Table 3-1 lists elements at risk and weightings used to compare the types and value of elements in different hazard areas. BGC used the following steps to assign a hazard exposure rating to each area:

1. Identify the presence of elements at risk.
2. Calculate their value and weight according to the categories listed in Table 3-1.
3. Sum the weightings to achieve a total for each area.
4. Assign exposure ratings to areas based on their percentile rank compared to other areas.

Software developed by BGC was used to automate the identification of elements at risk within geohazard areas. The elements at risk compiled for risk prioritization are not exhaustive and did not include a complete inventory of municipal infrastructure (e.g., complete inventory of utility networks). Elements where loss can be intangible, such as objects of cultural value, were not included in the inventory.

The exposure weightings were assigned by BGC and are subject to review by FBC and local authorities. They weigh the relative importance of elements at risk from a regional perspective with reference to the response goals of the BC Emergency Management System (BCEMS) (Government of BC, 2016). BCEMS goals are ordered by priority as follows:

1. Ensure the health and safety of responders
2. Save lives
3. Reduce suffering
4. Protect public health
5. Protect infrastructure
6. Protect property
7. Protect the environment
8. Protect economic and social losses.

Table 3-2 provides a more detailed breakdown of how weightings were assigned to critical facilities based on BCEMS response goals. Weightings also considered loss indicators cited by the United Nations in the areas of public safety, economic loss, services disruption, environmental loss, or social loss (culture, loss of security) (United Nations, 2016; UNISDR, 2015).

Table 3-1. Elements at risk and weightings.

Element at Risk	Description	Value	Weight
People	Total Census (2016) Population (Census Dissemination Block)[1]	1-10	5
		11 – 100	10
		101 – 1,000	20
		1,001 – 10,000	40
		>10,000	80
Buildings	Building Improvement Value[2] (summed by parcel)	<$100k	1
		$100k - $1M	5
		$1M - $10M	10
		$10M - $50M	20
		$50M - $100M	40
Critical Facilities	Critical Facilities[3] (point locations)	Emergency Response Services	36
		Emergency Response Resources	10
		Utilities	30
		Communication	18
		Medical Facilities	36
		Transportation	22
		Environmental	18
		Community	36
Businesses	Business annual revenue (summed) (point locations)	<$100k Annual Revenue or 1 Business	1
		$100k - $1M Annual Revenue or 2-5 Businesses	5
		$1M - $10M Annual Revenue or 6-10 Businesses	10
		$10M - $50M Annual Revenue or 11-25 Businesses	20
		$50M - $100M Annual Revenue or 26-100 Businesses	40
		>$100M annual revenue or >100 businesses	80
Lifelines[3]	Roads (centerline)	Road present; no traffic data	1
		Highway present; no traffic data	5
		0-10 vehicles/day (Class 7)	1
		10-100 vehicles/day (Class 6)	5

Element at Risk	Description	Value	Weight
		100-500 vehicles/day (Class)	10
		500-1000 vehicles/day (Class 4)	20
		> 1000 vehicles/day (Class <4)	40
	Railway	Presence of	10
	Petroleum Infrastructure	Presence of	15
	Electrical Infrastructure	Presence of	10
	Communication Infrastructure	Presence of	10
	Water Infrastructure	Presence of	10
	Sanitary Infrastucture	Presence of	10
	Drainage Infrastructure	Presence of	10
Environmental Values	Active Agricultural Area	Presence of	15
	Fisheries	Presence of	15
	Species and Ecosystems at risk	Presence of	15

Notes:

1. Census population was scaled according to the proportion of census block area intersecting a hazard area. For example, if the hazard area intersected half the census block, then half the population was assigned. The estimate does not account for spatial variation of population density within the census block.
2. Large parcels with only minor outbuildings or cabins, typically in remote areas, were not included in the assessment.
3. Lifelines were assigned a weighting based on the presence of at least one of a given type within the hazard area. This approach reflects how some elements are represented as geospatial features, to avoid accidental double counting where a single facility is spatially represented by multiple parts. Where more than one is present, the maximum weighting is applied. For critical facility points, the total weighting assigned to a hazard polygon is the sum of weightings applied to individual critical facilities.

Table 3-2. Basis for weightings applied to critical facilities.

Category Code	Category	Actual Use Value Description[1]	Risk to Life	Impacts Suffering	Impacts Public Health	Impacts infrastructure (supports recovery)	Impacts Property	Causes Economic and Social Loss	Total Weights
1	Emergency Response Services	Emergency Operations Center, Government Buildings (Offices, Fire Stations, Ambulance Stations, Police Stations)	14	12	10				36
2	Emergency Response Resources	Asphalt Plants, Concrete Mixing, Oil & Gas Pumping & Compressor Station, Oil & Gas Transportation Pipelines, Petroleum Bulk Plants, Works Yards				8		2	10
3	Utilities	Electrical Power Systems, Gas Distribution Systems, Water Distribution Systems		12	10	8			30
4	Communication	Telecommunications			10	8			18
5	Medical Facilities	Hospitals, Group Home, Seniors Independent & Assisted Living, Seniors Licenses Care	14	12	10				36
6	Transportation	Airports, Heliports, Marine & Navigational Facilities, Marine Facilities (Marina), Service Station		12		8		2	22
7	Environmental	Garbage Dumps, Sanitary Fills, Sewer Lagoons, Liquid Gas Storage Plants, Pulp & Paper Mills			10	8			18
8	Community	Government Buildings, Hall (Community, Lodge, Club, Etc.), Recreational & Cultural Buildings, Schools & Universities, College or Technical Schools.	14	12		8		2	36

Note:

1. The actual use value descriptions shown in this table were a starting point to compile an inventory of critical facilities, supplemented by information provided to BGC by Regional Districts within the TRW. They should be considered representative, but not exhaustive descriptions of facilities in each category.

Figure 3-1 shows the distribution of exposure scores for all geohazard areas, and Figure 3-1 and Table 3-3 shows how total weightings were grouped by percentile to assign exposure ratings.

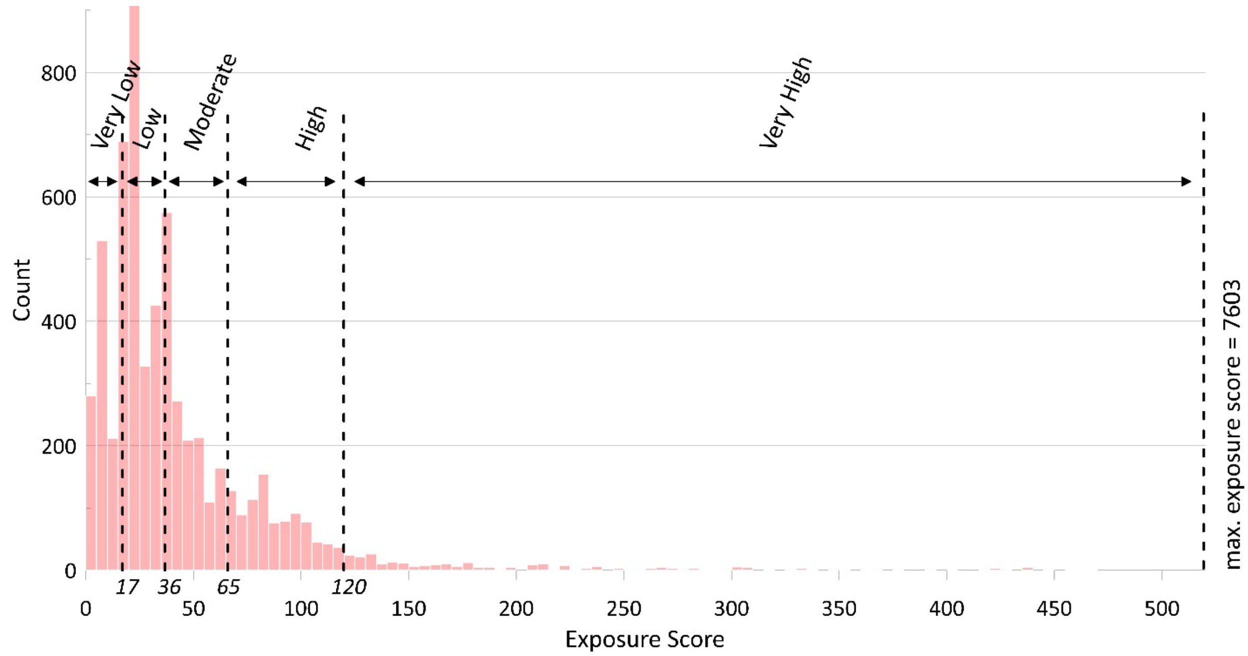


Figure 3-1. Distribution of exposure scores in the TRW and definition of associated exposure ratings.

Table 3-3. Hazard exposure rating.

Hazard Exposure Rating	Criteria	Total Weighting Value
Very High	Greater than 95th percentile	> 119
High	Between 80th and 95th percentile	65 to 119
Moderate	Between 60th and 80th percentile	36 to 64
Low	Between 20th and 60th percentile	17 to 35
Very Low	Smaller than 20th percentile	0 to 16

BGC emphasizes that the prioritization completed in this assessment depends strongly on the relative weightings applied to elements at risk. The weightings are intended to convey a screening level understanding of the overall "important" of assets in a geohazard area, for the purpose of policy, planning, legislation and emergency management. A government agency or owner responsible for a certain asset type (i.e., highways) might weight the importance of that asset differently than was applied in this study. In summary, applying different weightings would result in different priorities, and this factor should be considered in decision making based on the study results.

BGC notes that the exposure rating is relative to the study area, which is defined by the TRW boundary and includes multiple Regional Districts. Different choices of study area would affect this relative rating. If future studies extend the risk prioritization to include the entirety of Regional Districts intersecting the TRW, BGC suggests updating the hazard exposure ratings to reflect hazard exposure by District boundaries.

4. GEOHAZARD ASSESSMENT METHODS

This section describes how BGC defined the geohazard extents prioritized in this study. Areas considered in this inventory contained both elements at risk and were subject to clear-water floods, debris floods or debris flows, or landslide-dam floods. Appendices B to D provide further details on geohazard identification and characterization for clear-water flood, steep creek, and landslide-dam flood geohazards, respectively.

4.1. Clear-water Floods

4.1.1. Overview

Table 4-1 summarizes the approaches used to identify clear-water flood geohazard areas. In this study, flood areas were identified from the following spatial sources:

1. Inventory of historical flood event locations.
2. Existing historical and third-party floodplain mapping.
3. Modelled prediction of floodplain extents for streams, rivers and lakes using topographic analysis.

Appendix B provides further details on the methods used to identify clear-water flood hazards and associated limitations.

Table 4-1. Summary of clear-water flood identification approaches.

Approach	Area of TRW Assessed	Application
Geohazard process type identification	All watercourses	Classification of creeks as dominantly subject to clear-water floods, debris floods, or debris flows.
Historical flood event inventory	All creeks prone to clear-water flooding	Identification of creeks and rivers with historical precedent for flooding and location of 2018 spring freshet events. The historical flooding locations are approximate locations where known landmarks adjacent to a watercourse were flooded, or specific impact to structures (roads, houses) was reported in media.
Existing floodplain mapping	All creeks prone to clear-water flooding	Identification of floodplain extents from publicly available mapping historical and 3rd party data sources.
Floodplain extent prediction for lakes and streams	All lakes and streams without existing floodplain mapping and a Strahler stream order of 4 or greater	Identification of low-lying areas adjacent to streams using a topographic elevation offset applied to Strahler stream order of 4 or greater creeks. The approach developed by BGC was based on topographic analyses for inundation modelling described in Zheng et al. (2018).

Approach	Area of TRW Assessed	Application
	All creeks without existing floodplain mapping and a Strahler stream order of 3 or less	Identification of low-lying areas adjacent to streams using a 30 m topographic buffer applied to Strahler stream order of 3 or less. A buffering distance of 30 m was selected to approximate the riparian zone for smaller watercourses based on minimum setback distances for infrastructure from natural streams as established in MWLAP (2004).
Lake level prediction	All lakes with active gauge stations	Lake levels or elevations predicted for the 200-year return period event (AEP of 0.5%)

4.1.2. Stream Network

BGC's proprietary River Network Tools (RNT™) is a web-based application for analysis of hydrotechnical geohazards associated with rivers and streams. The basis for RNT is a digital stream network that is used to evaluate catchment hydrology, including delineating catchment areas and analysing flood frequencies over large geographical areas. RNT incorporates hydrographic data with national coverage from Natural Resources Canada's (NRCan's) National Hydro Network (NHN) at a resolution of 1:50,000 (NRCan, 2016). The publicly available stream network is enhanced by BGC-proprietary algorithms within the RNT database to ensure the proper connectivity of the stream segments even through complex braided sections. Modifications to the stream network within the RNT are made as necessary based on review of satellite imagery (e.g., Google Earth™) at approximately 1:10,000 scale.

In the RNT, the stream network is represented as a series of individual segments that includes hydraulic information such as:

- A water flow direction
- The upstream and downstream stream segment connections
- A local upstream catchment area for each stream segment (used to calculate total catchment area)
- A Strahler stream order classification (Strahler, 1952)
- A local channel gradient, which is determined using a topographic dataset to assess the elevation differential between the upstream and downstream limit of the segment.

Strahler stream order is used to classify stream segments by its branching complexity within a drainage system and is an indication of the significance in size and water conveying capacity at points along a river (Strahler, 1952). Strahler order 4 and higher streams are typically larger streams and rivers (e.g., Thompson River), while Strahler order 3 and lower streams are typically smaller, headwater streams (e.g., Sicamous Creek). An illustration of Strahler stream order classification is shown in Figure 4-1 and described conceptually for the TRW in Table 4-2.

For this study, Strahler order 4 and higher streams are considered potential clear-water flood hazards, while Strahler order 3 and lower streams are typically headwater streams. Most of these lower order creeks are prone to steep-creek flood processes, as described in Section 4.2. Strahler stream order was used to determine the method applied to predict the potential floodplain extents for streams and rivers within the study area as described in Section 4.1.7.

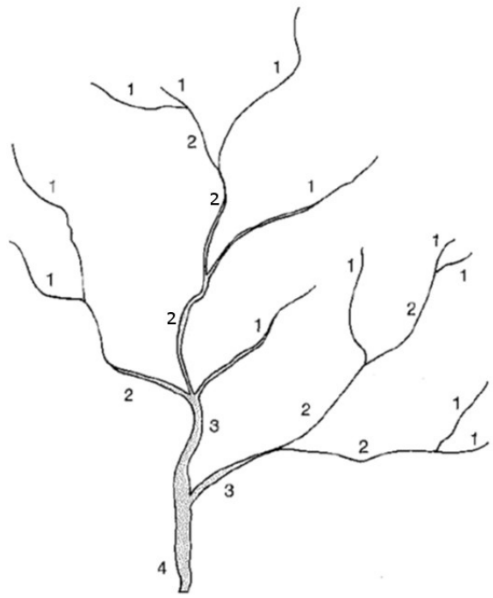


Figure 4-1. Illustration showing Strahler stream order (Montgomery 1990).

Table 4-2. Strahler order summary for the TRW stream network.

Strahler Order	Description	% of TRW Stream Segments	TRW Examples
1 – 3	Small, headwater streams generally on steeper slopes and typically subject to steep-creek processes (debris floods/ flows). Channel may be dry for a portion of the year. They are tributaries to larger streams and are typically unnamed.	85	Ashton Creek, Hummingbird Creek, Sicamous Creek
4 – 6	Medium stream or river. Generally, less steep and lower flow velocity than headwater streams.	13	Hefley Creek, Knouff Creek, Bessette Creek, Salmon River
7+	Large river. Larger volumes of runoff and potentially debris conveyed from smaller waterways.	2	Barriere River, Clearwater River, North and South Thompson Rivers

The stream network used in this assessment is defined according to the channel thalweg location as mapped at the time of delineation and not the high-water mark or bank location. Not all watercourses present within the TRW are contained within provincial (TRIM) or national river networks, and some have changed location since mapping (i.e., due to channel avulsion or migration). Mapped watercourses may or may not be consistent with the definition of watercourse contained in Floodplain Management Bylaws. A potential study gap due to limitations in the stream network data includes interpretation of fan characteristics that have since changed, and uncertainty in defining flood extents on watercourses that have moved since the original stream network mapping. Additionally, for small watercourses, the hazard area was defined from a setback from the mapped thalweg, rather than from the top of bank.

4.1.3. Flood Frequency Analysis

RNT also contains hydrometric data collected from Water Survey of Canada (WSC) stations across Canada. An estimation of flood discharge magnitude and frequencies for multiple return periods (2-year up to the 1 in 200-year event) are determined for each stream segment using a flood frequency analysis (FFA) approach as described in Appendix B for watercourses and historic lake levels.

In RNT, flood quantiles are either pro-rated from a nearby single gauge or estimated by regional FFA from multiple gauges. A total of 391 WSC gauges stations are located within the TRW (ECCC, July 16, 2018). Of these gauges, 51 are active and 340 are discontinued stations. Of the 51 active stations, 37 are also used for real-time flood monitoring (Figure 4-2).

Screening-level flood discharge quantiles were generated for every stream segment within the TRW and assigned to clear-water flood hazard polygons at the farthest downstream stream segment in the polygon. Because RNT is applied as a screening level tool to predict flows over a large geographical area, the flow estimates have the following limitations:

- Gauges on regulated rivers (i.e., rivers where flows are controlled by a dam) are not used in the FFA and flow regulation is not accounted for watercourses with flow controlled by dams. Flow regulation has a potential to impact flood magnitude.
- Attenuation from the many lakes, wetlands and marshes in the TRW may not be accounted for in the flow estimates. Peak flow values may be overestimated in catchments that contain these features. This can only be resolved via detailed rainfall/snowmelt-runoff modeling or a regional multiple regression FFA that includes watershed characteristics.
- Peak flow estimates do not account for potential outburst floods from ice jams, glacial or moraine-dammed lakes, beaver dams, landslide dams (see Appendix E), which may be of substantial magnitude in some locations.
- The stream network dataset does not reflect recent changes to drainage alignments due to natural river migration or artificial alterations, which could impact calculated catchment areas and the selection of stream segments available for analysis.
- The stream network does not include stormwater infrastructure and drainage ditches.
- Regional FFAs typically under-estimate peak flows for smaller watersheds (< 25 km^2), as such catchments are rarely gauged and runoff processes are not necessarily scalable compared to larger catchments.

Implication of these uncertainties include under or overestimation of flow discharge at a given return period. While important to consider for more detailed floodplain mapping, they are not addressed further in this study and are not expected to affect relative site priority rankings.

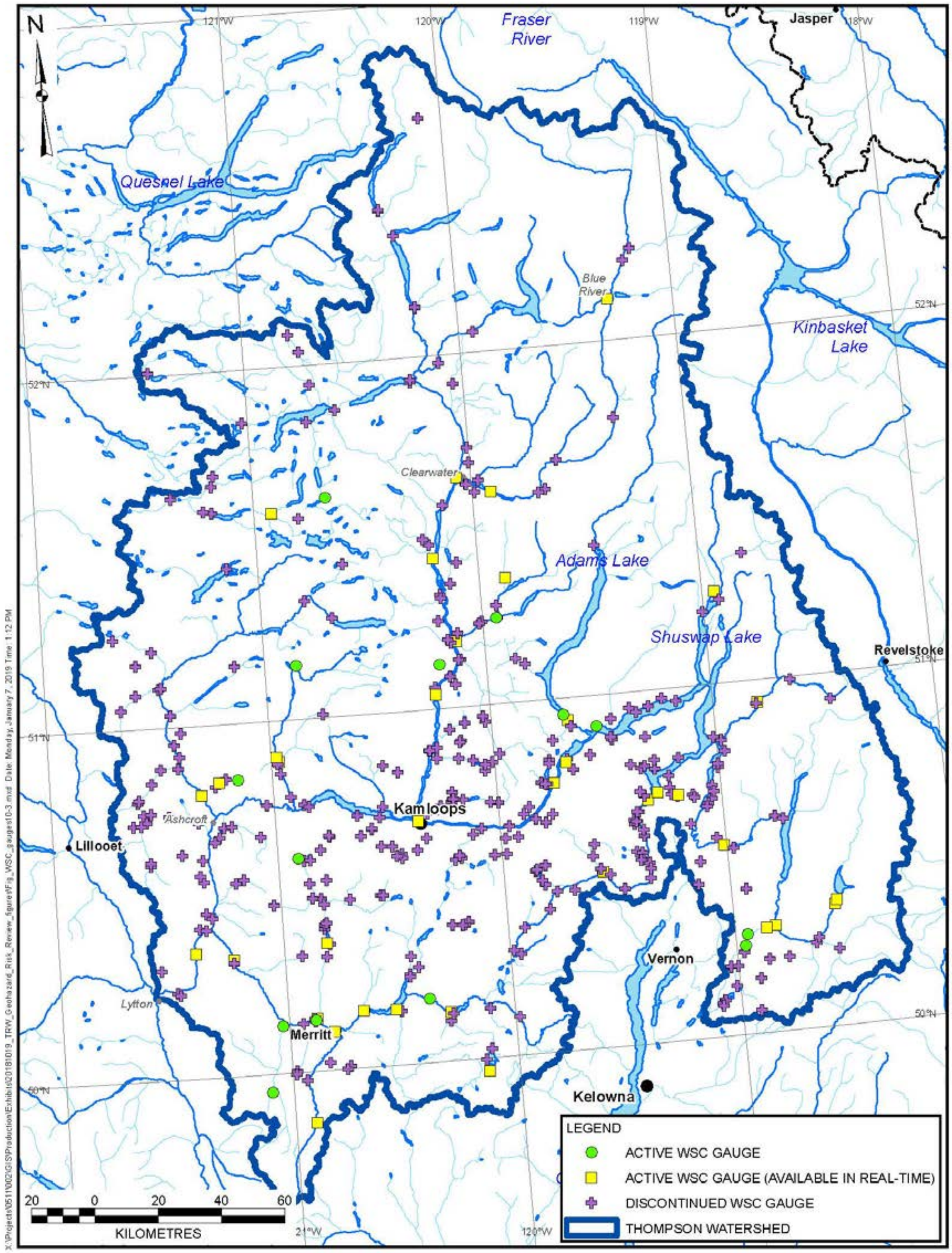


Figure 4-2. WSC active and inactive gauges within the TRW. Active stations are represented by a Green dot; Active stations that are also real-time monitoring stations are represented by a Yellow square; and Discontinued stations are represented by a Purple cross.

4.1.4. Geohazard Process Type

Every mapped stream segment in the TRW, from small tributary creeks to large rivers, was assigned a predicted process type (flood, debris flood or debris flow) based on statistical analysis of Melton Ratio[14] and watershed length[15]. These terrain factors are a useful screening-level indicator of the propensity of a creek to dominantly produce clear-water floods, debris floods or debris flows (Wilford et al., 2005; Jakob et al., 2015; Holm et al., 2016). The typical watershed characteristics that differentiate the primary geohazard for each creek are shown in Table 4-3. The web map displays every stream segment in the TRW and its associated predicted steep creek geohazard process type (clear-water flood, debris flood or debris flow).

Table 4-3. Class boundaries using Melton ratio and total stream network length.

Process	Melton Ratio	Stream Length (km)
Clear-water flood	< 0.2	all
Debris flood	0.2 to 0.5	all
	> 0.5	> 3
Debris flow	> 0.5	≤ 3

The advantage of statistically based classification is that it can be applied to large regions. However, classification reliability is lower than detailed studies, which typically combine multiple lines of evidence such as statistical, remote-sensed, and field observation data. In this study, process type identification should be considered more reliable for creeks with mapped fans than those without mapped fans. Classifying every stream segment in the TRW into one of three likely process-types (i.e., clear-water, debris-flood or debris flow hazards) also does not recognize that there is a continuum between clear-water floods and steep-creek processes that is not accounted for in morphometrics. For example, a site may be transitional between two process-type (e.g., a longer watershed might still be able to produce debris flows if there's a landslide-inducing processes in a hanging valley near the fan apex). To capture this uncertainty, a probabilistic approach was also used to determine the likelihood that a stream segment falls within each of the three categories as described in more detail in Appendix B. Results of the probabilistic analysis were used to check the classification of clear-water flood hazards interpreted as transitional between clear-water and debris flood process types and can help inform more detailed hazard assessments in future.

Process type identification outside the prioritized study creeks were not validated by other means. Based on the results of this classification, every stream segment was differentiated into either clear-water flood hazards or steep creek flood hazards (i.e., debris flood or debris flow) and characterized as described in this chapter.

[14] Melton ratio is watershed relief divided by the square root of watershed area (Melton 1957).
[15] Stream network length is the total channel length upstream of a given stream segment to the stream segment farthest from the fan apex.

4.1.5. Historical Flood Event Inventory

Historical flood events as summarized in Section 2.8 were used to confirm flood-prone low-lying terrain outside of the areas encompassed by historical floodplain maps. Clear-water flood hazard areas were intersected with the flood event inventory compiled by BGC to identify areas with greater potential susceptibility to flooding. Flood hazard polygons were cross-referenced with the historical flood event inventory as a qualitative check of the geohazard ratings.

4.1.6. Existing Floodplain Mapping

4.1.6.1. Historical Mapping Sources

The BC government provides publicly-available information on the location of floodplains, floodplain maps and supporting data (MFLNRO, 2016;). From 1975 to 2003, the Province managed development in designated floodplain areas under the Floodplain Development Control Program. From 1987 to 1998, the rate of mapping increased through the Canada / British Columbia Agreement Respecting Floodplain Mapping. The agreement provided shared federal–provincial funding for the program and included provisions for termination of the agreement as of March 31, 2003. A limited portion of the watershed was mapped during this time and was generally focused on major rivers as summarized in Table 4-4.

While the maps are now outdated, their use is indicated by the MFLNRO as often representing the best floodplain mapping information available (EGBC, 2017).

The historical floodplain maps typically show both the extent of inundation and flood construction levels (FCLs) based on the 0.5% AEP (200-year return period event) and include a freeboard allowance. At select locations, the 5% AEP (20-year return period) flood elevation (including a freeboard allowance) was also provided for septic tank requirements under the Health Act at the time. Flood levels associated with the 0.5% AEP (including a freeboard allowance) have been used to establish design elevations for flood mitigation works and to inform local floodplain management policy and emergency preparedness. The historical flood maps do not consider the occurrence and location of flood protection measures in the map extents.

In addition, the historical flood maps do not consider climate change impacts on flooding (directly by predicted changes in rainfall and/or snowmelt and indirectly by changes in vegetation cover through wildfires and/or insect infestations).

Additional description of the existing historical mapping is provided in Appendix B.

Table 4-4. Summary of historical floodplain mapping within the TRW.

Watercourse	Major Watershed	District	Mapping Year
Bonaparte River	Bonaparte	TNRD	1996
Eagle River	South Thompson	CSRD	1979
Nicola/Coldwater Rivers	Nicola	TNRD	1989
North Thompson River (Vavenby to Kamloops)	North Thompson	TNRD	1982
Salmon River (Falkland to Salmon Arm)	South Thompson	CSRD	1991/1992
Seymour River at Seymour Arm[1]	South Thompson	CSRD	1991
Shuswap River	South Thompson	RDNO	1980, 1998
Spius Creek	Nicola	TNRD	1989
Thompson River (Kamloops)	Thompson	TNRD	1976

Note:

1. Floodplain map indicated as withdrawn from Government of BC website [accessed July 11, 2018].

4.1.6.2. Third-Party Mapping Sources

BGC is aware of the following floodplain mapping completed by third parties (private consultants) that post-dates historical mapping. The mapping shown in bold was available in geospatial (GIS) format and incorporated into this study:

- **City of Kamloops (updated 2004; CoK, April 17, 2017**
- **City of Salmon Arm (updated November 14, 2011)**
- **Village of Lumby (awarded 2017; MoTI, March 22, 2017)**
- **City of Enderby (updated 2012; FBC, February 14, 2018)**
- Village of Cache Creek (awarded 2017; MoTI March 27, 2017, anticipated Spring 2019).

As a result of the limited existing floodplain mapping available within the TRW, BGC developed an approach to predict floodplain extents for locations where historical floodplain mapping was not available as summarized in Section 4.1.7 and detailed in Appendix B.

4.1.7. Floodplain Extent Prediction

A topographic analysis was conducted to provide a screening-level estimate of floodplain extent, in areas where historical floodplain mapping was unavailable. Two approaches were used to predict the potential floodplain extent for mapped watercourses and varied depending on the size of the watercourse. These approaches included:

1. A vertical offset model (4 m offset) to identify potential low-lying areas for lakes and larger watercourses (Strahler order 4 or higher).
2. A horizontal buffer model (30 m buffer) to identify potential low-lying areas for smaller watercourses (Strahler order 3 or lower).

The difference in approaches for larger and smaller watercourses was an artifact of the resolution of the spatial data compiled. Additional description of the methods used to predict floodplain extents using the vertical offset and horizontal buffer are provided in Appendix B.

The clear-water flood hazard assessment did not consider the channel geometry or river bathymetry, which has an impact on the precision and accuracy of estimated geohazard location, extents and intensity that would need to be considered for detailed floodplain mapping. The lack of detailed topography (Lidar) limited the accuracy of terrain analysis for clear-water flood hazard (and steep-creek fan) area delineation and characterization.

4.1.8. Hazard Likelihood Estimatation

Frequency analysis estimates how often geohazard events occur, on average. Frequency can be expressed either as a return period or an annual probability of occurrence. As described, floodplain maps are typically based on the designated flood as represented by the 0.5% AEP event. Therefore, the 200-year flood event likelihood was used to prioritize clearwater flood sites across the TRW, which corresponds to a representative AEP of 0.5% or a "low" geohazard likelihood as summarized in Table 4-5.

Table 4-5. Annual Exceedance Probability (AEP) ranges and representative categories.

Geohazard Likelihood	AEP Range (%) [1]	Representative AEP	Representative Return Period (years)
Very High	>10%	20%	5
High	>10% - <3.3%	5%	20
Moderate	>3.3% - 1%	2%	50
Low	>1% - <0.33%	0.5%	200
Very Low	<0.33% - 0.1%	0.2%	500

Note:

1. AEP ranges are consistent with those identified in EGBC (2018).

4.1.9. Hazard Intensity Estimation

Estimated flood depth was used as a measure of clear-water flood hazard intensity (destructive potential). In the absence of hydraulic modelling results for the study, a relationship between the flood event magnitude and the maximum flood depth associated with the event was developed as shown in Table 4-6. The categories of low, moderate and high flood depths are based on a similar flood risk prioritization study used to describe potential flood severity (Ebbwater, August 14, 2018). A discharge range for the categories was assigned based on experience by BGC from unrelated projects in the region. The results were used as a proxy for maximum flood depth and an estimate of potential flood severity.

Table 4-6. Relative flood intensity criteria relating maximum flood depth to flood magnitude.

Average Flood Depth above Ground Surface (m)	Q_{200} discharge (m^3/s)	Hazard Intensity
< 0.1	< 10	Low
0.1 – 1	10 – 500	Moderate
>1	500+	High

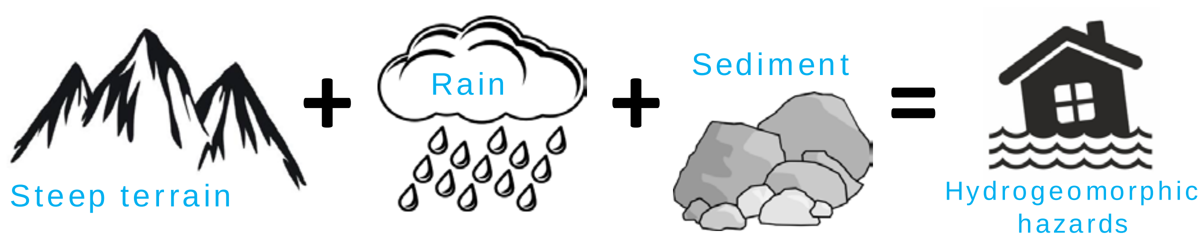
Note:

Flood depth and discharge are not necessarily directly correlated as shown in this table. Flood event peak discharge was used as a proxy for flood depth. Thresholds shown for discharge were assigned based on experience by BGC from unrelated projects in the region. These thresholds are relative estimates and cannot replace the use of flood stage-damage curves for detailed flood consequence estimation.

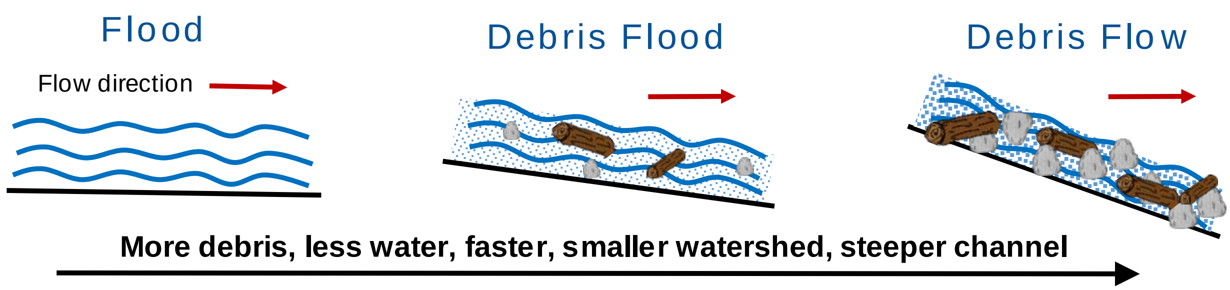
The flood depth thresholds shown in Table 4-6 are relative estimates and cannot replace the use of flood stage-damage curves for detailed flood consequence estimation (e.g., FEMA, May 2016). As well, the flood depths to not account for the occurrence of flood protection structures that could potentially alter the extent of flood inundation.

4.2. Steep Creek Geohazards

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



The main types of steep creek hazards are debris floods and debris flows. Debris floods occur when large volumes of water in a creek or river entrain the gravel, cobbles and boulders on the channel bed; this is known as "full bed mobilization". Debris flows involve higher sediment concentrations than debris floods. They are technically classified as landslides rather than floods, because their high sediment content and viscosity allows them to deposit at angles when water will continue to flow. The best common analogy of the behaviour of debris flows is wet concrete. It's easiest to think about hydrogeomorphic hazards as occurring in a continuum, as shown below. Further details about steep creek hazards are provided in Appendix C.



Steep creek geohazard areas prioritized in this study focused on fans, as these are the landforms most commonly occupied by elements at risk. The boundaries of fans define the steep creek geohazard areas that were prioritized. Upstream watersheds were assessed to identify geohazard processes and determine geohazard ratings but were not mapped.

4.2.1. Overview

Table 4-7 lists the approaches used to identify and rank steep creek geohazards: alluvial fan inventory, process type identification, hazard likelihood estimation, impact likelihood estimation, and hazard intensity (destructive potential) estimation. Together, these factors reflect an estimated likelihood that a geohazard process occurs and reaches areas with elements at risk with a certain level of intensity. This section provides a brief overview of assessment methods, with further details provided in Appendix C.

Table 4-7. Summary of steep creek geohazard identification and ranking approaches.

Approach	Area Assessed	Application
Alluvial fan Inventory	Prioritized study creeks	Delineation of alluvial fans to be prioritized; interpretation of terrain characteristics used to assign geohazard ratings.
Process type identification	All creeks	Classification of creeks as dominantly subject to clear-water floods, debris floods, or debris flows.
Hazard likelihood estimation	All steep creeks prone to debris flows or debris floods	Screening level identification and estimate of geohazard likelihood for all steep creeks; basis to assign geohazard ratings to prioritized study creeks.
Impact likelihood estimation	All steep creeks prone to debris flows or debris floods	Screening level estimate of impact likelihood for all steep creeks; basis to assign geohazard ratings to prioritized study creeks.
Intensity estimation	All steep creeks prone to debris flows or debris floods	Screening level estimate of relative geohazard intensity (destructive potential) of debris flows or debris floods.

4.2.2. Alluvial Fan Inventory

The boundary of alluvial fans represents the steep creek geohazard areas prioritized in this study (e.g., Figure 4-3). BGC mapped a total of 1,162 fans, based on the interpretation of available aerial and satellite imagery, Lidar DEM where available, and a review of previous reports and mapping. Geobase terrain models and satellite imagery available within the ESRI web map were used for terrain interpretations where Lidar was not available.

Figure 4-3. Example alluvial fan of Hummingbird Creek, near Sicamous.

Although this study was based on the best available information, the fan inventory is not exhaustive. Fans likely exist in some developed areas that may not have been detected at the screening level scale of study. For those mapped, BGC also notes that it is not possible to rule out the potential for steep creek geohazards to extend beyond the limit of the fan boundary in some cases. Most of the alluvial fans mapped in this study represent the accumulation of sediment over the Holocene period (since about 11,000 years BP). The fan boundary approximates the extent of sediment deposition since the beginning of fan formation. Geohazards can potentially extend beyond the fan boundary due to localized flooding, where the fan is truncated by a lake or river, in young landscapes where fans are actively forming (e.g., recently deglaciated areas) or where large landslides (e.g., rock avalanches) trigger steep creek events larger than any previously occurring. Assessment of such scenarios could form part of more detailed study. The limits of geohazard areas identified in this assessment (the alluvial fan boundary) should be treated as transitions, not exact boundaries.

4.2.3. Process Type Identification

Two methods were used to interpret the dominant geohazard process type on a stream: terrain analysis and morphometric statistics.

Terrain analysis was used to interpret the dominant geohazard process entering prioritized alluvial fans[16]. The analysis included review of airphoto or satellite imagery, and review of historical records if available. Section 4.1.4 described methods to assign a predicted process type (flood, debris-flood or debris flow) to every delineated stream in the TRW based on statistical analysis.

For the prioritized areas, a dominant process type was then assigned based on both the results of terrain analysis and statistical predictions. For the remaining streams, statistical predictions were not validated by other means and should be treated with a lower level of confidence. Table 4-8 summarizes the number of fans by process type.

Table 4-8. Summary of number of fans mapped by process type.

Process Type	Number of fans mapped
Debris Flood	418
Debris Flow	623
Flood	108
Paleofan	13
Total	**1162**

4.2.4. Hazard Likelihood Estimation

Hazard likelihood was estimated based on terrain interpretation considering both basin and fan activity. Basin activity considered parameters such as identifiable source areas, the nature of channels, and whether watersheds are supply-limited or unlimited. Fan activity focused on evidence of fresh deposit and lobes on the fan, and the type of vegetation. Basin and fan activity criteria were combined in a matrix to estimate hazard likelihood rating. Appendix C provides further description of methods to estimate geohazard likelihood and describes limitations and uncertainties.

4.2.5. Impact Likelihood Estimation

BGC estimated the relative likelihood that debris flows or debris floods will result in uncontrolled flows on fans, given occurrence of a geohazard. Appendix C provides further description of methods to estimate impact likelihood and describes limitations and uncertainties. The results of susceptibility modelling are shown as a layer on the web map.

[16] Note that many creeks with debris floods entering the fan apex also contain debris flow channels in their upper basins.

In summary, BGC used two methods to estimate impact likelihood: numerical modelling and terrain interpretation. Previous assessments and event records were also referenced where available. Both approaches were then combined in criteria to assign impact likelihood ratings at a fan level of detail. BGC notes that the actual likelihood of impact given hazard occurrence will vary across a fan, depending on the location. However, given the large number and diversity of elements at risk, no ratings were assigned for individual elements as would be completed for a detailed risk assessment.

In the numerical modelling method, BGC used a semi-automated approach based on the RNT, morphometric statistics (Section 4.1.2), and the Flow-R model[17] developed by Horton *et al*. (2008, 2013) to identify debris flow or debris flood hazards and model their runout potential. Terrain analyses then focused on identifying lack of channel confinement and evidence of channel avulsion, where uncontrolled flow outside the active channel is assumed to have higher potential to impact elements at risk.

4.3. Landslide-Dam Floods

A landslide-dam flood is a flooding event that can occur when a landslide blocks the flow of a watercourse (e.g., stream or river), leading to the impoundment of water on the upstream side of the dam and potentially the rapid downstream release of the impounded water following dam failure. For this part of the project, the ‘geohazard’ is landslide-dam flooding (both upstream inundation floods and downstream outburst floods). The formation and failure of a landslide dam is a complex geomorphic process because it involves the interaction of multiple geomorphic hazards. Major elements of the process are shown in Figure 4-4.

[17] "Flow-R" refers to "Flow path assessment of gravitational hazards at a Regional scale". See http://www.flow-r.org.

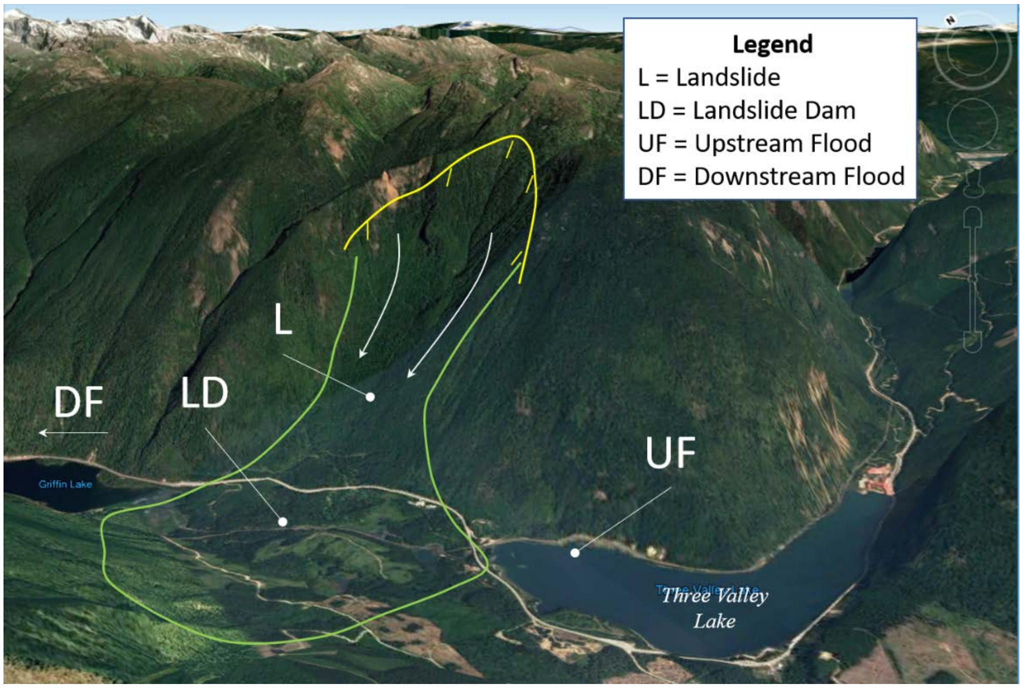


Figure 4-4. Major components of a landslide-dam floods. Oblique image from Google Earth showing Three Valley Lake, a landslide dam lake on the Eagle River, BC (See Appendix D Sectons D.1.3 and Figure D-2). Yellow shows the prehistoric landslide source areas and green lines show the approximate extent of landslide deposit.

4.3.1. Landslide-dam Flood Assessment Overview

This study follows a systematic approach to 1) define the extent of the study area, 2) perform landslide-dam flood geohazard characterization, and 3) assign geohazard and consequence ratings to prioritize landslide-dam flood prone areas in proximity to developed areas within the TRW. The assessment considers landslide-dam flood hazards within the TRW along the Thompson River and its main tributaries. This extent is represented by Strahler[18] order ≥6 watercourses.

The landslide-dam flood assessment framework consists of four main elements 1) Geohazard identification, 2) Geohazard rating, 3) Consequence rating, and 4) Priority rating. This section summarizes the inputs and processes used to perform the geohazard identification and estimate geohazard ratings that are illustrated in Figure 4-5. Consequence rating and priority ratings are discussed in Sections 5.3 and 5.4. Appendix D provides additional details about the landslide-dam flood hazard assessment methodology and workflow.

[18] Strahler stream order is a classification of stream segments by its branching complexity within a drainage system and is an indication of the significance in size and water conveying capacity at points along a river (Strahler, 1957).

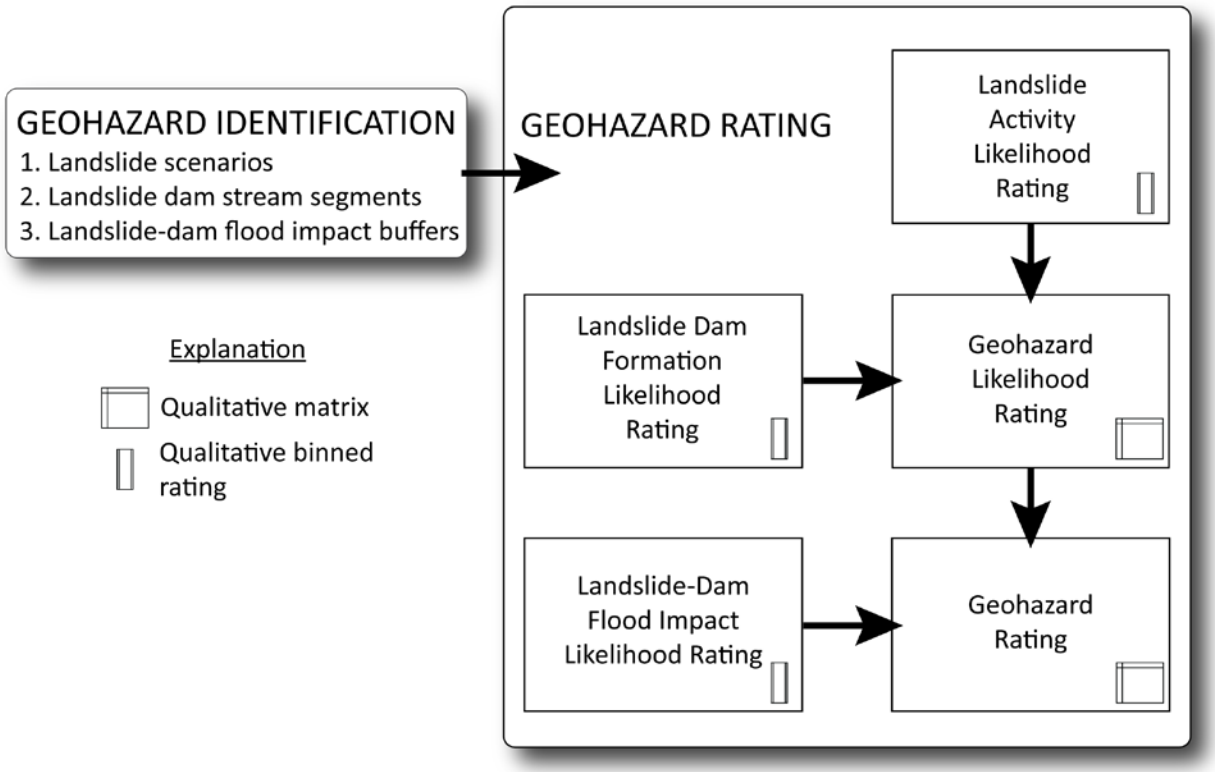


Figure 4-5. Workflow and key elements of the landslide-dam flood geohazard identification and geohazard ranking process.

4.3.2. Geohazard Identification

During geohazard identification process, available information is evaluated to determine the mechanisms and factors which cause landslide-dam flooding within the TRW. Key inputs for the assessment of landslide-dam flooding answer the following questions: (1) What types of landslides are likely to cause landslide dams?; (2) What sections of TRW watercourses are more likely to be blocked by a landslide dam?; and (3) What are the possible extents for upstream and downstream landslide-dam flooding?

Within the TRW most types and styles of landslide are possible, but not all are likely to create landslide dams. Using guidance from Clague and Evans (1994) who previously studied landslide-dam floods in western Canada, BGC considered rapid to extremely rapid (Varnes, 1978) landslides having volumes of $5x10^5$ m^3 or larger, and which occur from failures in bedrock slopes, dissected Quaternary valley fills, and relatively thin Quaternary sedimentary mantling rock slopes as most likely to form landslide dams.

The TRW is characterized by highly variable geologic and topographic conditions (see Section 2.3 and 2.4). This variability results in additional variability in landslide-dam flood geohazard conditions across the region and along individual watercourses. To identify unique segments of roughly uniform hazard and consequence at a scale appropriate for this study, watercourses were split into 146 shorter segments of relatively uniform conditions relevant to landslide dam formation.

The upstream and downstream extent of landslide-dam floods can be many kilometres from the dam location. Specifically, a landslide dam at some location in a river segment could result in flooding both within that segment and beyond its upstream and downstream limits.

Appendix D provides further description of the geohazard identification process and describes limitations and uncertainties.

4.3.3. Geohazard Rating

A landslide-dam flood geohazard rating was estimated for each of the ≥6 Strahler order stream segments (n = 146) and shown as a layer on the web map. The two factors which form the basis for geohazard rating are:

- Geohazard likelihood: What is the likelihood of landslide-dam flood event large enough to potentially impact elements at risk? (Section D.3.1)
- Impact Likelihood: Given a geohazard event occurs, how susceptible is the hazard area to uncontrolled flows that could impact elements at risk? (Section D.3.2)

4.3.4. Geohazard Likelihood Estimation

Geohazard likelihood is the estimated likelihood that landslides occur and result in landslide dams somewhere in the river segment. Two questions are addressed:

- Within a given stream segment, how likely is it that a potentially dam-forming landslide occurs?
- Given that such a landslide occurs, what is the likelihood that it actually forms a dam?

These two questions are addressed by assigning ratings for the likelihood that a landslide will happen (Landslide Activity Likelihood Rating) and – if it happens – form a dam capable of causing upstream and downstream flooding (Landslide-Dam Formation Likelihood rating). Landslide activity likelihood corresponds to the historic frequency and average annual probability of landsliding at a scale large enough to form a dam. Landslide-dam formation considers the likelihood that a landslide dam will form, and flooding will occur. Landslide dam formation is a complex and highly uncertain process which relies on the integration of multiple factors that may or may not result in landslide-dam related flooding.

Appendix D provides further description of the geohazard rating process and describes limitations and uncertainties.

4.3.5. Impact Likelihood Estimation

Landslide-dam floods can have far-reaching effects both upstream and downstream from a dam location. Impact likelihood estimates the proportion of a landslide-dam flood area expected to be impacted for a given landslide-dam flood. For downstream flooding, BGC considered clear-water flood extents 10 km beyond the downstream limit of a river segment. While the downstream limit of flood propagation is highly uncertain and may exceed 10 km, this distance captured sufficient elements at risk to reasonably compare areas from the perspective of hazard exposure. For upstream flooding caused by impoundment, BGC considered clear-water flood extents for a distance that was based on an average river gradient and landslide dam height of 10 m at the upstream end of the segment.

The process to define reasonable screening level upstream and downstream limits for flood impact areas, the impact likelihood ranking process, and related limitations and uncertainties are further described in detail in Appendix D.

5. GEOHAZARD RISK PRIORITIZATION METHODS

This section describes methods to assign ratings of hazard, consequence and risk-based priority to each geohazard area. The ratings are defined in three parts as follows:

1. Geohazard rating (Section 5.2). This rating estimates the relative likelihood a geohazard will occur and reach elements a risk.
2. Consequence rating (Section 5.3). This rating estimates the relative consequences given impact by a geohazard, based on proxies for the value of elements at risk and their vulnerability to damage or loss.
3. Priority rating (Section 5.4). This rating combines the geohazard and consequence ratings, to estimate the relative likelihood that geohazards could occur and result in a certain level of consequences.

5.1. Introduction

This section describes how geohazard areas were prioritized across the TRW. The prioritization approach is consistent across the range of geohazards assessed, where methods to estimate input values are specific to each hazard type.

The prioritization framework used in this study is based on the following general principles:

- Support decision making, but with the recognition that additional factors for risk management and policy making exist that are outside the scope of this assessment
- Provide results to incorporate into steep creek and river risk management policy
- Provide a framework that can be expanded to other types of geohazards (i.e., landslides)
- Apply an approach that can be refined and improved in the future without duplicating effort.

Figure 5-1 illustrates the three components of the risk prioritization framework used in this study: hazard, exposure, and vulnerability. The combination of exposure and vulnerability represents consequences, and all three components together represent risk. Each of these components is estimated separately and combined to form a priority rating for a given site.

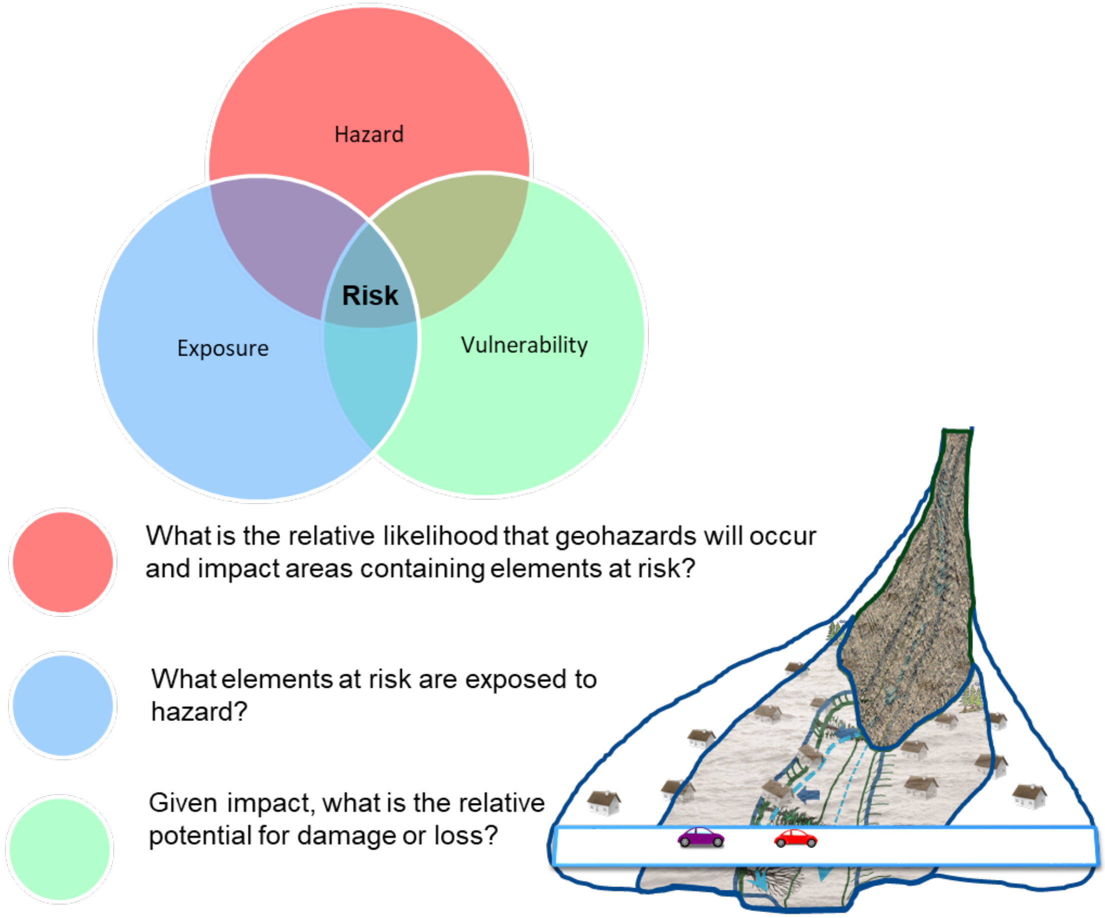


Figure 5-1. Elements of the prioritization approach.

The approach uses matrices to arrive at separate ratings for hazard and consequence, which are then combined to provide a priority rating for each hazard area. Higher ratings generally reflect a higher estimated likelihood that more destructive flows will impact more extensive development. This three-part approach facilitates risk management planning and policy implementation in that it is relatively simple while still identifying each factor contributing to risk.

At the same time, the results are aggregate ratings that support, but do not replace, more detailed risk assessment and risk reduction planning. Inputs used to generate each rating are provided on the web map and via data services and downloads. These original data can be used to include additional or different combinations of factors in risk management plans.

Sections 5.2 to 5.4 describe the steps used to determine geohazard, consequence, and priority ratings for each area. Appendices B, C, and D provide detailed description of methods to determine geohazard ratings for clear-water, steep creek and landslide-dam flood geohazard areas, respectively.

As a baseline study, BGC notes that the prioritization is based on current conditions for both geohazards and elements at risk. Appendix E provides additional assessment of the sensitivity of geohazard levels to change resulting from climate change.

5.2. Geohazard Rating

Table 5-1 presents the qualitative geohazard rating system used in this study. It combines hazard and impact likelihood ratings to rate the potential for events to occur and – if they occur - impact elements at risk. The two axes help clarify the source of hazard for later mitigation planning. For example, flood regulation can control hazard likelihood, whereas structural mitigation (i.e., dikes) can control impact likelihood.

Table 5-1. Geohazard rating.

Hazard Likelihood	Geohazard Rating				
Very High	M	H	H	VH	VH
High	L	M	H	H	VH
Moderate	L	L	M	H	H
Low	VL	L	L	M	H
Very Low	VL	VL	L	L	M
Impact Likelihood	Very Low	Low	Moderate	High	Very High

Geohazard ratings assume that elements at risk are present within the hazard zone at the time of impact, as would be expected for buildings, lifelines, critical facilities, and other immobile features that are the subject of this study.

Table 5-2 defines hazard and impact likelihood for each hazard type. Table 5-3 defines approximate frequency and return period ranges for hazard likelihood categories. Appendices B to D describe criteria used to assign impact likelihoods, and the methods used to estimate the values of the hazard and impact likelihood ratings.

As indicated in Table 5-2 and Appendices B, C, and D, single estimates for hazard likelihood were applied to each hazard area. The approach is considered reasonable for the purpose of relative risk prioritization but represents a limitation of the current study. Larger events could impact geohazard areas at lower likelihood than those considered in prioritization, and smaller events could impact parts of prioritized areas at higher frequency than is indicated by geohazard likelihood ratings. Section 7.2 describes further, more detailed assessment that would consider a wider range of geohazard frequencies and magnitudes than were considered in this study.

Table 5-2. Definitions of hazard likelihood and impact likelihood for the geohazard types assessed.

Factor	Geohazard Type	Definition
Hazard likelihood	Steep creeks	Likelihood of a steep-creek event large enough to impact elements at risk on an alluvial fan.
	Clear-water floods	0.5% AEP (200-year) flood.
	Landslide-dam floods	Likelihood of a landslide occurring, damming a watercourse, and retaining sufficient water volumes to create a credible threat to downstream (outburst flood) or upstream (impoundment flood) elements at risk.
Impact likelihood	Steep creeks	Estimated likelihood of an uncontrolled flow reaching elements at risk, given that a steep-creek event occurs.
	Clear-water floods	Assumed impact likelihood of High (Table 5-1) within the flood extent, given occurrence of the 5% AEP flood.
	Landslide-dam floods	Estimated likelihood of flooding of a location within a landslide-dam flood hazard area, given the formation of a landslide-dam (see Appendix D for a more detailed definition).

Table 5-3. Relative hazard likelihood and approximate frequency and return period categories.

Geohazard Likelihood	AEP range (1/years)	Approximate Return Period Range (years)	Representative Return Period (years)
Very High	> 0.1	< 10	5
High	0.1 – 0.03	10-30	20
Moderate	0.03 – 0.01	30-100	50
Low	0.01 – 0.003	100-300	200
Very Low	<0.003	>300	500

5.3. Consequence Rating

Consequence combines the value of the element at risk with its vulnerability to damage or loss, given impact by that hazard. Formally, it is the conditional probability that elements at risk will suffer some severity of damage or loss, given geohazard impact with a certain severity. In detailed studies, consequences can be measured qualitatively or quantitatively for areas such as public safety (i.e., probability of loss of life), economic loss, services disruption, environmental loss, or social loss (culture, loss of security) (United Nations, 2016; UNISDR, 2015).

The same principles apply to this study, but with some simplification that reflects the level of detail of assessment. Consequence ratings were assigned that compare the relative *potential* for loss between hazard areas, given hazard impact with a certain intensity (destructive potential). They consider the presence and value of elements at risk within the hazard area, and the intensity of flows that could impact elements at risk. Higher value or greater number of elements at risk, combined with the potential for more highly destructive flows, results in a higher consequence rating for a given area.

BGC assigned consequence ratings by combining two factors rating the exposure of elements at risk (exposure rating) to destructive flows (vulnerability rating).

5.3.1. Exposure Rating

The exposure rating is based on weightings assigned based on the value or presence of the elements at risk listed in Table 3-1. BGC used in-house software tools to identify the presence and value of elements at risk within hazard areas and calculate weightings. As noted in Section 3, the exposure rating is subjective and aims to weight the importance of elements at risk from a regional perspective, with reference to the response goals of the BC Emergency Management System (BCEMS) (Government of BC, 2016).

5.3.2. Intensity Rating

Elements at risk can be vulnerable to flood and steep creek processes through direct impact by water or debris and through secondary processes such as channel avulsion, channel aggradation or scour, bank erosion, channel encroachment, or landslides. This study primarily focused on direct flood inundation and debris impact.

The elements at risk considered in this study have different vulnerabilities to flood impact, and some simplification is required to arrive at aggregate ratings for a given area. The vulnerability of specific elements at risk was not estimated. BGC assumed that elements at risk would be generally more vulnerable to more highly destructive flows and used average estimates of flow intensity as a proxy for relative vulnerability.

Appendices F and G provide further description of methods to estimate destructive potential for each geohazard type, as well as limitations and uncertainties. In summary, detailed analysis of geohazard intensity requires numerical modelling of parameters such as flow depth and velocity, which are not available for all areas assessed. To address this limitation for relative risk prioritization, BGC used screening level estimates of clear-water, debris flood or debris flow discharge as a proxy for flow intensity. Statistical analysis of peak discharge estimates provided a relative rating of intensity for different sites.

5.3.3. Consequence Rating

Table 5-4 displays the matrix used to combine hazard exposure and intensity ratings, to arrive at a consequence rating. The two axes help clarify the source of consequence for mitigation planning. For example, land use and emergency response planning can manage hazard exposure (vertical access), whereas risk control measures (i.e., increased flood storage) can control hazard intensity (horizontal axis).

Table 5-4. Relative consequence rating.

Hazard Exposure	Relative Consequence Rating				
Very High	M	H	H	VH	VH
High	L	M	H	H	VH
Moderate	L	L	M	H	H
Low	VL	L	L	M	H
Very Low	VL	VL	L	L	M
Hazard Intensity	**Very Low**	**Low**	**Moderate**	**High**	**Very High**

5.4. Priority Rating

Table 5-5 displays a matrix used to prioritize each geohazard area based on the geohazard (Table 5-1) and consequence (Table 5-4) ratings.

As noted in Section 5.1, the original data used to generate each rating are provided on the web map and via data services and downloads. Methods to generate the value of ratings is contained in Appendices B-D for each hazard type assessed. These inputs can be used to consider additional or different combinations of factors in risk management plans, beyond the aggregate priority rating.

Table 5-5. Prioritization matrix (assets).

Geohazard Rating	Priority Rating (Elements at Risk)				
VH	M	H	H	VH	VH
H	L	M	H	H	VH
M	L	L	M	H	H
L	VL	L	L	M	H
VL	VL	VL	L	L	M
Consequence Rating	**VL**	**L**	**M**	**H**	**VH**

BGC notes that the geohazard areas prioritized are not all the same areal extent. This means that – all else being equal – larger areas may rank as higher priority because they contain more elements at risk. BGC attempted to avoid gross differences in hazard extents (i.e., by dividing large floodplain polygons in proximity to elements at risk into approximately equal units) but did not normalize ratings by unit area. The rationale to avoid normalization by area was based on the notion of "consultation zones", which define a geographic area considered for geohazard safety assessment (Geotechnical Engineering Office, 1998; Porter et al, 2009). In geohazard safety assessments, a consultation zone "includes all proposed and existing development in a zone defined by an approving authority that contains the largest credible area affected by geohazards, and where fatalities arising from one or more concurrent landslides would be viewed as a single catastrophic loss" (Porter et al., 2018). The chosen approach reflects societal perception of risk, where higher priority areas are those where there is a greater chance of more significant consequences.

6. RESULTS

This study provides baseline results in several ways:

- This report section provides a summary overview of results
- Geospatial data (prioritized geohazard áreas) provided separately for download in Geodatabase format
- Cambio Communities™ (www.cambiocommunities.ca) web application
- ArcGIS Representational State Transfer (REST) API provides access to geohazard área layers in a format accessible through an ArcGIS Online account. This option is intended for geomatics professionals on request
- Appendix I provides the example RAIT form required by the NDMP
- Appendix J provides an Excel spreadsheet with tabulated results.

In total, BGC prioritized 6225 geohazard areas encompassing over 4,000 km^2 (7%) of the TRW (Table 6-1, Figure 6-1). Compared to the entire TRW, about 30% of the Census population, 50% of assessed building values, 30% of business locations, and most of the major transportation routes, are in these areas.

The prioritized hazard areas are presented on a secure web application, Cambio Communities™ (Figure 1-6), at www.cambiocommunities.ca. Appendix H provides a guide to navigate Cambio Communities. In summary, Cambio Communities shows the following information:

1. Prioritized flood and steep creek hazard areas. These are the key outcome of this study. Clicking on a hazard area reveals priority ratings and supporting information.
2. Information provided by project stakeholders and referenced during the study, including:
    a. The built environment (elements at risk)
    b. Existing geohazard mapping.
3. Information generated by BGC during the study and provided for visual reference, including geohazard, hydrologic and topographic features (e.g., digital elevation model (DEM), watershed boundaries, and stream lines).

Note that the application should be viewed using Chrome or Firefox web browsers and is not designed for Microsoft Internet Explorer or Edge.

Table 6-2 lists the results worksheets provided in Appendix J. These worksheets can be filtered and sorted to view ranked hazard areas by type and priority. Note that clear-water flood and landslide-dam flood geohazard areas substantially overlap and elements at risk statistics about these areas should not be summed.

BGC emphasizes there are additional factors for risk management and policy making that are outside the scope of this assessment, that local authorities may also consider when reviewing prioritization results. For example, other factors include the level of risk reduction achieved by existing structural mitigation (dikes), comparison of the risk reduction benefit to the cost of new or upgraded flood risk reduction measures, and level of flood resiliency in different areas.

Table 6-1. Number of prioritized areas in the TRW, by geohazard type.

Row Labels	Priority Level					Grand Total
	Very High	High	Moderate	Low	Very Low	
Clear-Water Floods		**344**	**609**	**3969**	**0**	**4922**
Waterbody (subtotal)		67	109	379	0	**555**
Watercourse (subtotal)		277	500	3590	0	**4367**
Landslide-Dam Floods		**23**	**57**	**52**	**14**	**146**
Steep Creeks	**10**	**99**	**280**	**564**	**204**	**1157**
Grand Total (Count)	**10**	**466**	**946**	**4585**	**218**	**6225**
Grand Total (%)	**0.16%**	**7.49%**	**15.20%**	**73.65%**	**3.50%**	**100%**

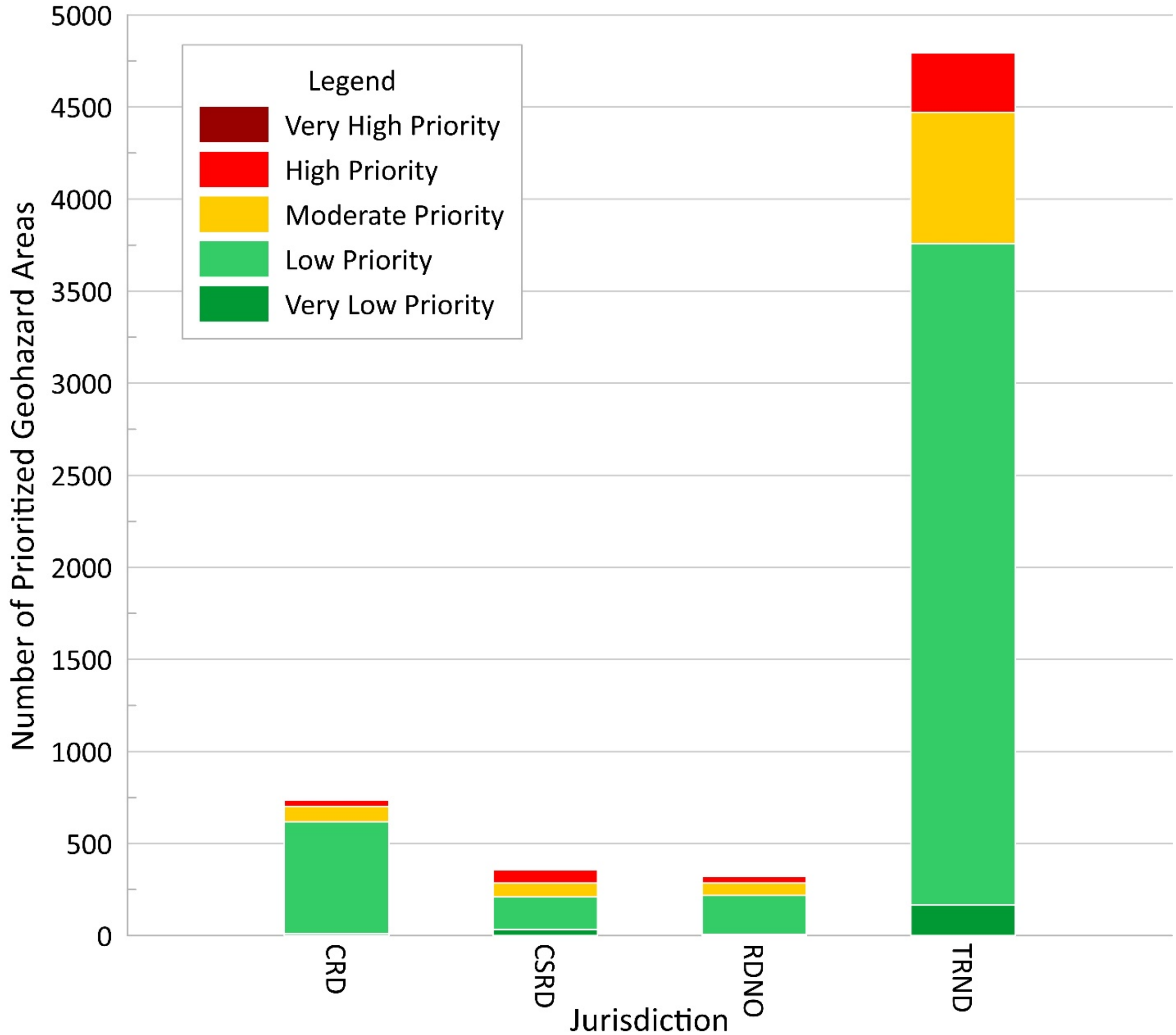


Figure 6-1. Number of prioritized areas in within the TRW.

Table 6-2. Results worksheets provided in Appendix J.

Appendix I (Excel Worksheet Name)	Contents
Study Area Metrics	Summary statistics of select elements at risk (count of presence in geohazard areas)
Study Area Hazard Summary	Summary statistics of elements at risk, according to their presence in geohazard areas
Study Area Hazard Type Summary	Summary statistics of geohazard areas, according to the presence of elements at risk.
Priority by Jurisdiction	Summary statistics of prioritization results by jurisdiction.
Steep Creek Hazard Attributes	Attributes displayed in the information sidebar on Cambio Communities for all steep creek geohazard areas.
Clear-water Flood Hazard Attributes	Attributes displayed in the information sidebar on Cambio Communities for all clear-water flood geohazard areas.
Landslide-dam Flood Hazard Attributes	Attributes displayed in the information sidebar on Cambio Communities for all lansIde-dam flood geohazard areas.

7. RECOMMENDATIONS

This chapter provides recommendations for consideration by FBC and project stakeholders. It may require review by different groups within municipal, regional and First-Nations government, including board members, managers, planners, emergency management staff, and geomatics staff.

Table 7-1 lists the recommendations described in this chapter, with further details provided in Sections 7.2 to 7.6. Each section starts with an italicized, bulleted list of recommendations, followed by background and justification. Appendix K provides further detail on recommended approaches and tasks for clear-water flood and steep creek geohazard assessments.

This chapter also compares the current study and its recommendations to a 2017 province-wide review of government response to flood and wildfire events during the 2017 wildfire and freshet season (Abbott & Chapman, 2018). The Abbott-Chapman report included a total of 108 recommendations to assist the Province in improving its systems, processes and procedures for disaster risk management. Section 7.7 lists recommendations of the Abbott-Chapman report that pertain to this study, and how this study and its recommendations supports those in the Abbott-Chapman report.

Table 7-1. Summary of recommendations.

Type	Section	Description
Data Gaps	7.1	• Develop a plan to resolve the baseline data gaps outlined in this section, including gaps related to baseline topographic, bathymetric and stream network data; geohazard sources, controls, and triggers; geohazard frequency- magnitude relationships, characteristics of flood protection measures and flood conveyance infrastructure, and hazard exposure (elements at risk).
Further Geohazards Assessments	7.2	• Geohazard areas: complete more detailed assessments for areas chosen by FBC or stakeholders as top priority, following review of this assessment. • Out-of-Scope areas: review areas noted as potentially containing geohazards, but not further assessed in this study.
Geohazards Monitoring	7.3	• Add real-time stream flow and precipitation monitoring functions to geohazard web applications, to support emergency monitoring. • Develop criteria for hydroclimatic alert systems informing emergency response. • Develop capacity for the automated delivery of alerts and supporting information informing emergency response.
Policy, Plans, and Bylaw Integration	7.4	• Review Development Permit Areas (DPAs) following review of geohazard areas defined by this study. • Review plans, policies and bylaws related to geohazards management. • Develop risk evaluation criteria that allow consistent risk reduction decisions (i.e., that define the term “safe for the use intended” in geohazards assessments for development approval applications)
Information Management	7.5	• Review approaches to integrate and share asset data and geohazard information across functional groups in government, stakeholders, data providers and risk management specialists. Such an effort would assist long-term geohazard risk management, asset management, and emergency response planning. • Develop a maintenance plan to keep study results up to date as part of ongoing support for bylaw enforcement, asset management, and emergency response planning.
Training and Stakeholder Communication	7.6	• Provide training to stakeholders who may rely on study results, tools and data services. • Work with communities in the prioritized geohazard areas to develop flood resiliency plans informed by stakeholder engagement.

7.1. Data Gaps

Recommendation:

- *Develop a plan to resolve the baseline data gaps outlined in this section.*

Table 7-2 summarizes gaps in baseline data that informed the current risk prioritization study and provides recommendations to resolve these gaps.

Table 7-2. Summary of data gaps and recommended actions.

Input	Description	Implication (Factor Affected)	Recommended Actions to Resolve Gaps
Topography	• Lack of detailed topography (Lidar) limited the accuracy of terrain analysis for steep creek fans and for clear-water flood hazard area delineation and characterization.	• Precision and accuracy of estimated geohazard location/extents, likelihood, and intensity.	• Lidar acquisition and processing. This action is already the subject of a NDMP Stream 4b application. This coverage focuses on valley bottoms and gaps remain for upslope areas. • Review and update to terrain analyses (i.e., fan boundary delineation) following Lidar acquisition. • Consider re-evaluating geohazard area delineation and characterization once Lidar data are available. Consider increasing the number of clear-water hazard sites evaluated with screening-level hydraulic modelling (if not already slated for detailed floodplain mapping). Review vertical offset model depth and consider using the methodology for smaller streams.
Bathymetry	• Clear-water flood hazard assessment did not consider the channel geometry or river bathymetry.	• Precision and accuracy of estimated geohazard location/extents and intensity.	• For more detailed, site-specific studies, bathymetry would be required.
Stream network	• Not all watercourses present within the TRW are contained within provincial (TRIM) or national river networks, and some have changed location since mapping (i.e., due to channel avulsion or migration). Mapped watercourses may or may not be consistent with the definition of watercourse contained in Floodplain Management Bylaws. The stream network used in this assessment is defined according to the channel thalweg location as mapped at the time of delineation and not the high-water mark or bank location.	• Gap in hydrologic analyses for fans not intersecting mapped streams • Uncertainty in defining flood extents on watercourses that have moved since the original stream network mapping. Additionally, for small watercourses, the hazard area was defined from a setback from the mapped thalweg, rather than from the top of bank.	• Incorporation of more detailed stream networks (i.e., TRIM) plus manual revisions if required to facilitate hydrologic, hydraulic, and geomorphic analyses required for geohazard risk management. • Consider running algorithms on region-wide Lidar to identify watercourse and bank locations, and to identify stream segments that are consistent with the bylaw definition for watercourse.
Geohazard Sources / Controls / Triggers	• Gaps exist in the inventory of geohazards within the TRW that represent sources, controls, or triggers for flood and steep creek geohazards. For example, landslides represent triggers for steep creek geohazards, and wildfires alter watershed hydrology in ways that can temporarily affect flood response and sediment transport. Landslides can also create temporary dams and associated inundation and outburst floods, as well as floods from waves triggered by landslides into lakes and reservoirs. Those have not been considered.	• Ability to identify sources, controls, or triggers for flood and steep creek geohazard. For example - identification of landslide hazards informing the development of frequency-magnitude relationships for detailed steep creek geohazards assessments.	• Given that not all studies can be completed at the same time, maintain a data information management system that integrates existing knowledge, with tools to grow an accessible knowledge base over time as funding permits. Organizing geospatial data so that all studies take advantage of a common resource will greatly reduce the costs of data compilation. • Require assessments to provide results in geospatial formats when generated during a study and provide data standards that facilitate their inclusion in a larger data model. • Initiate citizen science initiatives[19] to capture geohazards information, particularly events, in near-real time. A web application is currently being developed by Public Safety Canada that is anticipated to support this action for clear-water floods.
Geohazard Frequency-Magnitude Relationships.	• Flood magnitude and associated return periods were evaluated based on limited gauge data (gauge locations and record lengths) and were unavailable for rivers and lakes regulated by dams. Frequency-magnitude relationships have not been quantified for most steep creek geohazard areas in the TRW based on detailed investigations.	• Precision and accuracy of estimated geohazard location/extents, likelihood, and intensity.	• Advocate for improvements to WSC gauging in the TRW. • Establish frequency-magnitude relationships for individual steep creeks as part of detailed geohazards studies (Section 7.2, Appendix J).
Wildfires	• Post-wildfire geohazards assessments rely on remotely sensed burn severity mapping supplemented by field inspection of conditions at the ground surface. At present, only burn perimeter mapping is made widely available for all fires and burn severity mapping is not necessarily available for small wildfires. However, small fires occurring in basins prone to steep creek processes can still result in elevated geohazard levels.	• Ability to provide timely post-wildfire geohazards assessments for areas where changes in post-wildfire geohazard activity will have the strongest influence on risk.	• In advance of wildfire occurrence, apply the results of this assessment to define high priority areas where burn severity mapping should be completed, should a wildfire occur. High priority areas can be defined by watershed boundaries, which were already prepared as part of the current study. • Coordinate with the Province of BC to provide burn-severity mapping via their web service, in a format that can be directly incorporated into web-mapping of geohazard areas and elements at risk.

[19] i.e., collaborations between professionals and volunteer members of the public, to expand opportunities for data collection and to engage with community members.

Input	Description	Implication (Factor Affected)	Recommended Actions to Resolve Gaps
			• Use the existing study information in combination with burn severity maps to inform post-wildfire geohazard risk assessments when required
Flood Protection Measures, and Flood Conveyance Infrastructure	• Dikes, bank erosion protection, and appurtenant structures, in addition to culverts and bridges were excluded from the evaluation due to the limited data available on the location, properties and condition of these facilities	• Precision and accuracy of estimated geohazard location/extents, likelihood, and intensity.	• Develop data collection standards and sharing agreements between the various facility owners to facilitate their inclusion in a larger data model. • More detailed inventories and characterization of assets based on consistent data standards would improve and reduce the cost of hydraulic assessments. • Apply the results of this assessment to prioritize characterization of of risk reduction measures and consideration in further, more detailed geohazards assessments.
Exposure	• Gaps exist in the elements at risk (asset) data model developed for the TRW, in terms of location, attributes, and data formats. • Specifically, the layers showing land and improvements, lifelines, and environmental values on Cambio Communities are based on the best information available at the time of study but are not complete. • Local knowledge, particularly as it relates to intangible losses and flood resiliency, also represents a key gap outside the scope of the current study.	Ability to provide information that supports: • Hazard exposure and vulnerability estimation • Inclusion of assets required for later more detailed hazard modelling (i.e., drainage networks) • Level of detail of baseline data informing resiliency planning, the ability of a system to resist and recover from flooding or steep creek geohazard impact. • Level of detail of data informing asset management in geohazard areas • Level of detail of elements at risk information supporting emergency response planning	• Building footprints could be digitized for all parcels containing building improvements and intersecting geohazard areas. This information will be required for future detailed flood inundation modeling and risk assessments and to verify whether geohazards that intersect improved cadastral parcels intersect buildings on the parcel. Building footprints should include a unique identifier and Parcel ID to allow them to be joined to cadastral data. For parcels with multiple structures, the “main” dwelling should be distinguished from out-buildings, to allow them to be distinguished when assessing safety risk to dwelling occupants. This effort would also identify cases where properties contain buildings not recorded by BC Assessment.
	• BC Assessment (BCA) data reported for tax purposes are also key indicators to estimate geohazard vulnerability, but information gaps limit this application of the data.	• The use of BCA data to assess building vulnerability is helpful in that it is regularly updated and available in a consistent format province-wide. However, it is limited in that the data is being applied to a different purpose than the original intent, which is to inform appraised improvement values.	• Because the collection and dissemination of assessment data for tax purposes is likely to be funded for the foreseeable future, it represents a reliable way to maintain up-to-date records. BGC suggests that assessment data collection and reporting procedures be reviewed and updated to consider requirements of geohazard risk management and emergency response. Relatively minor adjustments to how assessment data is collected (i.e., attributes) and communicated (i.e., data formats and types) would greatly facilitate risk analyses. • Advocate for a standard data product, to be provided by BCA, that contains data elements for geohazard risk management and emergency response. This would reduce the cost per request, compared to custom data requests.
	• Data gaps exist for elements at risk located on First Nations Reserves.	• Underestimation of exposure and vulnerability on First Nations Reserves.	• Collection of data on elements at risk within First Nations reserves with a level of detail and format consistent with that outside reserve lands would facilitate geohazards assessments in these areas. BGC assumes this work would have to be led by a Federal government agency.
	• No information was readily available on road networks critical for use in a geohazard-related emergency. Some of these routes include forestry roads providing alternative access to remote communities. Because these roads are not typically high traffic, they do not weight heavily (i.e., are not assigned high importance) in the calculation of hazard exposure.	• Underestimation of priority where geohazard areas intersect evacuation routes along minor roads.	• Prepare map layer identifying emergency evacuation road networks. • Include an evacuation road network layer in hazard exposure analysis and update the study results.

7.2. Further Geohazards Assessments

Recommendations:

- *Geohazard areas: complete more detailed assessments for areas chosen by FBC or stakeholders as top priority, within the context of a geohazard risk management plan.*
- *Out-of-Scope areas: review areas noted as potentially containing geohazards, but not further assessed in this study.*

Sections 7.2.1 to 7.2.4 describe the rationale for these recommendations. Appendix J provides further detail on recommended approaches and tasks for clear-water flood and steep creek geohazard assessments. The appendix also notes areas where climate change can be considered in clear-water flood and steep creek geohazards assessments.

7.2.1. Geohazard Risk Management Plan

Geohazard risk assessments estimate the probability or likelihood of a loss (AGS, 2007) from a given hazard scenario and compare those risk levels to tolerance criteria. Risk assessment forms part of the process of risk management, which includes additional processes of risk communication, selection and implementation of risk control measures, and ongoing monitoring and review (Table 7-3).

The additional work proposed in this section focuses on the Geohazard Analysis stage of geohazard risk management. Table 7-3 provides a framework for the additional steps that should also be undertaken as part of more detailed mitigation planning at high priority sites.

Table 7-3. Risk management framework (adopted after Fell et al., 2005; CSA, 1997; AGS, 2007; ISO 31000:2009, and VanDine, 2012).

<table>
<tr><th colspan="5">Assessment Type</th><th></th><th></th><th></th></tr>
<tr><td rowspan="2">Geohazard Assessment</td><td rowspan="3">Geohazard Risk Identification</td><td rowspan="4">Geohazard Risk Estimation</td><td rowspan="5">Geohazard Risk Assessment</td><td rowspan="7">Geohazard Risk Management</td><td rowspan="7">Risk Communication and Consultation
Informing stakeholders about the risk management process</td><td>1. Scope Definition
a. Recognize the potential hazard
b. Define the study area and level of effort
c. Define roles of the client, regulator, stakeholders, and Qualified Registered Professional (QRP)
d. Identify ‘key’ consequences to be considered for risk estimation</td><td rowspan="7">Monitoring and Review
Ongoing review of risk scenarios and risk management process</td></tr>
<tr><td>2. Geohazard Analysis
a. Identify the geohazard process, characterize the geohazard in terms of factors such as mechanism, causal factors, and trigger factors; estimate frequency and magnitude; develop geohazard scenarios; and estimate extent and intensity of geohazard scenarios.</td></tr>
<tr><td rowspan="5"></td><td>3. Elements at Risk Analysis
a. Identify elements at risk
b. Characterize elements at risk with parameters that can be used to estimate vulnerability to geohazard impact.</td></tr>
<tr><td rowspan="4"></td><td>4. Risk Analysis
a. Develop geohazard risk scenarios
b. Determine geohazard risk parameters
c. Estimate geohazard risk</td></tr>
<tr><td rowspan="3"></td><td>5. Risk Evaluation
a. Compare the estimated risk against tolerance criteria
b. Prioritize risks for risk control and monitoring</td></tr>
<tr><td rowspan="2"></td><td>6. Risk Control Design
a. Identify options to reduce risks to levels considered tolerable by the client or governing jurisdiction
b. Select option(s) with the greatest risk reduction at least cost
c. Estimate residual risk for preferred option(s)</td></tr>
<tr><td>7. Risk Control Implementation
a. Implement chosen risk control options
b. Define and document ongoing monitoring and maintenance</td></tr>
</table>

7.2.2. Rationale – Clear-water Floodplain Mapping

Historical floodplain mapping completed under the Canada / British Columbia Agreement Respecting Floodplain Mapping program (1974-2003) was largely standards-based and focused on inundation mapping for the 0.5% AEP or 200-year return period event and included a freeboard allowance. Mapping completed in the program often lacked a design report to document the methods and assumptions used to create the maps.

Few of the prioritized clear-water flood areas have existing, historical flood mapping. The historical floodplain mapping within the TRW is more than 20 years old and does not:

- Reflect the full data record available for hydrometric stations within the watershed since the mapping was conducted
- Reflect potential changes in channel planform and bathymetry (e.g., aggradation, channel alterations such as bank erosion or avulsion), or development within the floodplain that could alter the extent of inundation

- Reflect changes to flow regulation schedules for dams located upstream of mapped flood areas, which results in changes to the design flood
- Accuracy is limited to the resolution of the input data. Mapping predates high resolution Lidar surveys and hydraulic analysis was generally limited to 1-dimensional (1D) analysis
- Consider climate change impacts on flooding either directly or indirectly
- Consider land use changes (e.g., wildfire, resource roads)
- Consider the effect of dikes on flood inundation extents, nor the possibility of dike failures.

Additional flood hazard mapping is recommended to modernize historical flood maps and develop new flood maps addressing the limitations of the historical floodplain mapping. Flood hazard maps will help identify potential impacts to people and critical infrastructure in the floodplain and should be used to plan future development or inform mitigation planning.

Further details on proposed assessment methodology, including further hydraulic modelling, are provided in Appendix J.

7.2.3. Rationale – Steep Creek Geohazards Assessments

Most of the stream channels prioritized in this current study are small creeks that are not only subject to clear-water floods, but also steep creek processes that carry larger volumetric concentrations of debris (i.e., debris floods and debris flows). These processes are typically more destructive than clear-water floods and require different assessment and mapping methods. The focus of more detailed steep creek hazard mapping would be on alluvial fans and fan deltas, which have been identified in this study as the main developed areas subject to steep creek hazards.

This regional study provides boundaries of steep creek geohazard areas, but detailed mapping of geohazard scenarios and characteristics inside these areas was outside the scope of work. Steep creek geohazard maps would be created with similar objectives to clear-water flood hazard maps: to describe the threat of a steep creek flood hazard scenario at a given location based on its anticipated extent and intensity (destructive potential). Intensity is a function of flow depth, velocity, scour and debris deposition, all of which vary depending on hazard magnitude and its probability of occurrence. As communities or infrastructure in mountainous regions are often built on alluvial fans adjacent to steep creeks, steep creek flood hazard maps are sometimes referred to as alluvial fan hazard maps, or debris flow/debris flood hazard maps.

The purpose of the steep creek flood hazard maps would be to support:

- Land use regulatory planning, including bylaw compliance and revisions
- Emergency planning and operations
- Flood risk management, including prevention and mitigation.

Further details on a proposed assessment methodology are provided in Appendix J.

7.2.4. Rationale – Landslide-Dam Flood Assessments

The current study characterizes landslide-dam flood geohazards and prioritizes landslide-dam flood prone areas in proximity to developed areas within the TRW. However, the current regional study does not:

1. Assess individual landslide sites within watercourse segments that could result in specific landslide-dam flood scenarios.
2. Assess upstream flood impoundment or downstream outbreak floods for specific landslide-dam scenarios, or the associated risk of these scenarios.
3. Consider potential landslide dam-related floods in watercourses with a Strahler order of < 6.

These limitations increase uncertainty in the following areas:

- Characterization of landslide-dam flood hazard source locations and scenarios.
- Estimates of the likelihood that landslide-dam flood scenarios will occur and reach developed areas and result in some level of damage and loss (i.e., estimates of risk).

Appendix K describes recommended work to address these uncertainties at high priority areas. In summary, two areas of work are recommended that could be undertaken as separate projects or in parallel. The two phases are as follows:

- Remote-sensed hazard identification and monitoring of landslide geohazard source areas.
- Landslide-dam flood geohazard assessments for high priority areas.

The objective of remote sensing would be to improve the identification and monitoring of large landslides that could block high priority water courses. BGC proposes to leverage a 2017-2019 initiative funded by the Canadian Space Agency, titled the Wide Area Landslide Alerting System (WALAS). The objective is to develop an operational, satellite Interferometric Synthetic Aperture Radar (InSAR) - based landslide identification and monitoring system for wide areas. InSAR is a radar technique used in geodesy to generate maps of surface deformation, and the WALAS initiative study area encompasses British Columbia.

The objective of more detailed landslide-dam flood geohazard assessments would be to:

- Refine estimates of the likelihood that landslide-dam flood scenarios will occur and reach developed areas
- Refine estimates of the extent of areas that could be impacted
- Integrate the results with the current study, to update priority ratings at a given site.

7.2.5. Out-of-Scope Assessment Areas

This section discusses one area FBC or stakeholders may wish to consider for future assessments that were identified but not further assessed in this study.

<u>Steep Creek Geohazards: Upper Basins</u>

As noted in Section 1.4, this study assesses clear-water flood and steep creek processes within ‘settled’ urban and rural areas of the TRW. For steep creeks, the assessment focused on fans at the outlet of steep creeks because these are the areas that are typically developed. However, parcels containg improvements exist in the TRW in areas potentially susceptible to steep creek processes, but that are not located on mapped fans. Typically, these parcels are located upstream of the fan apex.

BGC identified improved parcels that intersect debris flow or debris flood susceptibility modelling results and are not located on mapped fans. These are shown on Cambio Communities as "Improved Unassessed Steep Creek Parcels" under the "Unassessed Areas" dropdown in the layer list. However, they were not further characterized or prioritized.

Debris flow and debris flood susceptibility modelling provide a helpful tool to identify areas potentially subject to impact given occurrence of an event. However, this modeling does not provide information on hazard likelihood. As such, no statement is made for these parcels about hazard or risk levels. However, BGC suggests local authorities consider these properties when identifying requirements for future geohazards assessments. Note that any improved parcels that only slightly intersect fans, as well as debris flow or debris flood susceptibility modelling, were not identified in this layer.

7.3. Geohazards Monitoring

Recommendation:

- *Integrate real-time stream flow and precipitation monitoring with the results of this assessment, to support emergency monitoring.*
- *Develop criteria for hydroclimatic alert systems informing emergency response.*
- *Develop capacity for the automated delivery of alerts and supporting information informing emergency response.*

Real-time precipitation and stream flow monitoring are key inputs informing flood-related emergency monitoring and response. ECCC maintains the Canadian Precipitation Analysis (CaPA) system, which provides objective estimates of precipitation in 10 km by 10 km (at 60° N) grids across North America. Figure 7-1 shows an example of 24-hour accumulated precipitation in southern British Columbia, reported via BGC's River Network Tools[20]. ECCC also provides the Regional Deterministic Prediction System (RDPS), which is a 48 hour forecast data (at an hourly timestep) that is produced four times a day at similar resolution to the CaPA data. The forecast dataset includes many climate variables, including forecasted precipitation.

The WSC maintains approximately 1900 real-time stream flow gauges across Canada, of which 32 are located in the TRW. Figure 7-2 shows example screen shots of a real-time flow gauge location and metadata from BGCs RNT, and the WSC real-time hydrograph connected by a weblink.

[20] Results anticipated to soon be made available at finer resolution (1-3 km grid).

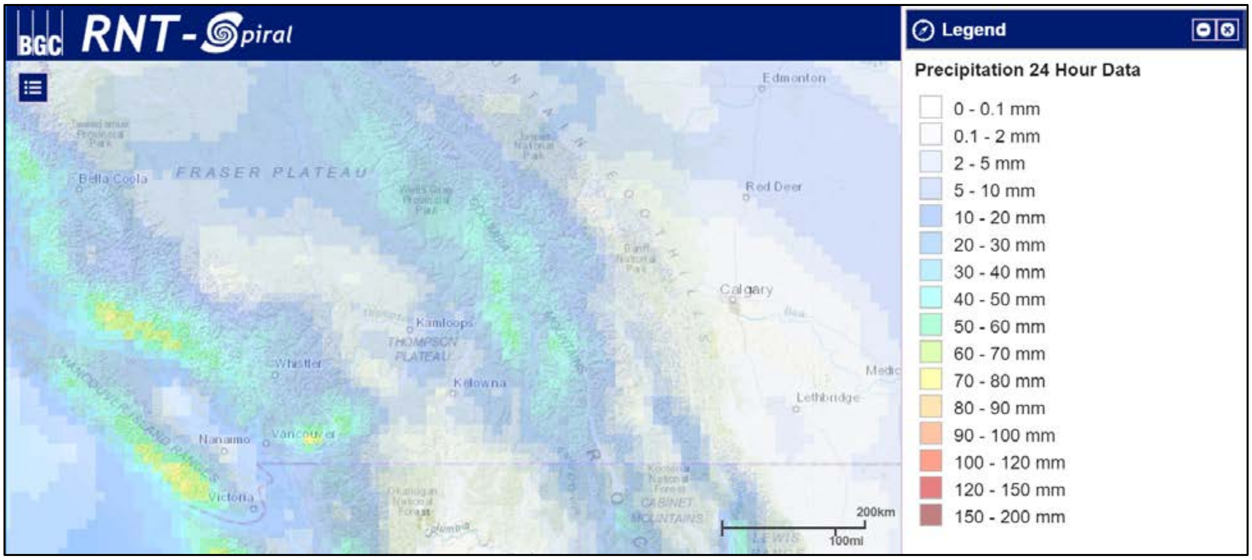


Figure 7-1. Example of 24-hour accumulated precipitation in southern British Columbia on November 3, 2018. Source: CaPA (2018, via BGC RNT).

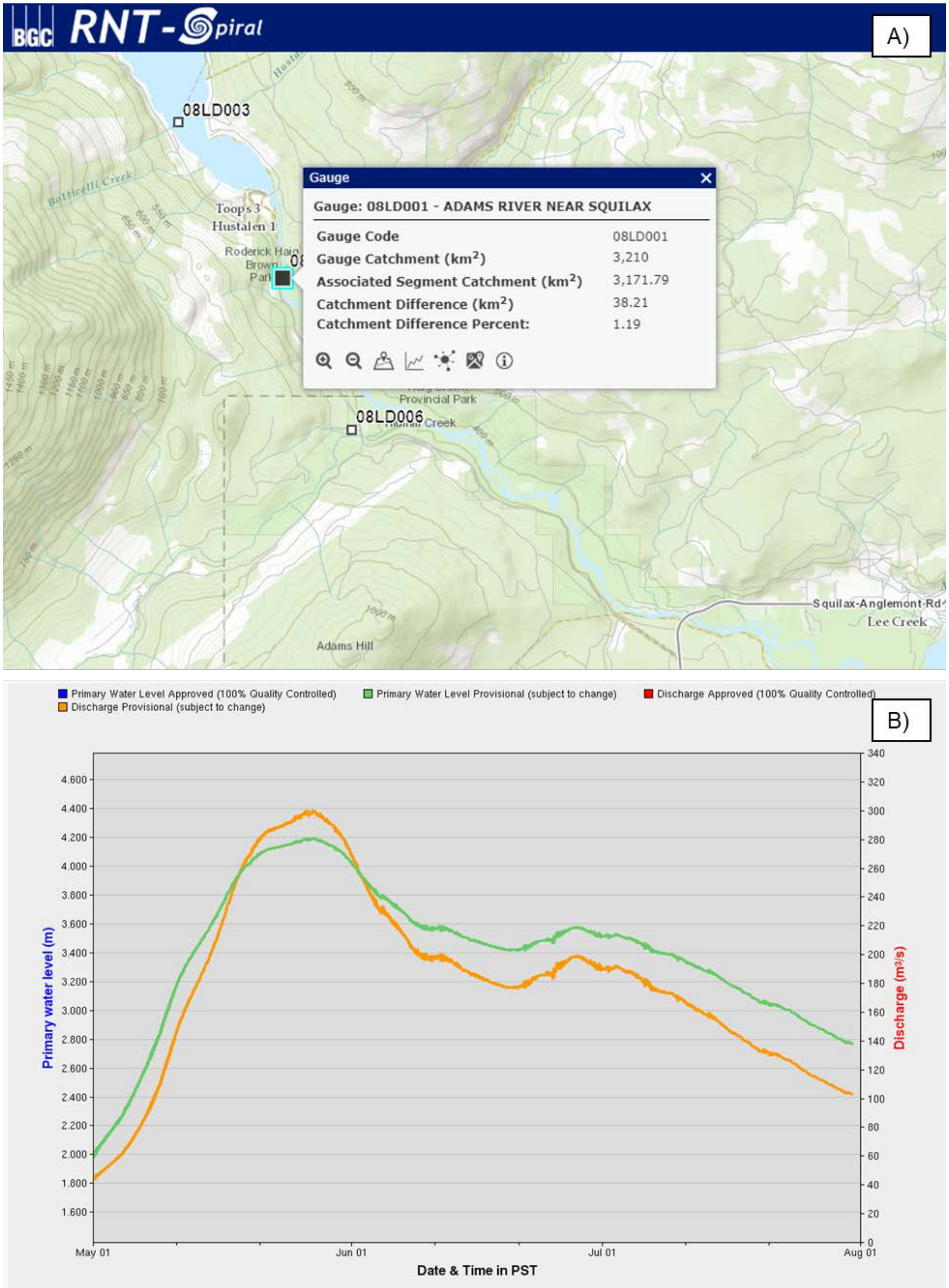


Figure 7-2. Example of a real-time streamflow gauge on Adams River (08LD001). (A) Displayed on BGC's RNT, with a direct weblink to (B) real-time hydrograph (WSC).

For real-time monitoring, a monitoring system could be compared to predetermined stage or discharge thresholds and an alert sent to relevant emergency response staff if the threshold is exceeded. The monitoring system could monitor multiple thresholds for a given site and hence provide staged warning levels.

For forecasted data, a precipitation forecast monitoring system could calculate a weighted precipitation average over the catchment of a high priority stream. The weighted precipitation forecast could then be compared to a predetermined threshold and an alert sent to relevant emergency response staff if the threshold is exceeded.

Implementing such monitoring support could be split into phases such as:

- Addition of real-time stream flow gauges and CaPa precipitation data on a web application along with the results presented in this study
- Addition of data from on-site weather stations if existing
- Determination of appropriate alert thresholds based on more detailed assessment
- Development of alert functions (software development).

Completion of the first step, addition of flow and regional precipitation monitoring data, could help support emergency response decision making in advance of alert systems. Because the input data are available North-America wide, initiatives triggered by any jurisdiction in BC could be extended province-wide with strong economies of scale, which may increase the likelihood of provincial funding. Feasibility to add data from on-site weather stations would need to be reviewed on a site-specific basis.

Determining alert thresholds would require more detailed geohazard assessment to determine input requirements, estimate thresholds and evaluate limitations and uncertainties. This work could also include estimation of alert thresholds for post-wildfire geohazard monitoring.

Additional functions, such as relating streamflow thresholds to potential geohazard scenario mapping informing emergency response, could also be completed at later stages of work. BGC notes that alert systems would require maintenance support and would be most cost effectively implemented provincially.

As an example, BGC is currently working with MoTI on the development of a pilot study concept comprised of a hydroclimatic warning system to assist MoTI with the management of highway operations. The work is motivated by damaging debris flows that occurred in 2018 after the 2017 Elephant Hill Fire near the communities of Ashcroft, Cache Creek, and Clinton. The first phase of the study is expected to involve the development of a rainfall threshold model for post-fire debris flows and debris floods. It is anticipated that the second phase may include methodology to incorporating the rainfall threshold model, forecasted rainfall conditions, and potentially information from on-site weather stations to identify warning levels that correspond to increasing post-wildfire debris-flow and debris-flood. Upon successful development and testing, the resulting methods and tools could be considered for a broader application than the site for which it is directly being developed.

7.4. Policy, Plans and Bylaw Integration

Recommendations:

- *Review Development Permit Areas (DPAs)*
- *Review plans, policies and bylaws related to geohazards management*
- *Develop risk evaluation criteria that support more consistent risk reduction decisions (i.e., that define the term "safe for the use intended" in geohazards assessments for development approval applications)*

7.4.1. Policy Review

Jurisdictions within the TRW administer policies and bylaws that rely on flood and steep creek hazard information and reference flood-related terminology. While standards-based approaches to geohazards management are the norm across across Canada, risk-informed approaches that target a level of risk reduction, rather than a standard flood return period, are being increasingly considered (Ebbwater, 2016).

Through the application of risk-informed policy in jurisdictions such as the Town of Canmore and the District of North Vancouver, the benefits and challenges of such approaches are becoming apparent (Strouth et al., 2019). BGC suggests that FBC and stakeholders review flood and steep-creek related policy, as well as geohazard and risk terminology, from the perspective of:

- Developing a risk-informed approach to geohazards management
- Defining risk evaluation criteria that provide the foundation for consistent risk reduction decision making (i.e., to define the term "safe for the use intended" in geohazards assessments for development approval applications)
- Reviewing the functional groups within government and information management systems that would be required to support the development and implementation of risk-informed community plans and bylaws by local authorities.

7.4.2. Development Permit Areas (DPAs)

Development Permit Areas (DPAs) are areas where special requirements and guidelines for any development or alteration of the land are in effect. In such areas, permits are typically required to ensure that development or land alteration is consistent with objectives outlined within applicable Official Community Plans.

BGC recommends that government jurisdictions within the TRW review the prioritized geohazard areas from the perspective of defining flood and steep creek DPAs. Application of study results to define DPAs should consider geohazard mapping uncertainties and the limitations listed in Section 1.4.2.

7.5. Information Management

Recommendations:

- *Review approaches to integrate and share asset data and baseline data (i.e., topography), across government agencies, stakeholders, data providers and risk management specialists. Such an effort would assist long-term geohazard risk management, asset management, and emergency response planning.*
- *Develop a maintenance plan to keep study results up to date as part of ongoing support for bylaw enforcement, asset management, and emergency response planning.*

7.5.1. Rationale

One of the most significant barriers, and potential opportunities, to improve and reduce the cost of geohazard risk and asset management at regional scale is to increase the coordination and assembly of the data required for such work, across multiple levels and sectors of government and private industry.

Because data are commonly segregated between agency functional groups, and data models are not typically visible to the end-user, it is not necessarily obvious how important these data are to risk management. Without integrated asset data, it is costlier to assess vulnerability and loss because there are gaps in the necessary supporting data, or more effort is required to span information silos across assets and agencies.

With effective data integration, flood and steep creek risk assessments are more likely to leverage – and contribute to – other types of risk assessments (i.e., for landslides, wildfires, snow avalanches, and earthquakes). This can help avoid information silos, improve consistency, and improve cost-efficiency. Moreover, it is easier to establish common datasets accessible to both emergency managers and those tasked with asset management.

Geohazard and asset information management would be greatly facilitated by support at the provincial and federal level, which would take advantage of efficiencies of scale. For example, the Integrated Cadastral Information Society (ICIS), with financial or in-kind support by different levels of government and private industry, currently compiles and disseminates asset and cadastral data to multiple stakeholders at provincial scale.

BGC notes that this recommendation focuses on translating basic data into information – the “ingredients” for geohazard risk identification, assessment, and management. Transforming his information into knowledge about geohazard risk and how such risks can be managed is still required. The assessment framework and Cambio Communities web application provided by this study focus on the “knowledge” piece. The feasibility to maintain and build this knowledge base long-term will hinge on access to well-organized and maintained information sources.

7.5.2. Requirements for Updates

The results of this study help the FBC and stakeholders identify the need and level of effort required for further assessments based on existing hazards and elements at risk. However, the assessment is a snapshot in time. It will require regular updates and maintenance to remain useful for decision making over the long term.

Procedures to identify requirements for updates and maintenance would need to consider factors such as:

- Data gaps such as those identified in this study
- Landscape changes affecting hazard levels (e.g., forest fires, new hazard events, or the construction of mitigation measures)
- Changes to elements at risk (e.g., new development).
- Future geohazards studies that should be incorporated into the integrated knowledge base.

Substantial efficiencies of scale exist within any data management system. Provincially funded support to maintain a current knowledge base (i.e., for asset inventories spanning multiple jurisdictions) would benefit all BC communities using the application. Inter-District coordination for initiatives serving common needs could help encourage provincial support.

7.6. Training and Stakeholder Communication

Recommendation:

- *Provide training to stakeholders who may rely on study results, tools and data services.*
- *Work with communities in the prioritized hazard areas to develop flood resiliency plans informed by stakeholder engagement.*

7.6.1. Training

The information collected for this assessment will have a broad range of application at the local jurisdiction level. BGC suggests FBC and stakeholders identify potential end-users and develop a workshop for communication and training. For example, potential end-users could include local community engineers, planners, developers, geomatics/GIS support staff, and emergency response workers. Such a workshop could include the following:

- Introduction to geohazard and risk assessments and risk management alternatives
- Introduction to the information displayed on Cambio Communities.
- Overview of steps required to identify, assess, and manage clear-water flood and steep creek risks as part of land use planning and development permitting
- Overview of requirements for applications for funding
- Information sharing between local jurisdictions and provincial staff.

Workshops would also provide a forum to gather additional local information on hazard events and consequences to local communities that might otherwise be undetected.

7.6.2. Stakeholder Communication

Flood resiliency planning represents an important next step following regional risk prioritization and hazard mapping, to capture local knowledge about indirect and intangible risks, better understand community vulnerabilities, and identify non-structural approaches to improve flood resilience.

The Cambio Communities web application is intended to provide easy access to hazard and exposure information that can help inform flood resiliency plans. It also represents a potential place to manage and disseminate new information gathered during stakeholder discussions. BGC notes that local knowledge can identify hazards and impacts not discernible at a regional scale of study, and new knowledge gathered in stakeholder workshops should be integrated with the current assessment to keep it up to date.

7.7. Abbott-Chapman Report Recommendations

Table 7-4 lists recommendations of the Abbott and Chapman (2017) report that pertain to this study, and how this study and its recommendations supports those in their report.

Table 7-4. Summary of Abbott & Chapman (2008) recommendations as they pertain to this study.

Abbott-Chapman Report (Quoted from the Report)			Comments About This Assessment	
#	Description	Rationale	Study Results	Study Recommendations
Recommendations Related to Land Stewardship				
36	BC [should] review and clarify roles and responsibilities for flood management, specifically the transfer of responsibility from provincial to local governments, including through the amendment of the Emergency Program Act, the BC Flood Response Plan, and other applicable statutes and regulations.	The experience of the Columbia Shuswap Regional District in 2017 suggests there is not a common understanding around roles and responsibilities when flood or debris flows occur. If costs for response and recovery ultimately rest with the Province, it may wish to reconsider the delegation of responsibility around local flood elevations and setback requirements.	This study provides a consistently applied, screening level assessment of geohazard areas in multiple jurisdictions, which can help inform the division of priorities and responsibilities between local governments, stakeholders, and provincial authorities.	Section 7.4 provides recommendations for policy, plans, and bylaw integration. This work should involve clarification of roles and responsibilities for geohazard risk management. In particular, BGC recommends that BC define risk evaluation criteria that support more consistent risk reduction decisions (i.e., that define the term "safe for the use intended" in geohazards assessments for development approval applications).
38	Evaluate all 200-year return-period flood elevations in BC, as well as all associated flood construction levels [FCLs] and horizontal setbacks.	Extreme weather patterns associated with climate change demand that British Columbians have the best possible understanding and modelling of what may occur in the years ahead.	This study defines flood extents at screening level of detail but does not include detailed estimation of 200-year flood elevations. The results support identification of higher priority areas for such work.	Section 7.2 and Appendix K recommend further assessments that will (among other outcomes) improve estimation of 200-year flood return period elevations and inform FCLs and setbacks.
39	Ensure streamflow forecast data provide sufficient accuracy and precision to manage flooding in BC. Assess and evaluate the adequacy of data networks, including snow, weather, streamflow, groundwater level and lake level, used to provide information to run provincial streamflow forecasting models.	Recent patterns of extreme weather events, including high-intensity rains, demand accuracy and precision in predicting and managing potential floods in BC.	This study made use of analytical software, developed by BGC, to estimate flow frequency and magnitude, as well as estimate lake elevations. These tools make use of snow, weather, streamflow and lake level monitoring stations. The deliverables of this study provide a framework for the addition of geohazards monitoring, forecasts and warning systems for clear-water floods, steep creek geohazards, and landslide-dam floods.	Section 7.3 recommends a three-phase approach to implement real-time stream flow and precipitation monitoring with the results of this study, develop threshold criteria for flood warning, and implement flood warning systems as part of a long-term geohazard risk management program.
40	Evaluate and upgrade the models used by the BC River Forecast Centre for forecasting streamflow and flooding: • Develop backup models for use when any of the required model input data is missing • Increase the frequency at which models are run • Investigate the utility of including weather forecasts in models • Regularly review and update models	Extreme weather events associated with climate change call for having the best information available.		
41	Build and provide sustained funding for a coordinated environmental data hub that organizes and disseminates information from the many data networks currently operating in BC. Provide equal access to information for Indigenous and non-Indigenous communities.	The long-term management of data networks must be improved so they can operate effectively on a sustainable basis, which would include ensuring they receive increased and predictable funding. It should also include regularly evaluating network density, identifying and filling gaps and converting manual stations into real-time automated stations.	The results of this study are delivered with an online map accessible via a standard web browser. EMBC is currently developing a "Common Operating Picture" (COP) web application, which will be a coordinated data hub supporting emergency management. The results of this study (prioritized geohazard areas) can also be provided for dissemination via COP.	Section 7.5 recommends information management to support coordinated data hubs with up-to-date geohazards information. BGC recommends that geospatial data produced by this assessment be consumed via a regularly updated web service rather than static downloads. This would provide more efficient data access and maintenance. The current study is designed to enable this approach.

<table>
<tr><th colspan="3">Abbott-Chapman Report (Quoted from the Report)</th><th colspan="2">Comments About This Assessment</th></tr>
<tr><th>#</th><th>Description</th><th>Rationale</th><th>Study Results</th><th>Study Recommendations</th></tr>
<tr><td>42</td><td>Develop values and risk modelling tools to support decision making and advance planning:
• Invest in generating quality data to support modelling, through the use of LiDAR, inclusion of Indigenous knowledge and recognition of cumulative effects
• Invest in ongoing training for users
• Ensure common data collection and provide access to the system for all users
• Effective monitoring of snowpack.</td><td>We believe that strengthening available planning tools is essential to meeting this objective.</td><td>The web application delivering the results of this study is an example of a regional scale risk modelling tool at screening level of detail. The current application version anticipates development of risk modelling and asset management tools to be implemented in future versions of the application.</td><td>Data hubs (recommendation #41) help organize information and are an important step. However, subject matter expertise is still required to interpret the available information and support decision making.
Risk modelling tools combine information from multiple sources (including data portals) to help users identify, estimate, evaluate, manage and monitor risk. The results can be delivered via interactive web application and their results can also consumed by, for example, the EMBC COP. Section 7.3 provides recommendations related to geohazards monitoring for inclusion in risk modelling tools, for example as input to Trigger Action Response Plans (TARP).
BGC also notes that the goals of asset management and disaster risk management are closely aligned in terms of the performance of assets in an emergency. Section 7.5 provides recommendations to organize data in support of both requirements.
BGC previously recommended areas for LiDAR acquisition that were submitted by FBC as a 2019 NDMP Stream 4 Funding Application. These data can be used, in conjunction with other data, to support modelling tools and advance planning.</td></tr>
</table>

Abbott-Chapman Report (Quoted from the Report)			Comments About This Assessment	
#	**Description**	**Rationale**	**Study Results**	**Study Recommendations**
Recommendations Related to Communication, Awareness and Engagement				
47	Build a central hub or 'onestop shop' emergency communications website to provide the public with reliable, responsive, adaptive, real-time and customer-focused information. This hub should collect information from provincial departments and agencies, First Nations and local governments and relevant stakeholder agencies, including media. It should also provide emergency updates for evacuees and include citizen information on how to assist, volunteer or donate.	In our engagement, past evacuees told us about the urgent need for accurate, real-time information during emergencies. In the absence of such information, especially in the age of social media, misinformation tends to fill the vacuum and heighten anxiety.	The results of this study include geohazard areas prioritized according to a risk assessment framework applicable province-wide. The study also included the development of a screening level 'exposure model' characterizing elements at risk. Ratings were developed to compare overall hazard exposure in different geohazard areas with reference to BCEMS objectives.	The prioritized geohazard areas and hazard exposure results of this study can potentially be provided via web service for inclusion in an EMBC COP web application. Table 7-2 in Section 7.1 highlights data gaps related to the identification and assessment of elements at risk located on First Nations reserves.
49	BC, First Nations and local governments, either individually or jointly, host readiness and postfreshet (flood) and wildfire season open houses to share information, knowledge and experiences, as well as develop best practices.	Having conversations between and among community members and their governments before and after flood and wildfire seasons provides an opportunity to identify and mitigate potential issues beforehand and to reflect on improvements that could be made.	A geohazard risk prioritization initiative for the entire TRW was launched in February 2018 at a Community-to-Community Forum in Kamloops, British Columbia (BC). The workshop was coordinated by FBC with participation of local governments and First Nations. Following the workshop, FBC retained BGC to complete this study and struck an Advisory Committee with representation from First Nations and several levels and branches of government to help guide the project.	The TRW completely or partially encompasses 6 Regional Districts, 16 municipalities and 29 areas under First Nations governments. The Secwepemc, Nlaka'pamux, Syilx and St'at'imc nations assert title and rights over different parts of the TRW. BGC and District Governments have proposed further geohazard mapping and risk prioritization, coordinated by FBC, supported by the NDMP and Union of BC Municipality Community Emergency Preparedness Fund (UBCM CEPF). FBC has invited the Advisory Committee to continue providing input. The committee also acts as points of contact to communicate results and implement study outcomes across multiple jurisdictions and areas of government. A key tenet of the current and proposed work is to complete assessments at watershed scale, with FBC coordinating on behalf of BC, First Nations, and local goverments.

Abbott-Chapman Report (Quoted from the Report)			Comments About This Assessment	
#	**Description**	**Rationale**	**Study Results**	**Study Recommendations**
64	Undertake a portfolio approach to prevention where all possible partners are identified, collaborate to reduce risk, and assess performance and success at the portfolio level, including: • Forest licensees • Partnerships between BC Wildfire Service and First Nations communities • Private land owners • Federal, First Nations and local governments • Ministry of Environment and Climate Change, including BC Parks • Ministry of Forests, Lands, Natural Resource Operations and Rural Development • Funding partners (current examples include: Forest Enhancement Society of BC and Strategic Wildfire Prevention Initiative	An active partnership among all those who work on the land or regulate land uses contributes to better overall land stewardship.	The hazard exposure assessment completed in this study can be used to identify potential partners in geohazards management who are stakeholders through their ownership or responsibility for assets at risk. Gaps exist (Section 7.1) that will require a portfolio approach to resolve.	BGC recommends that long-term geohazard risk and asset management programs be provincially supported where parties can rely on – and contribute to – a common knowledge base. Software development is required for decision support, consuming data (Recommendation #41) for risk modelling (Recommendation #42) to be reported via a central communications website (Recommendation #47). BGC can provide examples of where such a process is currently applied to major industry, on request. A portfolio approach to prevention will rely on policies, plans, and bylaws keeping pace with rapidly improving understanding of geohazards at provincial scale. Disconnection between geohazards information managed for the private sector and that in the public sphere can also be reduced through a portfolio approach to geohazard risk management.
74	As part of overall emergency management, BC undertake hazard risk mapping exercises and educational campaigns in communities vulnerable to crisis situations along major transport routes, such as pipelines, railways and highways.	We repeatedly heard from communities that partners must be prepared for emergencies arising from major infrastructure and a range of emergencies beyond flood and wildfire.	This assessment provides screening level hazard risk mapping and a framework to improve mapping accuracy and precision over time. The results can be used as a starting basis for hazard scenario planning.	This study can serve as a basis for community engagement. Section 7.6 recommends work with communities in prioritized geohazard areas to undertake hazard risk mapping exercises and flood resiliency plans informed by stakeholder input. Section 7.2 recommends further work that can also support public engagement once completed.
80	To increase the resiliency of BC's ecosystems and communities against climate change, BC establish a predictable and stable revenue stream to provide enhanced investment in prevention and preparedness. BC consider a new carbon tax revenue stream as a source of funds.	Climate change has been a reality for many years and financial resources are required to address approaches that individuals, communities, regions and districts can take.	This assessment provides results required by the terms of assessment but has been designed to facilitate long-term geohazard risk management including the management of a larger spectrum of geohazard types than those included in this scope of work.	Section 7.5.2 describes requirements for updates in the context of a long-term geohazards management program. Such work will require a predicable and stable funding stream. BGC can provide examples on request of where stability of funding has enabled higher quality and more cost effective geohazards management than is possible with short-term studies.

8. CLOSURE

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

Yours sincerely,

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APPENDIX A
DATA SOURCES

Location				Project			Hazard Type			Reference
Name	River Basin	District	NTS ID	Project Title	Report? (Y/N)	Spatial information?	Flooding?	Landslide?	Steep Creek?	Citation
Camp Creek	South Thompson	CSRD	082L15	Camp Creek Slide	Y	N			Y	Department of Highways, 1968. Camp Creek Slide. Report M2-486. 3 pages.
Creighton Valley	South Thompson	RDNO	082L02	Creighton Valley Terrain Stability Mapping	Y	Y - See Terrain Mapping		Y	Y	Golder Associates Ltd., 1998, Creighton Valley Terrain Stability Mapping - FRBC Project #TO96198T, Project No. 972-3104. 18 pages.
Hunters Range	South Thompson	RDNO	082L	Landslide susceptibility from watershed and fan characteristics	Y	N			Y	Eichel, A. and Fuller, T., 2002. Landslide susceptibility from watershed and fan characteristics, Salmon Arm and Vernon Forest Districts. Terrain Stability and Forest Management in the Interior of British Columbia. Technical Report 003. Nelson, BC.
Hunters Range/Eagle River	South Thompson	RDNO/CSRD	082L	N/A	Y	N			Y	Jakob, M., and Jordan, P. 2001. Design flood estimates in mountain streams — the need for a geomorphic approach. Canadian Journal of Civil Engineering 28: 425-439.
Hummingbird Creek	South Thompson	CSRD	082L14	An unusually large debris flow at Hummingbird Creek, Mara Lake, British Columbia	Y	N			Y	Jakob, M., Anderson, D., Fuller, T., Hungr, O., and Ayotte, D. 2000. An unusually large debris flow at Hummingbird Creek, Mara Lake, British Columbia. Canadian Geotechnical Journal 37: 1109-1125.
Fall Creek	South Thompson	RDNO	082L10	Landslide Risk Analysis of Historic Forest Development in the Interior of British Columbia—Challenges Encountered at Fall Creek	Y	N		Y	Y	Smith, F.R., and Vanbuskirk, C.D., 2002. Landslide Risk Analysis of Historic Forest Development in the Interior of British Columbia—Challenges Encountered at Fall Creek. In Terrain Stability and Forest Management in the Interior of British Columbia: Workshop Proceedings: May 23-25, 2001 Nelson, British Columbia, Canada.
Hummingbird Creek	South Thompson	CSRD	082L14	Sediment Coring at Swansea Point Fan Delta, Mara Lake, British Columbia	Y	N			Y	Fuller, T., 2002. Sediment Coring at Swansea Point Fan Delta, Mara Lake, British Columbia—Application of a Coring Method to Determine Historical Debris Flow Events. In Terrain Stability and Forest Management in the Interior of British Columbia: Workshop Proceedings: May 23-25, 2001 Nelson, British Columbia, Canada.
South Thompson	South Thompson	TNRD		South Thompson Settlement Strategy - Map 09 Natural Hazards	Y	N	Y	Y	Y	Thompson Nicola Regional District, 2011. South Thompson Settlement Strategy - Map 09 Natural Hazards. Schedule "A" of Bylaw No. 1888.
McIntyre Creek	South Thompson	CSRD	082L14	2014 McIntyre Creek Debris Flow	Y	N			Y	Westrek Geotechnical Services Ltd., 2015. 2014 McIntyre Creek Debris Flow Emergency Response and Investigation Findings. File 014-024.
Robinson Creek	South Thompson	CSRD	082L14	2017 Robinson Creek Debris Flow	Y	N			Y	Westrek Geotechnical Services Ltd., 2017. Summary of Emergency Response Activities and Intitial Geotechnical Assessment of the 2017 Robinson Creek Debris Flow. File 017-053.
Paraglacial fans I	Thompson	TNRD	092L	Some aspects of the morphology of paraglacial alluvial fans in South-Central British Columbia	Y	N			Y	Ryder, J. 1971. Some aspects of the morphology of paraglacial alluvial fans in South-Central British Columbia. Canadian Journal of Earth Sciences 8: 1252-1264.
Paraglacial fans II	Thompson	TNRD	092L	The stratigraphy and morphology of paraglacial alluvial fans in British Columbia	Y	N			Y	Ryder, J. 1971. SThe stratigraphy and morphology of paraglacial alluvial fans in British Columbia. Canadian Journal of Earth Sciences 8: 279-298.
Eagle River Valley	South Thompson	CSRD	082L	Debris torrent hazards along Highway 1 Sicamous to Revelstoke	Y	N			Y	Thurber Consultants Ltd. 1987. Debris torrent hazards along Highway 1 Sicamous to Revelstoke. File 15-3-51.
Sicamous Creek	South Thompson	Sicamous	082L15	Detailed terrain mapping of the Sicamous Creek Community Watershed	Y	Y - See Terrain Mapping			Y	Terratech Consulting Ltd. 1998, Detailed terrain mapping (TSIL C) of the Sicamous Creek Community Watershed. File 425-8
Silver Creek	South Thompson	CSRD	082L11	The Silver Creek Fire Watershed Hazards Assessment	Y	N			Y	Winkler, R., Giles, T., Turner, K., Hope, G., Bird, S., Schwab, K., Hogan, D., and Anderson, D., 1998. The Silver Creek Fire Watershed Hazards Assessment.
Loon Lake	Bonaparte	TNRD	092P03	Post-wildfire geohazard risk assessment: Elephant Hill Fire	Y	Y			Y	BGC Engineering Inc., 2017. Post-wildfire geohazard risk assessment: Elephant Hill Fire, BC. Project 1114012
Loon Lake	Bonaparte	TNRD	092P03	Detailed Post-Wildfire Natural Hazard Risk Assessment	Y	N			Y	Westrek Geotechnical Services Ltd. 2018. Detailed Post-Wildfire Natural Hazard Risk Assessment. Properties along the Northwest Side of Loon Lake Within the Elephant Hills Fire (K20637) Perimeter Loon Lake, BC. File No. 017-240.
Silver Creek	South Thompson	CSRD	082L11	Silver Creek Detailed Terrain Mapping	Y	Y - See Terrain Mapping		Y	Y	EBA Engineering Consultants Ltd., 1999. Detailed terrain mapping with interpretations for terrain stability, surface erosion potential, landslide induced stream sedimentation, and sediment delivery potential. Salmon Arm Forest District.
Deadman River	Thompson	TNRD	092I15	Deadman River Channel Stability Analysis	Y	N				Miles, M., 1995. Deadman River Channel Stability Analysis. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 2310.
Cornwall Creek	Thompson	TNRD	092I14	Cornwall Creek Community Watershed	Y	N	Y			Integrated Woods Services Ltd. 1997, Cornwall Creek Community Watershed Level 1 Interior Watershed Assessment Procedure.
Criss Creek	Thompson	TNRD	092I14	Lower Criss Creek Sub-basin, Reconnaissance Channel Assessment Procedure	Y	N	Y			Integrated Woods Services Ltd., 2000. Lower Criss Creek Sub-basin, Reconnaissance Channel Assessment Procedure.

Location				Project			Hazard Type			Reference
Name	River Basin	District	NTS ID	Project Title	Report? (Y/N)	Spatial information?	Flooding?	Landslide?	Steep Creek?	Citation
Durand Creek	Thompson	TNRD	092I10	Durand Creek Watershed	Y	N	Y			Integrated Woods Services Ltd., 1998. Durand Creek Watershed. Level 1 Interior Watershed Assessment Procedure.
East Murrary/Twaal Creek	Thompson	TNRD	092I	East Murrary Sub-Basin and Twaal Creek Watershed	Y	N	Y			Integrated Woods Services Ltd. 2001. East Murrary Sub-Basin and Twaal Creek Watershed. Channel conditions and prescriptions assessment/watershed assessment update.
Jimmies Creek	Thompson	TNRD	092I	Jimmies Creek Community Watershed	Y	N	Y			Integrated Woods Services Ltd. 1997, Jimmies Creek Community Watershed Level 1 Interior Watershed Assessment Procedure.
Debris Flow Bibliography	All	All	All	Bibliography Canadian Subaerial Channelized Debris Flows	Y	N			Y	VanDine, D.F., 2000. Bibliography Canadian Subaerial Channelized Debris Flows.
Murrary Creek/Twaal Creek	Thompson	TNRD	092I	Murrary Creek Community Watershed and Twaal Creek Watershed	Y	N	Y			Integrated Woods Services Ltd., 1999. Overview Channel Conditions and Prescriptions Assesssment in the Murrary Creek Community Watershed and Twaal Creek Watershed
Tranquille River	Thompson	TNRD	092I	Watershed Risk Analysis for Tranquille River.	Y	N	Y			M.J. Milne & Associates Ltd., 2009. Watershed Risk Analysis for Tranquille River.
Nicoamen River	Thompson	TNRD	092I03	Nicoamen River Watershed, Hydrologic Review	Y	N	Y			Integrated Woods Services Ltd., 2000. Nicoamen River Watershed, Hydrologic Review.
Ross Creek	South Thompson	CSRD	082L14	Channel and Debris Flow Risk Assesment of Ross Creek	Y	N	Y		Y	M.J. Milne & Associates Ltd., and Grainger and Associates Consulting Ltd., 2002. Channel and debris flow risk assessment of Ross Creek.
Finn Creek	North Thompson	TNRD	082M	Interior Watershed Assessment for the Finn Creek Watershed.	Y	N	Y			Dobson Engineering Ltd., 1997. Interior Watershed Assessment for the Finn Creek Watershed.
Wylie Creek	North Thompson	TNRD	092P09	Reconnaissance watershed assessment of Wylie Creek Study Area	Y	N	Y			Summit Environmental Consultants Ltd., 2000. Reconnaissance waterhsed assessment of Wylie Creek Study Area. Project #770.3
Tranquille River/Peterson River	Thompson/North Thompson	TNRD	092I15/092P(	Tranquille-Watching and Peterson-Rosen Community Watersheds.	y	Y - See Terrain Mapping			Y	Denny Maynard & Associates Ltd., 2002. Upgrade of terrain classification, terrain stability, surface erosion potential, and sediment delivery potential of Tranquille-Watching and Peterson-Rosen Community Watersheds.
Eakin Creek/Lemieux Creek	North Thompson	TNRD	092P	Eakin Creek and Lemieux Creek Detailed Terrain Stability Mapping	Y	Y - See Terrain Mapping			Y	AMEC Earth and Environmental Ltd., 2001. Eakin Creek and Lemieux Creek Detailed Terrain Stability Mapping Kamloops Forest District. Job No. KX12459
Sicamous Creek	South Thompson	Sicamous	082L15	Interior Watershed Assessment for the Sicamous Creek Watershed	Y	N			Y	Dobson Engineering Ltd., 1998. Interior Watershed Assesment for the Sicamous Creek Watershed.
Cooke Creek	South Thompson	RDNO	082L10	Maintenance of the Cooke Creek Forest Service Road near Enerby	Y	N			Y	Forest Practices Board, 2016. Maintenance of the Cooke Creek Forest Service Road near Enerby. Complaint Investigation #15083.
Cedar Hills	South Thompson	CSRD	082L11	Post-wildfire landslides in Southern British Columbia	Y	N			Y	Jordan, P., 2012. Post-wildfire landslides in Southern British Columbia. In 11th Internation & 2nd North American Symposium on Landslides, Banff, Alberta, Canada, June 3-8, 2012.
Chase Creek	South Thompson	CSRD	082L12	Investigations of 22 landslides in Upper Chase Creek, B.C.	Y	N		Y	Y	Grainger, B., 2002. Investigations of 22 landslides in Upper Chase Creek, B.C.
Mile 5.5	Thompson	TNRD	092I03	5.5 Mile Debris Fence	Y	N			Y	Bichler, A., Yonin, D., Stelzer, G., N.D. Flexible debris flow mitigation: introducting the 5.5 Mile Debris Fence.
Hummingbird Creek	South Thompson	CSRD	082L14	Community of Swansea Point, Sicamous, British Columbia.	Y	N			Y	Singh, N., 2004. Quantitative Analysis of Partial Risk from Debris Flows and Debris Floods: Community of Swansea Point, Sicamous, British Columbia. In Landslide Management Handbook 56. Landslide Risk Case Studies in Forest Development Planning and Operations.
Bonaparte River	Bonaparte	TNRD	092I14	Floodplain Mapping Bonaparte River at Cache Creek	Y	Y - See Floodplain Mapping	Y			KPA Engineering, 1996. Floodplain Mapping Bonaparte River at Cache Creek. Design Brief. File 5739 008 00 02
Bonaparte River	Bonaparte	TNRD	092I	Lower Bonaparte River Watershed	Y	N	Y			Integrated Woods Services Ltd., 1998. Lower Bonaparte River Watershed Level 1 Interior Watershed Assesement Procedure.
Chase Creek	South Thompson	CSRD	082L12	Chase Creek Hydrologic Assessment	Y	N	Y			Dobson Engineering Inc. 2004. Chase Creek Hydrologic Assessment Impact of Mountain Pine Beetle Infestations on Peak Flows
Charcoal Creek	South Thompson	CSRD	082L12	Charcoal Creek Detailed Terrain Stability Mapping	Y	Y - See Terrain Mapping	Y		Y	EBA Engineering Consultants Ltd., 2000. Charcoal Creek Detailed Terrain Stability Mapping (TSIL C). EBA Project No. 0801-99-81086
Chase Creek	South Thompson	CSRD	082L12	Hydrology of the Chase Creek watershed	Y	N	Y			Dobson Engineering Inc. 2005. Hydrology of the Chase Creek watershed. FIA Activity 2029021

Location				Project			Hazard Type			Reference
Name	River Basin	District	NTS ID	Project Title	Report? (Y/N)	Spatial information?	Flooding?	Landslide?	Steep Creek?	Citation
Bonaparte River	Bonaparte	TNRD	092I	Bonaparte River Interior Watershed Assessment	Y	N	Y			Bioterra Consulting, 1997. Bonaparte River Interior Watershed Assessment
Cedar Hills	South Thompson	CSRD	082L11	Post-wildfire landslides in southern British Columbia	Y	N			Y	Jordan, P., 2012. Post-wildfire landslides in southern British Columbia. 11th International & 2nd North American Symposium on Landslides, Banff, Alberta, Canada, 3-8 June, 2012.
Cedar Hills	South Thompson	CSRD	082L11	Developing a risk analysis procedure for post-wildfire mass movement and flooding in British Columbia.	Y	N			Y	Jordan, P., Turner, K., Nicol, D., Boyer, D. 2006. Developing a risk analysis procedure for post-wildfire mass movement and flooding in British Columbia. 1st Specialty Conference on Disaster Mitigation. Calgary, Alberta, Canada. May 23-26, 2006.
Cedar Hills	South Thompson	CSRD	082L11	Debris flows and floods following the 2003 wildfires in Southern British Columbia.	Y	N			Y	Jordan, P., and Covert, S.A., 2009. Debris flows and floods following the 2003 wildfires in Southern British Columbia. Environmental & Engineering Geoscience 15 (4): 217-234.
Thompson	Thompson	TNRD	092I	Quaternary stratigraphy and geomorphology of the Lower Thompson Valley, British Columbia.	Y	N				Anderton, L. J., 1970. Quaternary stratigraphy and geomorphology of the Lower Thompson Valley, British Columbia. Unpublished MSc. Thesis, University of British Columbia.
Mabel Lake	South Thompson	RDNO	082L	Mabel Lake Tributaries Interior Watershed Assessment	Y	N	Y			Wildstone Group, N.D., Mabel Lake Tributaries Interior Watershed Assessment
Thompson River	Thompson	TNRD	092I	South Thompson River (Kamloops to Chase) Floodplain Mapping.	Y	Y - See Floodplain Mapping	Y			BC Water Surveys Unit and Canada-BC Floodplain Mapping Program. 1976. South Thompson River (Kamloops to Chase) Floodplain Mapping. BC Ministry of Environment.
Hunters Range	South Thompson	CSRD	082L	Hunters Range (Kingfisher)	Y	Y - See Terrain Mapping		Y	Y	Terratech Consulting Ltd., 2001. Detailed Terrain Stability Mapping (TSIL C) Hunters Range (Kingfisher). File 425-13
Upper Momich	South Thompson	TNRD	082M	Upper Momich Drainage	Y	Y - See Terrain Mapping		Y	Y	Terratech Consulting Ltd., 1999. Detailed Terrain Stability Mapping (TSIL C) of Upper Momich Drainage
Pisima Face	South Thompson	TNRD	082M	Pisima Face Area Within Forest License A18693	Y	Y - See Terrain Mapping		Y	Y	Terratech Consulting Ltd., 1999. Detailed Terrain Stability Mapping (TSIL C) of Pisima Face Area within Forest License A18693
Hummingbird Creek/Mara Creek	South Thompson	CSRD/RDNO	082L	Hummingbird Creek and Mara Creek Watersheds	Y	Y - See Terrain Mapping		Y	Y	Terratech Consulting Ltd., 1999. Detailed Terrain Stability Mapping (TSIL C) Hummingbird Creek and Mara Creek Watersheds
Brash Creek/Siddle Creek/Ashton Creek	South Thompson	RDNO	082L	Detailed Terrain Mapping Brash, Siddle, and Ashton Creeks	Y	Y - See Terrain Mapping		Y	Y	Terratech Consulting Ltd. 1998. Detailed Terrain Mapping with Interpretations for Slope Stability, Erosion Potential, and Sediment Transfer - Brash, Siddle, and Ashton Creeks. File 425-7
Hiuihill Creek	South Thompson	TNRD	082M	Watershed Assessment of Hiuihill Creek Watershed.	Y	N	Y			Summit Environmental Consultants Ltd., 2002. Watershed Assessment of Hiuihill Creek Watershed. File 037-13.00
Upper Momich	South Thompson	TNRD	082M	Reconnaissance watershed assessment of Upper Momich River Watershed	Y	N	Y			Summit Environmental Consultants Ltd. 1999. Reconnaissance waterhsed assessment of Upper Momich River Watershed. Project 802
Corning Creek	South Thompson	CSRD	082L13	Interior Watershed Assessment for the Corning Creek Watershed	Y	N	Y		Y	Silvatech Consulting Ltd. 2000. Interior Watershed Assessment for the Corning Creek Watershed.
Tumtum Lake	South Thompson	TNRD	082M14	Reconnaissance Channel Assessments of East Facing Tributaries of Tumtum Lake.	Y	N	Y			Silvatech Consulting Ltd. 2000. Interior Watershed Assessment for the Corning Creek Watershed.
Sinmax Creek	South Thompson	TNRD	082M04	Sinmax Creek Watershed	Y	N	Y			Silvatech Consulting Ltd. 1999. Interior Watershed Assessment Procedure for the Sinmax Creek Watershed.
Kingfisher Creek/Cooke Creek/Noisy Creek	South Thompson	RDNO	082L10	Kingfisher, Cooke, and Noisy Creek Watersheds.	Y	N	Y			Silvatech Consulting Ltd. 1998. Interior Watershed Assessment Procedure for the Kingfisher, Cooke, and Noisy Creek Watersheds.
Spapilem Creek	South Thompson	TNRD	082M04	Spapilem Operating Area.	Y	N	Y			Silvatech Consulting Ltd. 1998. Channel Assesment Procedure for the Spapilem Operating Area.
Momich River/Cayenne Creek	South Thompson	TNRD	082M06	Momich River/Cayenne Creek Watershed	Y	N	Y			Silvatech Consulting Ltd. 1996. Bell Pole Co. Ltd. Level 1 IWAP Overview Conditions Assessments for the Momich River/Cayenne Creek Watershed.
Fisher Creek	South Thompson	TNRD	082M06	Fisher Creek Operating Area.	Y	Y - See Terrain Mapping		Y	Y	Redding, T., and Giles, T., 1999. Detailed Terrain Stability Mapping of the Fisher Creek Operating Area.

Location				Project			Hazard Type			Reference
Name	River Basin	District	NTS ID	Project Title	Report? (Y/N)	Spatial information?	Flooding?	Landslide?	Steep Creek?	Citation
Monashee Creek/Yeoward Creek	South Thompson	RDNO	082L01	Monashee/Yeoward Creeks Terrain Stability Report.	Y	Y - See Terrain Mapping		Y	Y	Quaterra Environmental Consulting Ltd. 2001. Monashee/Yeoward Creeks Terrain Stability Report.
Hidden Lake/Sowsap Creek	South Thompson	RDNO	082L10	Hidden Lake/Sowsap Creek Area Terrain Stability Report.	Y	Y - See Terrain Mapping		Y	Y	Quaterra Environmental Consulting Ltd. 2000. Hidden Lake/Sowsap Creek Area Terrain Stability Report.
Trinity Creek	South Thompson	RDNO	082L	Trinity Operating Area Terrain Stability Report	Y	Y - See Terrain Mapping		Y	Y	Quaterra Environmental Consulting Ltd. 1999. Trinity Operating Area Terrain Stability Report
Salmon River	South Thompson	CSRD		Salmon River Tributaries Terrain Stablity Report.	Y	Y - See Terrain Mapping		Y	Y	Quaterra Environmental Consulting Ltd. 1999. Trinity Operating Area Terrain Stability Report
Flood Protection Works - Appurtenant Structures	All	All	N/A	Flood Protection Works - Appurtenant Structures	N	Y	Y			Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2017. Flood Protection Works - Appurtenant Structures. Digital Dataset. https://catalogue.data.gov.bc.ca/dataset/flood-protection-works-appurtenant-structures
Flood Protection Works - Structural Works	All	All	N/A	Flood Protection Works - Structural Works	N	Y	Y			Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2017. Flood Protection Works - Structural Works. Digital Dataset. https://catalogue.data.gov.bc.ca/dataset/flood-protection-works-appurtenant-structures
Mapped Floodplains in BC (Historical).	All	All	N/A	Mapped Floodplains in BC (Historical).	N	Y	Y			Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2017. Mapped Floodplains in BC (Historical). Digital Dataset. https://catalogue.data.gov.bc.ca/dataset/mapped-floodplains-in-bc-historical
Alluvial fans - Lau	All	All	N/A	Channel scour on temperate alluvial fans on British Columbia.	Y	Y			Y	Lau, C.A., 2017. Channel scour on temperate alluvial fans on British Columbia. Unpublished M.Sc. Thesis, Simon Fraser University.
Historical Floods and Landslides	All	All	N/A	Flooding and Landslide Events Southern British Columbia	Y	BGC to Digitize Locations			Y	Septer, D. 2007. Flooding and Landslide Events Southern British Columbia 1808-2006. Ministry of the Environment
Terrain Mapping	All	All	N/A	Terrain Mapping	N	Y		Y	Y	Ministry of Environment and Climate Change Strategy, 2016. Digital Dataset dated 16 Sep 2016. http://www.env.gov.bc.ca/esd/distdata/ecosystems/TEI/TEI_Data/
All	All	All	N/A	Historical DriveBC Events	N	Y				Ministry of Transportation and Infrastructure, 2018. Historical DriveBC Events. Digital Data Source. https://catalogue.data.gov.bc.ca/dataset/historical-drivebc-events
Mabel Lake	South Thompson	RDNO	082L	Mabel Lake Reconnaissance Terrain Stability Report	Y	Y - See Terrain Mapping		Y	Y	Quaterra Environmental Consulting Ltd., 1998. Mabel Lake Reconnaissance Terrain Stability Report.
Bessette Creek	South Thompson	RDNO	082L	Bessette Creek Basin Storage Study	Y	N	Y			Government of British Columbia. 1977. Bessette Creek Basin Storage Study
Johnson Lake	South Thompson	TNRD	082M04	Johnson Creek Hydrology	Y	N	Y			Department of Lands, Forests, and Water Resources, 1975. Johnson Creek Hydrology
Shuswap River	South Thompson	RDNO	082L11	Shuswap River Flood Plain Mapping	Y	Y - See Floodplain Mapping	Y			Province of British Columbia, N.D., Shuswap River Flood Plain Mapping
Shuswap River/Bessette Creek/Duteau Creek	South Thompson	RDNO	082L	Floodplain Mapping Program, Shuswap River, Bessette and Duteau Creeks Design Brief	Y	Y - See Floodplain Mapping	Y			Klohn-Cripper Consultants Ltd. 1998. Floodplain Mapping Program, Shuswap River, Bessette and Duteau Creeks Design Brief.
Fortune Creek	South Thompson	RDNO	082L	Fortune Creek Hydrology Study	Y	Y - See Floodplain Mapping	Y			Ministry of Environment. 1978. Fortune Creek Hydrology Study
Duteau Creek	South Thompson	RDNO	082L03	Duteau Creek Hydrology Division Report	Y	N	Y			British Columbia Water Resources Service. 1974. Duteau Creek Hydrology Division Report.
Salmon River	South Thompson	CSRD	082L11	Floodplain Mapping Program, Salmon River Shuswap Lake to Spa Creek Design Brief	Y	Y - See Floodplain Mapping	Y			Crippen Consultants. 1990. Floodplain Mapping Program, Salmon River Shuswap Lake to Spa Creek Design Brief
Scotch Creek	South Thompson	CSRD	082M03	Channel Assessment Procedure for Scotch Creek	Y	N	Y			Dobson Engineering Inc., 1997. Channel Assessment Procedure for Scotch Creek.
Harris Creek	South Thompson	RDNO	082L02	Interior Watershed Assessment for the Harris Creek Watershed	Y	N	Y			Dobson Engineering Inc., 1997. Interior Watershed Assessment for the Harris Creek Watershed
Duteau Creek	South Thompson	RDNO	082L03	Interior Watershed Assessment for the Duteau Creek Watershed	Y	N	Y			Dobson Engineering Ltd., 1999. Interior Watershed Assessment for the Duteau Creek Watershed.

Location				Project			Hazard Type			Reference
Name	River Basin	District	NTS ID	Project Title	Report? (Y/N)	Spatial information?	Flooding?	Landslide?	Steep Creek?	Citation
Scotch Creek	South Thompson	CSRD	082M03	Results of the Interior Watershed Assessment Procedure for the Scotch Creek Watershed	Y	N	Y			Dobson Engineering Ltd., 1999. Results of the Interior Watershed Assessment Procedure for the Scotch Creek Watershed
Cherry Creek	Thompson	TNRD	092I	Hydrologic Assessment of the Cherry Creek Watershed	Y	N	Y			Dobson Engineering Ltd., 2000. Hydrologic Assessment of the Cherry Creek Watershed
Wap Creek	South Thompson	RDNO	082L	Results of the Interior Watershed Assessment Procedure for the Wap Creek Watershed	Y	N	Y			Dobson Engineering Ltd. 2000. Results of the Interior Watershed Assessment Procedure for the Wap Creek Watershed.
Twig Creek	South Thompson	TNRD	082L05	Watershed Condition Report for Twig Creek	Y	N	Y			Dobson Engineering Ltd. 2001. Watershed Condition Report for Twig Creek.
Weyman Creek	South Thompson	TNRD	082L05	Watershed Condition Report for Weyman Creek	Y	N	Y			Dobson Engineering Ltd. 2001. Watershed Condition Report for Weyman Creek.
Nikwikwaia Creek	South Thompson	CSRD	082L04	Terrain Stability and Hydrology of the Nikwikwaia Creek Watershed	Y	Y - See Terrain Mapping	Y	Y	Y	Dobson Engineering Ltd. N.D. Terrain Stability and Hydrology of the Nikwikwaia Creek Watershed
Celista Creek/Sim Creek/Pickett/Syphon/Palmer Creek	South Thompson	CSRD	082M	Celista Creek-Humamilt Lake, Sim Creek, and Pickett-Syphon-Palmer Creek Watersheds	Y	Y - See Terrain Mapping		Y	Y	EBA Engineering Inc. 1997, Reconnaissance Terrain Stability Mapping (TSIL D) for the Celista Creek-Humamilt Lake, Sim Creek, and Pickett-Syphon-Palmer Creek Watersheds
Sugar Lake	South Thompson	CSRD	082L	Sugar Lake, Vernon Forest District, British Columbia.	Y	Y - See Terrain Mapping		Y	Y	EBA Engineering Inc., 1998. Detailed Terrain Stability Mapping, Sugar Lake, Vernon Forest District, British Columbia. File 0806-97-87495
Sugar Lake/Gates Creek	South Thompson	CSRD	082L	Sugar Lake and Gates Creek Areas, British Columbia.	Y	Y - See Terrain Mapping		Y	Y	EBA Engineering Inc., 1999. Detailed and Reconnaissance Terrain Mapping with Interpretation of Terrain Stability, Erosion Potential and Potential Fine Sediment Transfer, Sugar Lake and Gates Creek Areas, British Columbia. Project No. 0801-98-87752.
Creighton Creek/Ferry Creek	South Thompson	CSRD	082L	Upper Creighton Creek and Ferry Creek	Y	N	Y			EBA Engineering Inc., 1999. Interim Interior Watershed Assessment Procedure Upper Creighton Creek and Ferry Creek
Creighton Creek/Bonneau Creek/Ferry Creek	South Thompson	CSRD	082L	Upper Creighton Creek, Bonneau Creek, Ferry Creek	Y	N	Y			EBA Engineering Inc., 1999. Reconnaissance Channel Assessment Procedure (ReCAP) As Part of the Interior Watershed Assessment Procedure for Upper Creighton Creek, Bonneau Creek, Ferry Creek.
Scotch Creek/Kwikoit Creek/Corning Creek	South Thompson	CSRD	082M03	Scotch Creek, Kwikoit Creek, Corning Creek	Y	Y - See Terrain Mapping		Y	Y	EBA Engineering Inc., 1999. Detailed and Reconnaissance Terrain Mapping with Interpretation of Terrain Stability, Erosion Potential and Sediment Transfer Potential
Blueberry Creek/Skimikin Lake	South Thompson	CSRD	082M/082L	Blueberry Creek and Skimikin Lake Terrain Stability Mapping	Y	Y - See Terrain Mapping		Y	Y	EBA Engineering Inc., 2000. Salmon Arm Forest District Federated Co-operatives Limited Operating Area (Blueberry Creek and Skimikin Lake) Terrain Stability Mapping
Squilax Creek/ Broderick Creek/ Reinecker Creek	South Thompson	CSRD	082L	Squilax, Broderick Creek, Reinecker Creek, TFL 33.	Y	Y - See Terrain Mapping		Y	Y	EBA Engineering Inc., 2001. Salmon Arm Forest District Federated Co-operatives Limited Detailed Terrain Stability Mapping Squilax, Broderick Creek, Reinecker Creek, TFL 33. EBA Project No. 0801-00-81153
Reiter Creek/Holstein Creek	South Thompson	CSRD	082L	Reiter and Holstein Creeks Bobbie Burns Mountain	Y	Y - See Terrain Mapping		Y	Y	EBA Engineering Inc., 2002 Detailed Terrain Stability Mapping Reiter and Holstein Creeks Bobbie Burns Mountain
Wap Creek	South Thompson	RDNO	082L15	Detailed Terrain Stability Mapping Wap Creek	Y	Y - See Terrain Mapping		Y	Y	EBA Engineering Inc., 2002. Detailed Terrain Stability Mapping Wap Creek.
Shuswap Lake and Mara Lake	South Thompson	CSRD	082L	Shuswap Watershed Mapping Project	Y	N	Y			Ecoscape Environmental Consultants Ltd., 2009. Shuswap Watershed Mapping Project - Foreshore Inventory and Mapping
Anstey River/Eagle River	South Thompson	CSRD	082L/082M	Anstey and Eagle River Watersheds	Y	N	Y			Forsite Forest Management Consultants, 1998. Anstey and Eagle River Watersheds Level 1 Interior Watershed Assessment and Report
Celista Creek	South Thompson	CSRD	082M06	Celista Creek (Humamilt Lake)	Y	N	Y			Forsite Forest Management Consultants, 1998. Celista Creek (Humamilt Lake) Watershed Channel Assessment Procedure (CAP)
Salmon River	South Thompson	CSRD	082L	The stability of stream channels within the Salmon River Watershed	Y	N	Y			Forsite Forest Management Consultants, 1998. The stability of stream channels within the Salmon River Watershed

Location				Project			Hazard Type			Reference
Name	River Basin	District	NTS ID	Project Title	Report? (Y/N)	Spatial information?	Flooding?	Landslide?	Steep Creek?	Citation
Adams River	South Thompson	TNRD	082M	Upper Adams Watershed Risk Analysis	Y	N	Y		Y	Forsite Forest Management Specialists, 2005. Upper Adams Watershed Risk Analysis
Hiuhill Creek	South Thompson	TNRD	082M	Hui Hill Level 1 Interior Watershed Assessment British Columbia	Y	N	Y			Golder Associates Ltd. 1996. Hui Hill Level 1 Interior Watershed Assessment British Columbia
Onyx Creek	South Thompson	CSRD	082L14	Onyx Creek Watershed Salmon Arm, B.C.	Y	N	Y			Golder Associates Ltd. 1996. Level 1 - Interior Watershed Assessment Onyx Creek Watershed Salmon Arm, B.C.
Brash Creek	South Thompson	RDNO	082L	Brash Creek Watershed.	Y	N	Y			Dobson Engineering Inc., 1998. Interior Watershed Assessment for the Brash Creek Watershed.
Robert Creek	South Thompson	TNRD	082M12	Robert Creek Watershed Assessment	Y	N	Y			Integrated Woods Services Ltd. 2000. Robert Creek Watershed Assessment
Duteau Creek	South Thompson	RDNO	082L03	Duteau Creek Watershed Assessment	Y	N	Y			Kerr Wood Leidal and Dobson Engineering Ltd., 2008. Duteau Creek Watershed Assessment & Recommendations for Source Protection.
Seymour Arm	South Thompson	CSRD	082M	Soil and Terrain of the Seymour Arm Area	Y	N			Y	Kowall, R.C., 1980. Soil and Terrain of the Seymour Arm Area (N.T.S. Map 82M)
Salmon River	South Thompson	CSRD	082L	Floodplain Mapping Program Salmon River Spa Creek to Falkland	Y	Y - See Floodplain Mapping	Y			KPA Engineering Ltd., 1991. Floodplain Mapping Program Salmon River Spa Creek to Falkland.
Hiuhill Creek	South Thompson	TNRD	082M	Channel Stability Mapping Hiuihill Creek	Y	N	Y			M. Miles and Associates, 1995. Channel Stability Mapping Hiuihill Creek Between Km 0 and Km 25
Salmon River	South Thompson	CSRD	082L	Salmon River Channel Stability Analysis	Y	N	Y			M. Miles and Associates, 1995. Salmon River Channel Stability Analysis
Harris Creek	South Thompson	RDNO	082L02	Watershed Risk Assessment for Harris Creek	Y	N	Y			M.J. Milne & Associates, 2010. Watershed Risk Assessment for Harris Creek
Eagle-Perry Area	South Thompson	CSRD	082M	Detailed Terrain Stabiltiy Report Eagle-Perry Area	Y	N		Y	Y	R.T. Banting Engineering Ltd., 2001. Detailed Terrain Stabiltiy Report TSIL "C" Eagle-Perry Area.
Adams Lake	South Thompson	TNRD	082M	Adams Lake TSIL D Reconnaissance Slope Stability	Y	Y - See Terrain Mapping		Y	Y	Terratech Consulting Ltd. 1998. FL A18693 - Adams Lake Kamloops and Clearwater Forest Districts TSIL D Reconnaissance Slope Stability
Campbell Creek	South Thompson	TNRD	092I	Campbell Creek Watershed	Y	N	Y			Ministry of Environment, 1989. Campbell Creek Watershed
Hummingbird Creek	South Thompson	CSRD	082L	Forest Practices and the Hummingbird Creek Debris Flow	Y	N			Y	Forest Practices Board, 2001. Forest Practices and the Hummingbird Creek Debris Flow
Fishtrap Creek	North Thompson	TNRD	092P01	Short term morphodynamics of Fishtrap Creek following wildfire	Y	N	Y			Christie, A., 2010. A stream in transition : short term morphodynamics of Fishtrap Creek following wildfire. Unpublished M.Sc. Thesis, University of British Columbia.
Thompson River	Thompson	TNRD	092I	Thompson and North Thompson Rivers (Kamloops Area) Floodplain Mapping	Y	Y - See Floodplain Mapping	Y			BC Water Surveys Unit and Canada-BC Floodplain Mapping Program. 1976. Thompson and North Thompson Rivers (Kamloops Area) Floodplain Mapping and BC Water Surveys Data. BC Ministry of Environment.
Thompson River	Thompson	TNRD	092I	Thompson River Data	Y	N	Y			Barr, L. 1989. Thompson River Data (Thompson, North Thompson, South Thompson Rivers). BC Ministry of Environment.
Deception Creek/Spanish Creek	North Thompson	CRD	092P01	Deception/Spanish Creek Watershed.	Y	N	Y			AIM Environmental Consultants Ltd. 1997. Results of the Interior Watershed Assessment Procedure for the Deception/Spanish Creek Watershed. Prepared for Weldwood Canada Ltd.
Hellroar Creek	North Thompson	TNRD	083D03	Interior Watershed Assessment for the Hellroar Creek Watershed.	Y	N	Y			Dobson Engineering Ltd. 1997. Interior Watershed Assessment for the Hellroar Creek Watershed. Prepared for Weyerhauser Canada Ltd.
Jamieson Creek	North Thompson	TNRD	092I	Level 1 Channel Assessment for the Jamieson Creek Watershed: Final Report	Y	N	Y			Dobson Engineering Ltd. 1999. Level 1 Channel Assessment for the Jamieson Creek Watershed: Final Report. Prepared for Weyerhauser Canada Ltd.
Louis Creek/Vavenby	North Thompson	TNRD	082M	North Thompson River Flood Hazard Risk Assessment	Y	N	Y			Doyle Engineering. 2006. Priority sites for improved flood protection on the North Thompson River from Exlou to Vavenby. Prepared for Thompson-Nicola Regional District
Fishtrap Creek	North Thompson	TNRD	092P01	Wildfire, morphologic change and bed material transport at Fishtrap Creek, British Columbia.	Y	N	Y			Eaton, B, Andrews, A, Giles, T and Phillips, J. 2010. Wildfire, morphologic change and bed material transport at Fishtrap Creek, British Columbia. Geomorphology 118:409-424.
Fishtrap Creek	North Thompson	TNRD	092P01	Fishtrap Creek Watershed Project.	Y	N	Y			Eaton, B, Giles, T, Heise, B, Moore, RD, Owens, P and Petticrew, E. 2010. Fishtrap Creek Watershed Project. Streamline Watershed Management Bulletin. 14(1):12-13.

Location				Project			Hazard Type			Reference
Name	River Basin	District	NTS ID	Project Title	Report? (Y/N)	Spatial information?	Flooding?	Landslide?	Steep Creek?	Citation
Fishtrap Creek	North Thompson	TNRD	092P01	Forest fire, bank strength and channel instability: the 'unusual" response o fFishtrap Creek, British Columbia.	Y	N	Y			Eaton, B, Moore, RD and Giles, T. 2010. Forest fire, bank strength and channel instability: the 'unusual" response o fFishtrap Creek, British Columbia. Earth Surface Processes and Landforms 35:1167-1183.
Fishtrap Creek	North Thompson	TNRD	092P01	The broader significance of the morphologic life cycle - Watershed Response to the McLure Forest Fire	Y	N	Y			Eaton, B. 2008. Channel morphology, aquatic habitat, and disturbance: The broader significance of the morphologic life cycle - Watershed Response to the McLure Forest Fire. Streamline Watershed Management Bulletin 12(1):10-11.
Fishtrap Creek	North Thompson	TNRD	092P01	Predicting the range of potential morphologic changes - Watershed Response to the McLure Forest Fire.	Y	N	Y			Eaton, B. 2008. UBC Regime Model: Predicting the range of potential morphologic changes - Watershed Response to the McLure Forest Fire. Streamline Watershed Management Bulletin 12(1):10.
Fishtrap Creek	North Thompson	TNRD	092P01	Fishtrap Creek Workshop: Watershed Response to the MacLure Forest Fire.	Y	N	Y			Eaton, B. 2008. Workshop Handbook: Fishtrap Creek Workshop: Watershed Response to the MacLure Forest Fire. FORREX and UBC
North Thompson River	North Thompson	TNRD	092P01	North Thompson River (Kamloops to Vavenby) Floodplain Mapping (including Barriere and Clearwater Rivers)	Y	Y - See Floodplain Mapping	Y			BC Water Surveys Unit and Canada-BC Floodplain Mapping Program. 1982. North Thompson River (Kamloops to Vavenby) Floodplain Mapping (including Barriere and Clearwater Rivers). BC Ministry of Environment.
TMEP	All	TNRD	N/A	Trans Mountain Pipeline Expansion Project: Route Physiography and Hydrology.	Y	N	Y			BGC Engineering Inc. 2013. Trans Mountain Pipeline Expansion Project: Route Physiography and Hydrology. Prepared for Trans Mountain Pipeline ULC.
TMEP	All	TNRD	N/A	Trans Mountain Pipeline Expansion Project: Terrain Mapping and Geohazard Inventory	Y	Y		Y	Y	BGC Engineering Inc. 2013. Trans Mountain Pipeline Expansion Project: Terrain Mapping and Geohazard Inventory. Prepared for Trans Mountain Pipeline ULC.
Shannon Creek	North Thompson	TNRD	082M14	Waterpower project scope for the Shannon Creek Waterpower Project.	Y	N	Y			Bieber, W. 2011. Waterpower project scope for the Shannon Creek Waterpower Project. Prepared for Soler Logging Ltd.
Raft Creek	North Thompson	TNRD	082M	West Raft & Raft Residual TSIL D Terrain Stability Mapping (BAPID 4674).	Y	Y - See Terrain Mapping		Y	Y	Bruce Geotechnical Services Ltd. 1999. West Raft & Raft Residual TSIL D Terrain Stability Mapping (BAPID 4674). Prepared for Slocan Forest Products Ltd.
Fishtrap Creek	North Thompson	TNRD	092P01	Interception Loss - Watershed Response to the McLure Forest Fire	Y	N	Y			Carlyle-Moses, D. 2008. Interception Loss - Watershed Response to the McLure Forest Fire. Streamline Watershed Management Bulletin 12(1):3.
Deception Creek/Spanish Creek	North Thompson	CRD	092P01	Deception/Spanish Watershed Integrated Resrource Restoration Plan.	Y	N	Y			Carr Environmental Consultants Ltd. 1998. Deception/Spanish Watershed Integrated Resrource Restoration Plan. Prepared for Weldwood Canada Ltd.
North Thompson River	North Thompson	TNRD	N/A	List of creeks and rivers in the North Thompson River Watershed	Y	N	Y			Chan, B. 1974. List of creeks and rivers in the North Thompson River Watershed. BC Ministry of Environment
Fadear Mountain	North Thompson	TNRD	082M	Fadear Mountain - Moose Meadows Operating Area,	Y	Y - See Terrain Mapping		Y	Y	Denton, J and Giles, T. 1999. Detailed Terrain Stability Mapping of the Fadear Mountain - Moose Meadows Operating Area, BAPID 4945. BC Ministry of Forests and Range.
Fishtrap Creek	North Thompson	TNRD	092P01	Detection of runoff timing changes in pluvial, nival, and glacial rivers of western Canada.	Y	N	Y			Dery, S, Stahl, K, Moore, RD, Whitfield, P, Menounos, B and Burford, JE. 2009. Detection of runoff timing changes in pluvial, nival, and glacial rivers of western Canada. Water Resources Research 45: doi:10.1029/2008WR006975
Foam Creek	North Thompson	TNRD	082M14	Interior Watershed Assessment Procedure Foam Creek.	Y	N	Y			EBA Engineering Consultants Ltd. 2000. Interior Watershed Assessment Procedure Foam Creek. Prepared for Weyerhauser Canada Ltd.
Thompson Plateau	North Thompson	TNRD	092P	Thompson Plateau Risk Analysis.	Y	N	Y		Y	Forsite Consultants Ltd. 2005. Thompson Plateau Risk Analysis. Prepared for Wyerhauser Canada Ltd.
Yellowhead/ Hellroar Creek/Mud Creek/Peddie Creek/Wilkens Creek/Foghorn Creek	North Thompson	TNRD	083M/083D	Risk Assessment for Selected Watersheds in the Headwaters Forest District	Y	N	Y		Y	Forsite Consultants Ltd. 2007. Risk Assessment for Selected Watersheds in the Headwaters Forest District. Prepared for BC Timber Sales.
North Thompson River	North Thompson	TNRD	083D03	Detailed Terrain Stability Mapping of the Upper North Thompson River Area	Y	Y - See Terrain Mapping		Y	Y	Giles, T. 1999. Detailed Terrain Stability Mapping of the Upper North Thompson River Area. BC Ministry of Forests.
Fishtrap Creek	North Thompson	TNRD	092P01	Channel Morphology - Watershed Response to the McLure Forest Fire.	Y	N	Y			Giles, T. 2008. Channel Morphology - Watershed Response to the McLure Forest Fire. Streamline Watershed Management Bulletin 12(1):5.

Location				Project			Hazard Type			Reference
Name	River Basin	District	NTS ID	Project Title	Report? (Y/N)	Spatial information?	Flooding?	Landslide?	Steep Creek?	Citation
North Thompson River	North Thompson	TNRD	082M12	Clearwater-Vavenby Community Watersheds Terrain Stability Mapping	Y	Y - See Terrain Mapping		Y	Y	Golder Associates Ltd. 1998. Clearwater-Vavenby Community Watersheds Terrain Stability Mapping (BAPID 4932). Prepared for Slocan Forest Products Ltd.
Leonie Creek/Skowootum Creek/Cayoosh Creek	North Thompson	TNRD	092P01	Leonie and Skowootum Cayoosh Creek Watershed: Overview Assessment	Y	N	Y			Integrated ProAction Corp. 2006. Leonie and Skowootum Cayoosh Creek Watershed: Overview Assessment. Tolko Industries Ltd.
Raft River	North Thompson	TNRD	082M	Raft River Watershed Channel Assessment.	Y	N	Y			Integrated Woods Services Ltd. 2002. Raft River Watershed Channel Assessment. Prepared for Slocal Forest Products Ltd.
Raft River	North Thompson	TNRD	082M	Raft River Level 1 Watershed Assessment.	Y	N	Y			Integrated Woods Services Ltd. 1996. Raft River Level 1 Watershed Assessment. Prepared for Slocal Forest Products Ltd.
Barriere River	North Thompson	TNRD	082M	Barriere River Level 1 Interior Watershed Assessment Procedure	Y	N	Y			Integrated Woods Services Ltd. 1997. Barriere River Level 1 Interior Watershed Assessment Procedure. Prepared for Tolko Industries Ltd.
Lopex Creek	Thompson	TNRD	092I14	Lopex Creek Community Watershed	Y	N	Y			Integrated Woods Services Ltd. 1997. Lopex Creek Community Watershed Level 1 Interior Watershed Assessment Procedure. Prepared for Ainsworth Lumber Co.
Mann Creek	North Thompson	TNRD	092P09	Mann Creek Watershed Assessment Procedure.	Y	N	Y			Integrated Woods Services Ltd. 1997. Mann Creek Watershed Assessment Procedure. Prepared for Slocan Forest Products Ltd.
Birk Creek	North Thompson	TNRD	082M	Birk Creek Channel Conditions and Prescription Assessment.	Y	N	Y			Integrated Woods Services Ltd. 1998. Birk Creek Channel Conditions and Prescription Assessment. Prepared for Tolko Industries Ltd.
Leonie Creek	North Thompson	TNRD	082M	Leonie Creek Community Watershed Channel Conditions and Prescription Assessment.	Y	N	Y			Integrated Woods Services Ltd. 1998. Leonie Creek Community Watershed Channel Conditions and Prescription Assessment. Prepared for Tolko Industries Ltd.
Skowootum Creek	North Thompson	TNRD	082M	Skowootum Creek Community Watershed Channel Conditions and Prescription Assessment.	Y	N	Y			Integrated Woods Services Ltd. 1998. Skowootum Creek Community Watershed Channel Conditions and Prescription Assessment. Prepared for Tolko Industries Ltd.
Barriere River	North Thompson	TNRD	082M	Barriere River Watershed Residual Sub-basin Channel Assessment Procedure.	Y	N	Y			Integrated Woods Services Ltd. 1999. Barriere River Watershed Residual Sub-basin Channel Assessment Procedure. Prepared for Tolko Industries Ltd.
Mann Creek	North Thompson	TNRD	092P09	Final Report: Mann Creek Watershed Assessment Procedure.	Y	N	Y			Integrated Woods Services Ltd. 1999. Final Report: Mann Creek Watershed Assessment Procedure. Prepared for Slocan Forest Products Ltd.
Heffley Creek	North Thompson	TNRD	092I16	Heffley Creek Watershed Assessment Procedure	Y	N	Y			Integrated Woods Services Ltd. 1999. Heffley Creek Watershed Assessment Procedure. Prepared for Tolko Industries Ltd.
Canimred Creek	Bonaparte	CRD	092P15	Level 2 Watershed Assessment for the Canimred Creek Sub-basin	Y	N	Y			Integrated Woods Services Ltd. 1999. Level 2 Watershed Assessment for the Canimred Creek Sub-basin. Slocan Forest Products
Brookfield Creek	North Thompson	TNRD	092P09	Level 2 Watershed Assessment: Brookfield Creek Watershed.	Y	N	Y			Integrated Woods Services Ltd. 1999. Level 2 Watershed Assessment: Brookfield Creek Watershed. Prepared for BC Ministry of Forests.
Louis Creek	North Thompson	TNRD	092P01/092I1	Louis Creek Watershed Assessment Procedure.	Y	N	Y			Integrated Woods Services Ltd. 1999. Louis Creek Watershed Assessment Procedure. Prepared for Tolko Industries Ltd.
Albreda River	North Thompson	TNRD	083D11	Albreda River Watershed Channel Conditions and Prescriptions Assessment.	Y	N	Y			Integrated Woods Services Ltd. 2000. Albreda River Watershed Channel Conditions and Prescriptions Assessment. Prepared for Slocan Forest Products Ltd.
Spahats Creek	North Thompson	TNRD	082M	Spahats Creek Watershed Assessment.	Y	N	Y			Integrated Woods Services Ltd. 2000. Draft: Spahats Creek Watershed Assessment. Prepared for Slocan Group.
Aver Creek/Foghorn Creek/Two Mile Creek	North Thompson	TNRD	082M12	Aver, Foghorn, and Two Mile Creek Watershed Assessments	Y	N	Y			Integrated Woods Services Ltd. 2000. Final Report: Aver, Foghorn, and Two Mile Creek Watershed Assessments. Prepared for Slocal Forest Products Ltd.
Paul Lake	North Thompson	TNRD	092I	Paul Lake Community Watershed Integrated Watershed Restoration Plan and Updated Watershed Assessement	Y	N	Y			Integrated Woods Services Ltd. 2000. Final Report: Paul Lake Community Watershed Integrated Watershed Restoration Plan and Updated Watershed Assessement. Prepared for Weyerhauser Canada Ltd.
East Bone	North Thompson	TNRD	083D03	Review of road and channel conditions for the East Bone Creek Residual Sub-Basin.	Y	N	Y		Y	Integrated Woods Services Ltd. 2000. Review of road and channel conditions for the East Bone Creek Residual Sub-Basin. Prepared for BC Ministry of Forests.

APPENDIX A - DATA COMPILATION

Location				Project			Hazard Type			Reference
Name	River Basin	District	NTS ID	Project Title	Report? (Y/N)	Spatial information?	Flooding?	Landslide?	Steep Creek?	Citation
Russell/Haschaek/ McDougal Creek	North Thompson	TNRD	092P09/082N	Watershed Assessment of Russell, Hascheak, and McDougall Creek Community Watersheds.	Y	N	Y			Integrated Woods Services Ltd. 2001. Watershed Assessment of Russell, Hascheak, and McDougall Creek Community Watersheds. Prepared for Weyerhauser Canada Ltd.
Fishtrap Creek	North Thompson	TNRD	092P01	TFL 35 Fishtrap Creek Watershed Detailed Terrain Stability Mapping.	Y	Y - See Terrain Mapping		Y	Y	JM Ryder and Associates Ltd. 1999. TFL 35 Fishtrap Creek Watershed Detailed Terrain Stability Mapping. Prepared for Weyerhauser Canada Ltd.
Blue River	North Thompson	TNRD	083D03	Detailed and Reconnaissance Terrain Stability Mapping of Cedar- Cook-Whitewater, Blue River, Finn Creek and Foam Creek areas (Vavenby)	Y	Y - See Terrain Mapping		Y	Y	JM Ryder and Associates. 1999. Detailed and Reconnaissance Terrain Stability Mapping of Cedar-Cook-Whitewater, Blue River, Finn Creek and Foam Creek areas (Vavenby) BAPID 4772, 4773, 4930, 4774. Prepared for Weyerhauser Canada Ltd.
Avola	North Thompson	TNRD	082M11	Wallace-Loyst-Anderson and Shannon-Wirecache Areas (Vavenby): Detailed and Reconnaissance Terrain Stability Mapping	Y	Y - See Terrain Mapping		Y	Y	JM Ryder and Associates. 1999. Wallace-Loyst-Anderson and Shannon-Wirecache Areas (Vavenby): Detailed and Reconnaissance Terrain Stability Mapping. Prepared for Weyerhauser Canada Ltd.
Brookfield Creek	North Thompson	TNRD	092P09	Canfo - Vavenby Division, Forest Road Risk Management, Risk Evaluation Report.	Y	N			Y	Keystone Environmental Ltd. 2005. Canfo - Vavenby Division, Forest Road Risk Management, Risk Evaluation Report. Prepared for Canfor.
Albreda River/Avola	North Thompson	TNRD	082M14/083D	Terrain classification and terrain stability mapping: Albreda and Messiter Project Areas.	Y	Y - See Terrain Mapping		Y	Y	Madrone Environmental Services Ltd. 2007. Terrain classification and terrain stability mapping: Albreda and Messiter Project Areas. Prepared for BC Timber Sales.
Louis Creek	North Thompson	TNRD	092P01/092I	Hydrotechnical assessment: Louis Creek Watershed	Y	N	Y		Y	Miles, M and Associates Ltd. 1996. Hydrotechnical assessment: Louis Creek Watershed. Prepared for BC Ministry of Environment
Russell/Haschaek/ McDougal Creek	North Thompson	TNRD	092P09/082N	Watershed Risk Analysis and Forest Development Suitability Report for Russell, Hascheak and MacDougal Creeks	Y	N	Y			MJ Milne and Associates Ltd. 2010. Watershed Risk Analysis and Forest Development Suitability Report for Russell, Hascheak and MacDougal Creeks. Prepared for Wells Gray Community Forest Corporation.
Fishtrap Creek	North Thompson	TNRD	092P01	Introduction to the Fishtrap Creek Study - Watershed Response to the McLure Forest Fire.	Y	N	Y			Moore, RD. 2008. Introduction to the Fishtrap Creek Study - Watershed Response to the McLure Forest Fire. Streamline Watershed Management Bulletin 12(1):1-2.
South Thompson River	South Thompson	City of Kamlo	092I09	South Thompson River Watershed Management Study	Y	N	Y			Northwest Hydraulic Consultants Ltd and Urban Systems Ltd. 1996. South Thompson River Watershed Management Study: Draft Final Report. South Thompson/Chase Creek Turbidity Task Force, City of Kamloops.
Fishtrap Creek/Jamieson Creek	North Thompson	TNRD	092P01	Changes in sediment sources following wildfire in mountainous terrain: A paired catchment approach	Y	N	Y			Owens, P, Blake, W and Petticrew, E. 2006. Changes in sediment sources following wildfire in mountainous terrain: A paired catchment approach, British Columbia, Canada. Water, Air and Soil Pollution 6:637-645.
Fishtrap Creek	North Thompson	TNRD	092P01	Post-fire determination of fine-grained sediment sources - Watershed Response to the McLure Forest Fire.	Y	N	Y			Owens, P, Petticrew, E, Blake, WH, Giles, TR and Moore, RD. 2008. Post-fire determination of fine-grained sediment sources - Watershed Response to the McLure Forest Fire. Streamline Watershed Management Bulletin 12(1):6-7.
Fishtrap Creek	North Thompson	TNRD	092P01	Techniques for monitoring channel disturbance: A case study of Fishtrap Creek, British Columbia	Y	N	Y			Phillips, J and Eaton, B. 2008. Techniques for monitoring channel disturbance: A case study of Fishtrap Creek, British Columbia. Streamline Watershed Management Bulletin 12(1):16-21.
Fishtrap Creek	North Thompson	TNRD	092P01	Detecting the timing of morphologic change using stage-discharge regressions: A case study at Fishtrap Creek, British Columbia, Canada.	Y	N	Y			Phillips, J and Eaton, B. 2009. Detecting the timing of morphologic change using stage-discharge regressions: A case study at Fishtrap Creek, British Columbia, Canada. Canadian Water Resources Journal 34: DOI:10.4296/cwrj3403285
North Thompson River	North Thompson	TNRD	082M12	Detailed terrain stability mapping of the upper North Thompson Watershed: Lebher Creek - Miledge Creek	Y	Y - See Terrain Mapping		Y	Y	Quaterra Environmental Consulting Ltd. 2000. Detailed terrain stability mapping of the upper North Thompson Watershed: Lebher Creek - Miledge Creek (BAPID 4675). Prepared for Tolko Industries Ltd.
Mayson Lake	North Thompson	TNRD	092P01	Mayson Lake Study Examines Hydrological Processes.	Y	N	Y			Redding, T, Winkler, R, Carlyle-Moses, D and Spittlehouse, D. 2007. Mayson Lake Study Examines Hydrological Processes. LINK 9(2): 10-11.
Fishtrap Creek	North Thompson	TNRD	092P01	Fishtrap Creek: Studying the Effects of Wildfire on Watersheds.	Y	N	Y			Redding, T. 2008. Fishtrap Creek: Studying the Effects of Wildfire on Watersheds. LINK 10(1): 1-2.

Location				Project			Hazard Type			Reference
Name	River Basin	District	NTS ID	Project Title	Report? (Y/N)	Spatial information?	Flooding?	Landslide?	Steep Creek?	Citation
Berry Creek	North Thompson	TNRD	082M14	Interior Watershed Assessment for Berry Creek	Y	N	Y			Silvatech. 2001. Interior Watershed Assessment for Berry Creek. Prepared for Weyerhauser Canada Ltd.
Peddie Creek	North Thompson	TNRD	083D03	Interior Watershed Assessment for the Peddie Creek Study Are	Y	N	Y			Silvatech. 2001. Interior Watershed Assessment for the Peddie Creek Study Area. Prepared for Weyerhauser Canada Ltd and Gilbert Smith Forest Products Ltd.
White River	North Thompson	TNRD	083D03	Interior Watershed Assessment for the White River Watershed.	Y	N	Y			Silvatech. 2001. Interior Watershed Assessment for the White River Watershed. Prepared for Gilbert Smith Forest Products Ltd.
Clanwilliam Landslide	Eagle River	CSRD	082L	The 1999 Clanwilliam Landslide: A preliminary Analysis of Potential Failure Mechanisms	Y	N		Y		Brideau, M-A., Stead, D., Couture, R. 2008, The 1999 Clanwilliam Landslide: A preliminary Analysis of Potential Failure Mechanisms *In* J. Locat, D., Perret, D., Turmel, D. Demers, et S. Leroueil, (2008). Comptes rendus de la 4e Conférence canadienne sur les géorisques: des causes à la gestion. Proceedings of the 4th Canadian Conference on Geohazards : From Causes to Management.Presse de l'Université Laval, Québec, 594 p
McAuley Creek Landslide	Paradise Creek	NORD	082L	Three-dimensional distinct element modelling and dynamic runout analysis of a landslide in gneiss rock	Y	N		Y		Brideau, M-A., McDougall, S., Stead, D., Evans, S.G., Couture, R., Turner, K. 2012, Three-dimensional distinct element modelling and dynamic runout analysis of a landslide in gneiss rock, British Columbia, Canada, Bull Eng Geol. Environ 71: 467-486
Thompson River valley landslides south of Aschroft	Thompson River	TNRD	092I	2003 Geologic Framework of Large Historic Landslides in Thompson River Valley	Y	N		Y		Clague, J.J., Evans, S.G., 2003 Geologic Framework of Large Historic Landslides in Thompson River Valley, British Columbia, Environmental & Engineering Geoscience, Vol IX, No. 3, August 2003, pp.201-212.
Thompson River valley landslides south of Aschroft	Thompson River	TNRD	092I	Complex Earth Slides in the Thompson River Valley, Ashcroft, British Columbia	Y	N		Y		Eshraghian, A., Martin, C.D., Cruden, D.M. 2007, Complex Earth Slides in the Thompson River Valley, Ashcroft, British Columbia, Environmental & Engineering Geoscience, Vol. XIII, No. 2, May 2007, pp. 161-181.
Thompson River valley landslides south of Aschroft	Thompson River	TNRD	092I	Hazard Analysis of an active slide in the Thompson River Valley, Aschroft, British Columbia	Y	N		Y		Eshraghian, A., Martin, C.D., and Morgenstern, N.R., 2008. Hazard Analysis of an active slide in the Thompson River Valley, Aschroft, British Columbia, Canada, Can. Geotech J. v.45, pp.297-313 (2008).
Thompson River valley landslides south of Aschroft	Thompson River	TNRD	092I	Movement triggers and mechanisms of two earth slides in the Thompson River Valley, Aschroft, British Columbia	Y	N		Y		Eshraghian, A., Martin, C.D., and Morgenstern, N.R., 2008. Movement triggers and mechanisms of two earth slides in the Thompson River Valley, Aschroft, British Columbia, Canada, Can. Geotech J. v.45, pp.1189-1209 (2008).
South Central BC Landslides	Many	TNRD, NORD	092P, 092I, 0	Landslides in layers of volcanic successions with particular reference to the Tertiary rocks of south central British Columbia	Y	N		Y		Evans, S.G., 1983. Landslides in layers of volcanic successions with particular reference to the Tertiary rocks of south central British Columbia, University of Alberta Thesis, Department of Geology, Fall 1983
South Central BC Landslides	Many	TNRD, NORD	092P, 092I, 0	Landslides in the Kamloops Group in South-Central British Columbia, A Progress Report, Scientific and Technical Notes in Current Research	Y	N		Y		Evans, S. and Cruden, D.M.. 1981, Landslides in the Kamloops Group in South-Central British Columbia, A Progress Report, Scientific and Technical Notes in Current Research, Part B; Geol. Surv. Can. Paper 81-1b.
Spence's Bridge	Thompson River	TNRD	092I	Landslides and surficial deposits in urban areas of British Columbia	Y	N		Y		Evans, S.G. 1982, Landslides and surficial deposits in urban areas of British Columbia: A Review, Can. Geotech J. v. 19, pp. 269-288.
Ripley Slide (Ashcroft Area)	Thompson River	TNRD	092I	Effects of Thompson River elevation on velocity and instability of Ripley Slide	Y	N		Y		Hendry, M.T., Macciotta, R., Martin, C.D., Reich, B.. 2014, Effects of Thompson River elevation on velocity and instability of Ripley Slide, NRC Research Press, Can. Geotech. J., v52, pp. 257-267
Thompson River valley landslides south of Aschroft	Thompson River	TNRD	092I	Measuring displacements of the Thompson River valley landslides, south of Ashcroft, BC, Canada, using satellite InSAR	Y	N		Y		Journault, J., Macciotta, R., Hendry, M.T., Charbonneau, F., Huntley, D., Bobrowsky, P.T.. 2017, Measuring displacements of the Thompson River valley landslides, south of Ashcroft, BC, Canada, using satellite InSAR, Landslides, DOI 10.1007/s10346-017-0900-1, Published online: 23 September 2017.
Blais Creek DsGSD	Blais Creek	TNRD	083D	Blais Creek DsGSD (Monashee Mountains, BC, Canada).	Y	N		Y		Moretti, D., Giardino, M., Stead, D., Clague, J., Gibson, D., Ghirotti, M., Perotti, L., 2013. Multidisciplinary approach (geology, geomorphology, geomechanics, geomatics) for the characterization of the Blais Creek DsGSD (Monashee Mountains, BC, Canada), Geophysical Research Abstracts, Vol. 15, EGU2013-7522-1.
Thompson River valley landslides south of Aschroft	Thompson River	TNRD	092I	Characterization of a landslide-prone glaciolacustrine clay from the Thompson River Valley near Ashcroft, British Columbia	Y	N		Y		Le Meil, G. 2017, Characterization of a landslide-prone glaciolacustrine clay from the Thompson River Valley near Ashcroft, British Columbia, University of Alberta Master's Thesis, Department of Civil and Environmental Engineering.

Location				Project			Hazard Type			Reference
Name	River Basin	District	NTS ID	Project Title	Report? (Y/N)	Spatial information?	Flooding?	Landslide?	Steep Creek?	Citation
Thompson River valley landslides south of Aschroft	Thompson River	TNRD	092I	Climatic influences on the Ashcroft Thompson River Landslides, British Columbia	Y	N		Y		Tappenden, K.M. 2014b. Climatic influences on the Ashcroft Thompson River Landslides, British Columbia, Canada. *In* Proceedings of the 6th Canadian Geohazards Conference, 15-17 June 2014. Kingston, Ontario, Canada.
Drynoch Landslide	Thompson River	TNRD	092I	Drynoch Landslide, British Columbia – a history	Y	N		Y		VanDine, D.F. 1983, Drynoch Landslide, British Columbia – a history, Can. Geotech J., v20 pp.82-103.
Thompson River valley landslides south of Aschroft	Thompson River	TNRD	092I	Geotechnics and hydrology of landslides in Thompson River Valley, near Ashcroft, British Columbia	Y	N		Y		Bishop, N.F., 2008. Geotechnics and hydrology of landslides in Thompson River Valley, near Ashcroft, British Columbia, University of Waterloo Masters thesis.
Southwestern BC	Thompson River	TNRD	092I	Risk Analysis of Landslides Affecting Major Transportation Corridors in Southwestern British Columbia	Y	N		Y		Hazzard, J., 1998. Risk Analysis of Landslides Affecting Major Transportation Corridors in Southwestern British Columbia, University of British Columbia Masters Thesis.
Harris Creek	Harris Creek	NORD	082L	The relations between false gold anomalies, sedimentological process and landslides in Harris Creek, British Columbia	Y	N		Y		Hou, Z., and Fletcher, W.K., 1996. The relations between false gold anomalies, sedimentological process and landslides in Harris Creek, British Columbia, Canada, Journal of Geochemical Exploration, Vol. 57, pp. 21-30.
Little Chief Slide	former Columbia R.	CSRD	083D	Movement behavior of the Little Chief Slide	Y	N		Y		Mansour, M.F., Martin, C.D., and Morgenstern, N.R., 2011. Movement behavior of the Little Chief Slide, Can. Geotech J., Vol., 48, pp.655-670.
Thompson River valley landslides south of Aschroft	Thompson River	TNRD	092I	High Magnitude-Low Frequency Catastrophic Landslides in British Columbia	Y	N		Y		Evans, S.G., 1991. High Magnitude-Low Frequency Catastrophic Landslides in British Columbia in Bobrowsky, P., 1992. Geologic Hazards in British Columbia Proceedings in the Geologic Hazards '91 Workshop February 20-21, 1992, Victoria, BC, British Columbia Geological Survey Branch Open File 1992-15.
South Central BC Landslides	Multiple	CRD, TNRD	092P	Landslide susceptibility and element at risk assessment – web mapping and mobile solution	Y	N		Y		Ramesh, A., 2015. Landslide susceptibility and element at risk assessment – web mapping and mobile solution, GeoBC Decision Support Section, preliminary presentation November 17, 2015.
	Multiple	CRD, TNRD,	Multiple	Review of Landslide Management in British Columbia	Y	N	Y	Y	Y	Symonds, B. and Zandbergen, J., 2013. Review of Landslide Management in British Columbia, Ministry of Forests, Lands and Natural Resource Operations, Provence of BC.
Thompson River valley landslides south of Aschroft	Thompson River	TNRD	092I	Landslide Risk to Railway Operations and Resilience in the Thompson River Valley near Ashcroft, British Columbia	Y	N		Y		Tappenden, K.M., 2017. Landslide Risk to Railway Operations and Resilience in the Thompson River Valley near Ashcroft, British Columbia, University of Alberta Masters Thesis.
Thompson River valley landslides south of Aschroft	Thompson River	TNRD	092I	Landslide Risk and Resilience for Rail Operations in the Thompson River Valley near Ashcroft	Y	N		Y		Tappenden, K.M., and Martin, C.D., 2015. Landslide Risk and Resilience for Rail Operations in the Thompson River Valley near Ashcroft, British Columbia, Canadian Rail Research Laboratory, Research Update, December 2015.
Thompson River valley landslides south of Aschroft	Thompson River	TNRD	092I	Formation and Failure of Natural Dams in the Canadian Cordillera	Y	N		Y		Clague, J., and Evans, S.G., 1994. Formation and Failure of Natural Dams in the Canadian Cordillera, Geological Survey of Canada Bulletin 464.
	Multiple	Multiple	Multiple	Landslide Susceptibility Map of Canada	N	Y		Y		Bobrowsky, P.T., Dominguez, M.J., Landslide Susceptibility Map of Canada, Geological Survey of Canada, Open-File 7228, 2012, 1 sheet
Candle Creek	Thompson River	TNRD	092P	Candle Creek Watershed Assessment	Y	N	Y			Silvatech. 2002. Candle Creek Watershed Assessment. Prepared for Slocan Forest Products Ltd.
Cahilty Creek	Thompson River	TNRD	082L13	Cahilty Creek Channel Assessment.	Y	N	Y			Summit Environmental Consultants Ltd. 1996. Final Report: Cahilty Creek Channel Assessment. Prepared for Tolko Industries Ltd.
Finn Creek	Thompson River	TNRD	082M14	Finn Creek Integrated Watershed Restoration Plan, Sediment Source Survey, Channel Assessment Procedure, and Access Management Strategy.	Y	N	Y		Y	Summit Environmental Consultants Ltd. 1998. Final Report: Finn Creek Integrated Watershed Restoration Plan, Sediment Source Survey, Channel Assessment Procedure, and Access Management Strategy. Prepared for Weyerhauser Canada Ltd.
Otter Creek	Thompson River	TNRD	082M11	Otter Creek Watershed Assessment.	Y	N	Y			Summit Environmental Consultants Ltd. 1998. Final Report: Otter Creek Watershed Assessment. Prepared for Weyerhauser Canada Ltd..
Otter Creek/Hellroar Creek/Finn Creek	Thompson River	TNRD	082M	Otter, Hellroar and Finn Creeks Channel Assessment.	Y	N	Y			Summit Environmental Consultants Ltd. 1998. Final Report: Otter, Hellroar and Finn Creeks Channel Assessment. Prepared for Weyerhauser Canada Ltd.
Blue River	Thompson River	TNRD	083D	Blue/Macrae (Blue River) Watershed Assessment.	Y	N	Y			Summit Environmental Consultants Ltd. 1999. Final Report: Blue/Macrae (Blue River) Watershed Assessment. Prepared for Weyerhauser Canada Ltd.

Location				Project			Hazard Type			Reference
Name	River Basin	District	NTS ID	Project Title	Report? (Y/N)	Spatial information?	Flooding?	Landslide?	Steep Creek?	Citation
Leonie/Bottrel/Chip Creeks	Thompson River	TNRD	092P01	Hydrological Review: Leonie/Bottrel/Chip Creeks.	Y	N	Y			Summit Environmental Consultants Ltd. 1999. Hydrological Review: Leonie/Bottrel/Chip Creeks. Tolko Industries Ltd.
Lemieux Creek	Thompson River	TNRD	092P	Reconnaissance Watershed Assessment of Lemieux Creek Watershed	Y	N	Y			Summit Environmental Consultants Ltd. 2000. Reconnaissance Watershed Assessment of Lemieux Creek Watershed. Prepared for Tolko Industries Ltd.
Barriere River	North Thompson	TNRD	082M	Reconnaissance Watershed Assessment of Barrierre River Watershed	Y	N	Y			Summit Environmental Consultants Ltd. 2001. Final Report: Reconnaissance Watershed Assessment of Barrierre River Watershed. Prepared for Tolko Industries Ltd.
Newhykulston Creek	North Thompson	TNRD	092P08	Reconnaissance Watershed Assessment of Newhykulston Creek Watershed	Y	N	Y			Summit Environmental Consultants Ltd. 2001. Final Report: Reconnaissance Watershed Assessment of Newhykulston Creek Watershed. Prepared for Tolko Industries Ltd.
Barriere River	North Thompson	TNRD	082M	Barriere River Watershed TSIL D Reconnaissance Terrain Stability Mapping	Y	Y - See Terrain Mapping		Y	Y	Terratech Consulting Ltd. 1999. Barriere River Watershed TSIL D Reconnaissance Terrain Stability Mapping. Prepared for Tolko Industries Ltd.
Leonie/Skowootum Creek	Thompson River	TNRD	092P01	Detailed Terrain Stability Mapping (TSIL C) of the Leonie and Skowootum Creek Community Watershed	Y	Y - See Terrain Mapping		Y	Y	Terratech Consulting Ltd. 1999. Detailed Terrain Stability Mapping (TSIL C) of the Leonie and Skowootum Creek Community Watershed (BAPID 4947). Prepared for Tolko Industries Ltd.
Tyner Creek	Nicola	TNRD	092I07	Overview Hydrological Assessment of the Tyner Creek Sub-basin	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Hydrological Assessment of the Tyner Creek Sub-basin. Prepared for Aspen Planers Ltd.
Stumbles Creek	Nicola	TNRD	092I02	Overview Hydrological Assessment for the Stumbles Creek Sub-basin	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Hydrological Assessment for the Stumbles Creek Sub-basin. Prepared for Aspen Planers Ltd.
Steffens Creek	Nicola	TNRD	092I	Overview Hydrological Assessment for the Steffens Creek Sub-basin.	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Hydrological Assessment for the Steffens Creek Sub-basin. Prepared for Aspen Planers Ltd.
Spius Creek	Nicola	TNRD	092I03	Overview Hydrological Assessment for the Spius Creek Watershed.	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Hydrological Assessment for the Spius Creek Watershed. Prepared for Aspen Planers Ltd.
Shuta Creek	Nicola	TNRD	092I	Overview Hydrological Assessment for the Shuta Creek Sub-basin	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Hydrological Assessment for the Shuta Creek Sub-basin. Prepared for Aspen Planers Ltd.
Rey Creek	Nicola	TNRD	092I07	Overview Hydrological Assessment for the Rey Creek Sub-basin	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Hydrological Assessment for the Rey Creek Sub-basin. Prepared for Aspen Planers Ltd.
Quilchena Creek	Nicola	TNRD	092I01	Overview Assessment for the Quilchena Creek above Wasley Creek Watershed.	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Assessment for the Quilchena Creek above Wasley Creek Watershed. Prepared for Weyerhauser Canada Ltd.
Pothole Creek	Nicola	TNRD	092H15	Overview Assessment for the Pothole Creek Sub-basins	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Assessment for the Pothole Creek Sub-basins #139. Prepared for Weyerhauser Canada Ltd.
Pennask Creek	Nicola	TNRD	092H16	Channel condition and prescription assessment and riparian assessment and prescription procedure for the Pennask Creek	Y	N	Y			Dobson Engineering Ltd. 1999. Channel condition and prescription assessment and riparian assessment and prescription procedure for the Pennask Creek: Final Report. Prepared for Pennask Lake Fish and Game Club.
Nicola River	Nicola	TNRD	092I	Nicola River: Spences Bridge to Nicola Lake Floodplain Mapping	Y	Y - See Floodplain Mapping	Y			BC Water Surveys Unit and Canada-BC Floodplain Mapping Program. 1989. Nicola River: Spences Bridge to Nicola Lake Floodplain Mapping (Including Coldwater River and Spius Creek). BC Ministry of Environment.
Gordon Creek	Nicola	TNRD	092I03	Overview Hydrological Assessment of the Gordon Creek Residual Area	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Hydrological Assessment of the Gordon Creek Residual Area. Prepared for Aspen Planers Ltd.
Gordon Creek	Nicola	TNRD	092I06	Overview Hydrological Assessment of the Gordon Creek Sub-basin.	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Hydrological Assessment of the Gordon Creek Sub-basin. Prepared for Aspen Planers Ltd.
Guichon Creek	Nicola	TNRD	092I	Overview Hydrological Assessment of the Guichon Creek Residual Area	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Hydrological Assessment of the Guichon Creek Residual Area. Prepared for Aspen Planers Ltd.
Guichon Creek	Nicola	TNRD	092I	Guichon Creek Community Watershed, Level 1 Interior Watershed Assessment Procedure.	Y	N	Y			Integrated Woods Services Ltd. 1997. Guichon Creek Community Watershed, Level 1 Interior Watershed Assessment Procedure. Ainsworth Lumber Company Ltd.
Guichon Creek	Nicola	TNRD	092I	Hydrology Section Report: Guichon Creek	Y	N	Y			Obedkoff, W. 1987. Hydrology Section Report: Guichon Creek. BC Ministry of Environment
Hector Creek	Nicola	TNRD	092I02	Overview Hydrological Assessment for the Hector Creek Sub-basin	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Hydrological Assessment for the Hector Creek Sub-basin. Prepared for Aspen Planers Ltd.

Location				Project			Hazard Type			Reference
Name	River Basin	District	NTS ID	Project Title	Report? (Y/N)	Spatial information?	Flooding?	Landslide?	Steep Creek?	Citation
Jesse Creek	Nicola	TNRD	092I02	Overview Hydrological Assessment for the Jesse Creek Sub-basin	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Hydrological Assessment for the Jesse Creek Sub-basin. Prepared for Aspen Planers Ltd.
Juliet Creek	Nicola	TNRD	092H11	Overview Hydrological Assessment of Juliet Creek Watershed	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Hydrological Assessment of Juliet Creek Watershed. Prepared forTolko Industries Ltd.
July Creek	Nicola	TNRD	092H11	Reconnaissance Channel Assessment and Detailed CAP of July Creek	Y	N	Y			Klohn-Crippen Consultants Ltd. 1999. Reconnaissance Channel Assessment and Detailed CAP of July Creek. Prepared for BC Ministry of Forests.
Kwinshatin/Skuagam Creek	Nicola	TNRD	092I02	Interior Watershed Assessment of Kwinshatin and Skuagam Creeks.	Y	N	Y			Henderson Environmental Consulting Ltd. 2002. Interior Watershed Assessment of Kwinshatin and Skuagam Creeks. Prepared for Tolko Industries Ltd.
Lauder Creek	Nicola	TNRD	092I01	Lauder Creek Watershed Yield	Y	N	Y			Obedkoff, W. 1979. Lauder Creek Watershed Yield. BC Ministry of Environment.
Meadow Creek	Nicola	TNRD	092I07	Overview Hydrological Assessment for the Meadow Creek Face Unit	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Hydrological Assessment for the Meadow Creek Face Unit. Prepared for Weyerhauser Canada Ltd.
Moore Creek	Nicola	TNRD	092I08	Moore Creek - Water Supply - Freshet Runoff Estimates	Y	N	Y			Obedkoff, W. 1989. Moore Creek - Water Supply - Freshet Runoff Estimates. BC Ministry of Environment
Nicola Lake	Nicola	TNRD	092I	Nicola Lake Inflow Forecasting Model Review	Y	N	Y			Costerton, RW. 1993. Nicola Lake Inflow Forecasting Model Review. BC Ministry of Environment.
Nicola Lake	Nicola	TNRD	092I	Nicola Lake Foreshore Inventory and Mapping.	Y	N	Y			Ecoscape Environmental Consultants Ltd. 2012. Nicola Lake Foreshore Inventory and Mapping. Prepared for Thompson-Nicola Regional District and Fisheries and Oceans Canada.
Nicola Lake	Nicola	TNRD	092I	Overview Hydrological Assessment of the Nicola Lake Sub-basin (	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Hydrological Assessment of the Nicola Lake Sub-basin (#191). Prepared for Aspen Planers Ltd.
Nicola River	Nicola	TNRD	092I	A design brief on the floodplain mapping study of the Nicola River	Y	Y - See Floodplain Mapping	Y			Nichols, RW. 1988. A design brief on the floodplain mapping study of the Nicola River: An overview of the study undertaken to produce floodplain mapping for the Nicola River from Spences Bridge to Nicola Lake. BC Ministry of Enviroment.
Abbot Creek	Nicola	TNRD	092I06	Overview Hydrological Assessment of the Abbot Creek Sub-basin	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Hydrological Assessment of the Abbot Creek Sub-basin. Prepared for Aspen Planers Ltd.
Beak Creek	Nicola	TNRD	082L04	Beak Creek Watershed: Hydrologic Assessment and ECA Evaluation.	Y	N	Y			Dobson Engineering Ltd. 2005. Beak Creek Watershed: Hydrologic Assessment and ECA Evaluation. Prepared for Riverside Forest Products Ltd.
Spius Creek	Nicola	TNRD	092I03	Spius Creek Reconnaissance Terrain Stability Mapping	Y	Y - See Terrain Mapping		Y	Y	EBA Engineering Consultants Ltd. 1999. Spius Creek Reconnaissance Terrain Stability Mapping. Prepared for Weyerhauser Canada Ltd.
Brook Creek	Nicola	TNRD	092H15	Interior Watershed Assessment of Brook Creek.	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Interior Watershed Assessment of Brook Creek. Prepared for Tolko Industries Ltd.
Brook Creek	Nicola	TNRD	092H15	Detailed Terrain Stability Mapping (TSIL C) Brook Creek Watershed	Y	Y - See Terrain Mapping		Y	Y	Terratech Consulting Ltd. 2002. Detailed Terrain Stability Mapping (TSIL C) Brook Creek Watershed (BAPID 4882). Prepared for Tolko Industries.
Broom Creek	Nicola	TNRD	092I07	Overview Hydrological Assessment for the Broom Creek Sub-basin	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Hydrological Assessment for the Broom Creek Sub-basin. Prepared for Aspen Planers Ltd.
Chataway Creek	Nicola	TNRD	092I07	Overview Hydrological Assessment for the Chataway Creek Watershed	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Hydrological Assessment for the Chataway Creek Watershed. Prepared for Aspen Planers Ltd.
Chataway Creek	Nicola	TNRD	092I07	Three-year (2000,2002) Results of Channel Monitoring in Chataway Creek	Y	N	Y			Henderson Environmental Consulting Ltd.2003. Three-year (2000,2002) Results of Channel Monitoring in Chataway Creek - Final Report. Prepared for Aspen Planers Ltd.
Clapperton Creek	Nicola	TNRD	092I07	Overview Hydrological Assessment for the Clapperton Creek Residual Area.	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Hydrological Assessment for the Clapperton Creek Residual Area. Prepared for Aspen Planers Ltd.
Clapperton Creek	Nicola	TNRD	092I07	Overview Hydrological Assessment for the Clapperton Creek Sub-basin	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Hydrological Assessment for the Clapperton Creek Sub-basin. Prepared for Aspen Planers Ltd.
Clapperton Creek	Nicola	TNRD	092I07	Overview Hydrological Assessment for the Clapperton Creek West of Helmer Lake Sub-basin.	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Hydrological Assessment for the Clapperton Creek West of Helmer Lake Sub-basin. Prepared for Aspen Planers Ltd.
Coldwater River	Nicola	TNRD	092H	Coldwater Watershed Level 1 - IWAP Assessment	Y	N	Y			Borrett Engineering Ltd. 1998. Coldwater Watershed Level 1 - IWAP Assessment. Prepared for Tolko Industries.
Coldwater River	Nicola	TNRD	092H	Coldwater River Study	Y	N	Y			McPhail, JD. 1980. Coldwater River Study. BC Ministry of Environment.
Coldwater River	Nicola	TNRD	092H	Bank vegetation, bank strength, and application of the university of British Columbia regime model to stream restoration	Y	N	Y			Millar, RG and Eaton, BC. 2011. Bank vegetation, bank strength, and application of the university of British Columbia regime model to stream restoration. In: Stream restoration indynamic fluvial systems: Scientific approaches, analyses and tools. Geophysical Monographs Series 194. American Geophysical Union.

Location				Project			Hazard Type			Reference
Name	River Basin	District	NTS ID	Project Title	Report? (Y/N)	Spatial information?	Flooding?	Landslide?	Steep Creek?	Citation
Coldwater River	Nicola	TNRD	092H	Coldwater River Encroachment/Confinement Assessment: Kingsvale to Juliet Draft Report	Y	N	Y			Northwest Hydraulic Consultants Ltd. 2002. Coldwater River Encroachment/Confinement Assessment: Kingsvale to Juliet Draft Report. Prepared for Pacific Salmon Foundation.
Dupuis Creek	Nicola	TNRD	092I07	Overview Hydrological Assessment for the Dupuis Creek Sub-basin	Y	N	Y			Henderson Environmental Consulting Ltd. 1999. Overview Hydrological Assessment for the Dupuis Creek Sub-basin. Prepared for Aspen Planers Ltd.
Logan Lake	Nicola	TNRD	092I10	Logan Lake Community Forest Road Risk Analysis	Y	N			Y	Forsite Consultants Ltd. 2010. Logan Lake Community Forest Road Risk Analysis. Foresite Consutants Ltd.
TRIM Water Points	All	All	N/A		N	Y	Y			Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, 2017. TRIM Water Points. Online data source. https://catalogue.data.gov.bc.ca/dataset/trim-water-points
Hydrometric Stations - Active and Discontinued	All	All	N/A		N	Y	Y			Ministry of Environment and Climate Change Strategy, 2018. Hydrometric Stations - Active and Discontinued. Online Data Source. https://catalogue.data.gov.bc.ca/dataset/hydrometric-stations-active-and-discontinued
BC Points of Diversion with Water Licence Information	All	All	N/A		N	Y	Y			Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, 2017. BC Points of Diversion with Water Licence Information. Online resource. https://catalogue.data.gov.bc.ca/dataset/bc-points-of-diversion-with-water-licence-information
Ground Water Aquifers	All	All	N/A		N	Y	Y			Ministry of Environment and Climate Change Strategy, 2017. Ground Water Aquifers. Online Resource. https://catalogue.data.gov.bc.ca/dataset/ground-water-aquifers
Water Resource Management Streams	All	All	N/A		N	Y	Y			Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, 2017. Water Resource Management Streams. Online resource. https://catalogue.data.gov.bc.ca/dataset/water-resource-management-streams
Bathymetric Maps	All	All	N/A		N	Y	Y			Ministry of Environment and Climate Change Strategy, 2017. Bathymetric Maps. Online Resource. https://catalogue.data.gov.bc.ca/dataset/bathymetric-maps
Surface Water Monitoring Sites	All	All	N/A		N	Y	Y			Ministry of Environment and Climate Change Strategy, 2018. Surface Water Monitoring Sites. Online Resource. https://governmentofbc.maps.arcgis.com/apps/webappviewer/index.html?id=0ecd608e27ec45cd923bdcfeefba00a7
PSCIS Assessments	All	All	N/A		N	Y	Y			Ministry of Environment and Climate Change Strategy, 2017. PSCIS Assessments. Online Resource. https://catalogue.data.gov.bc.ca/dataset/7ecfafa6-5e18-48cd-8d9b-eae5b5ea2881
PSCIS Habitat Confirmations	All	All	N/A		N	Y	Y			Ministry of Environment and Climate Change Strategy, 2017. PSCIS Habitat Confirmations. Online Resource. https://catalogue.data.gov.bc.ca/dataset/572595ab-0a25-452a-a857-1b6bb9c30495
PSCIS Remediation	All	All	N/A		N	Y	Y			Ministry of Environment and Climate Change Strategy, 2017. PSCIS Remediation. Online Resource. https://catalogue.data.gov.bc.ca/dataset/1596afbf-f427-4f26-9bca-d78bceddf485
PSCIS Design Proposal	All	All	N/A		N	Y	Y			Ministry of Environment and Climate Change Strategy, 2017. PSCIS Design Proposal. Online Resource. https://catalogue.data.gov.bc.ca/dataset/0c9df95f-a2da-4a7d-b9cb-fea3e8926661
BC Dams	All	All	N/A		N	Y	Y			Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, 2017. B.C. Dams. Online resource. https://catalogue.data.gov.bc.ca/dataset/b-c-dams
Reservoirs - Permits over Crown Land	All	All	N/A		N	Y	Y			Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, 2017. Reservoir Permits Over Crown Land. Online resource. https://catalogue.data.gov.bc.ca/dataset/reservoir-permits-over-crown-land
Soil Survey Spatial View	All	All	N/A		N	Y	Y			Ministry of Environment and Climate Change Strategy, 2018. Soil Survey Spatial View. Online Resource. https://catalogue.data.gov.bc.ca/dataset/soil-survey-spatial-view
Flood Protection Works Inspection Guide	N/A	N/A	N/A	Flood Protection Works Inspection Guide	Y	N	Y			Minstiry of Environment Lands and Parks, 2000. Flood Protection Works Inspection Guide. https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/integrated-flood-hazard-mgmt/fld_prot_insp_gd.pdf

Location				Project			Hazard Type			Reference
Name	River Basin	District	NTS ID	Project Title	Report? (Y/N)	Spatial information?	Flooding?	Landslide?	Steep Creek?	Citation
EGBC Professional Practice Guidelines for Flood Mapping in BC	N/A	N/A	N/A	Flood Mapping in BC - APEGBC Professional Practice Guidelines V1.0	Y	N	Y			Engineers and Geoscientists of British Columbia, 2017. Flood Mapping in BC - APEGBC Professional Practice Guidelines V1.0. https://www.egbc.ca/getmedia/8748e1cf-3a80-458d-8f73-94d6460f310f/APEGBC-Guidelines-for-Flood-Mapping-in-BC.pdf.aspx
Professional Practice Guidelines for Legislated Flood Assessments in a Changing Climate in BC	N/A	N/A	N/A	Legislated Flood Assessments in a Changing Climate in BC	Y	N	Y			Engineers and Geoscientists of British Columbia, 2012. Legislated Flood Assessments in a Changing Climate in BC. https://www.egbc.ca/getmedia/18e44281-fb4b-410a-96e9-cb3ea74683c3/APEGBC-Legislated-Flood-Assessments.pdf.aspx
Professional Practice Guidelines for Landslide Assessments	N/A	N/A	N/A	Landslide Assessments for Proposed Residential Developments in BC	Y	N	Y			Engineers and Geoscientists of British Columbia, 2010. Landslide Assessments for Proposed Residential Developments in BC. https://www.egbc.ca/getmedia/5d8f3362-7ba7-4cf4-a5b6-e8252b2ed76c/APEGBC-Guidelines-for-Legislated-Landslide-Assessments.pdf.aspx
Global Landslide Catalogue	N/A	N/A	N/A	Global Landslide Catalogue	N	Y		Y	Y	NASA Global Landslide Catalogue, 2018. Online Resource. https://maps.nccs.nasa.gov/arcgis/apps/webappviewer/index.html?id=824ea5864ec8423fb985b33ee6bc05b7
Ministry of Transportation (MOT) Road Structures	All	All	N/A	Ministry of Transportation (MOT) Road Structures	N	Y				Ministry of Transportation and Infrastructure, 2017. Ministry of Transportation (MOT) Road Structures. Online resource. https://catalogue.data.gov.bc.ca/dataset/ministry-of-transportation-mot-road-structures
Ministry of Transportation (MOT) Culverts	All	All	N/A	Ministry of Transportation (MOT) Culverts	N	Y				Ministry of Transportation and Infrastructure 2017. Ministry of Transportation (MOT) Culverts. Online resource. https://catalogue.data.gov.bc.ca/dataset/ministry-of-transportation-mot-culverts
Ministry of Transportation (MOT) Road Features Inventory (RFI)	All	All	N/A	Ministry of Transportation (MOT) Road Features Inventory (RFI)	N	Y				Ministry of Transportation and Infrastructure, 2017. Ministry of Transportation (MOT) Road Features Inventory (RFI). Online resource. https://catalogue.data.gov.bc.ca/dataset/ministry-of-transportation-mot-road-features-inventory-rfi
Ashcroft/Spences Bridge	Thompson	TNRD	N/A	Landslide Damming in the Cordillera of Western Canada	Y	N		Y		Evans, S.G. (1986). Landslide damming in the Cordillera of Western Canada. In R. L. Schuster (Ed.), Landslide dams: processes, risk, and mitigation (pp. 111-130). New York, New York: American Society of Civil Engineers.
Hummingbird Creek	South Thompson	CSRD	082L14	Hummingbird Creek Debris Event July 11, 1997.	Y	N			Y	Ministry of Environent, Lands and Parks, Ministry of Forests, Ministry of Transportation and Highways, Ministry of Attorney General (Interagency Report). (1997). Hummingbird Creek Debris Event July 11, 1997 [Report].
Hummingbird Creek	South Thompson	CSRD	082L14	Stream restoration and restoration alternatives at Hummingbird Creek, Mara Lake, B.C.	Y	N			Y	EBA Engineering Consultants Ltd. & Kerr Wood Leidal Associates Ltd. (1998). Stream restoration and restoration alternatives at Hummingbird Creek, Mara Lake, B.C. [Report]. Prepared for Ministry of Environment, Lands, and Parks.
Salmon Arm	South Thompson	CSRD	082L064	Geotechnical & Environmental Assessment Modified Area B Comprehensive Development Plan Salmon Arm, British Columbia.	Y	N			Y	Golder Associates Ltd. (1998). Geotechnical & Environmental Assessment Modified Area B Comprehensive Development Plan Salmon Arm, British Columbia [Report]. Prepared for T.R. Underwood Engineering Ltd.
Fall Creek	South Thompson	RDNO	082L056	Debris Flow Hazard Assessment Fall Creek Slide Area	Y	N			Y	Thurber Consultants Ltd. 1990. Debris Flow Hazard Assesement Fall Creek Slide Area [Report]. Prepared for Provincial Emergency Program Ministry of Solictor General.
Cache Creek/ Ashcroft/ Bonaparte Valley	Thompson	TNRD	092I	Post-wildfire Natural Hazards Risk Analysis Elephant Hill Wildfire (K20637, 2017)	Y	N			Y	SNT Geotechnical Ltd. (2017). Post-wildfire Natural Hazards Risk Analysis Elephant Hill Wildfire (K20637, 2017) [Report]. Prepared for BC Ministry of Forests, Lands, and Natural Resource Operations and Rural Development.
Sorrento	South Thompson	CSRD	082L083		Y	N	Y			Onsite Engineering Ltd. (2018, August 14). Flood Hazard Assessment for the Development at 1374 Gillespie Rd, Sorrento, BC. Legal address: Lot 2, Section 15, Township 22, Range 11, W6M, KDYD, Plan 24433.

APPENDIX B
HAZARD ASSESSMENT METHODOLOGY: CLEAR-WATER FLOODS

B.1. INTRODUCTION

B.1.1. Objective

This appendix describes the approach used by BGC Engineering Inc. (BGC) to identify and characterize clear-water flood geohazards within the Thompson River watershed (TRW). The results form the basis to assign hazard and consequence ratings to prioritize flood-prone areas in proximity to developed areas within the study area.

This appendix is organized as follows:

- Section B.1 provides background information and key terminology
- Section B.2 describes methods and data sources used to identify and characterize areas
- Sections B.3 describes methods used to assign priority ratings.

Appendices C and D describes the approach used by BGC to identify and characterize steep creek geohazards and landslide dams within the TRW. Appendix E provides a detailed list of the elements at risk and the exposure assessment methodology. The main report describes how geohazard and consequence ratings were combined to prioritize each geohazard area.

B.1.2. Context

Damaging floods are common in the TRW. Areas most susceptible to flood-related losses include settled valley bottoms such as the communities located along the Thompson Rivers, and areas where lifeline infrastructure traverse floodplains. While the TRW has historical precedent for flooding, recent floods around the Kamloops area in 2017 (Figure B-1) and the post-wildfire flood events of 2018 near Cache Creek have highlighted the need for a coordinated, watershed scale approach to flood management in the TRW.

Figure B-1. Damage from flooding of Noble Creek in Kamloops, BC (CFJC Today, May 5, 2017).

Although flooding can happen at any time of the year, the most severe flooding in the TRW occurs during the spring freshet due to an accumulation of heavy rain and snowmelt at higher elevations. In the wide-valley bottoms of the region, flood waters tend to rise slowly in response to a precipitation event and recede after a period of time, while in mountainous areas of the region, floods can occur within hours, transport large volumes of debris and quickly erode their banks. In the TRW, most stream channels are small, tributary creeks subject to steep creek processes that can carry larger volumetric concentrations of debris (i.e., debris floods and debris flows) than clear-water floods.

Excessive rainfall or snowmelt over an extended period can cause a stream or river to exceed its natural or engineered capacity. Overbank flooding occurs when the water in the stream or river exceeds the banks of the channel and inundates the adjacent floodplain in areas that are not normally submerged (Figure B-2).

The severity of a flood event can vary considerably depending on:

- The amount and duration of the precipitation (rain and snowmelt) event
- The antecedent moisture condition of the soils
- The size of the watershed
- The floodplain topography
- The effectiveness and stability of flood protection measures.

Climate change also has the potential to impact the probability and severity of flood events by: augmenting the frequency and intensity of rainfall events; altering snowpack depth, distribution, timing, snow water equivalent, and freezing levels; and causing changes in vegetation type, distribution and cover. Impacts are likely to be accentuated by increased wildfire activity and/or insect infestations (MOE, June 2016). Additional discussion on climate change impacts in the TRW are provided in Appendix F.

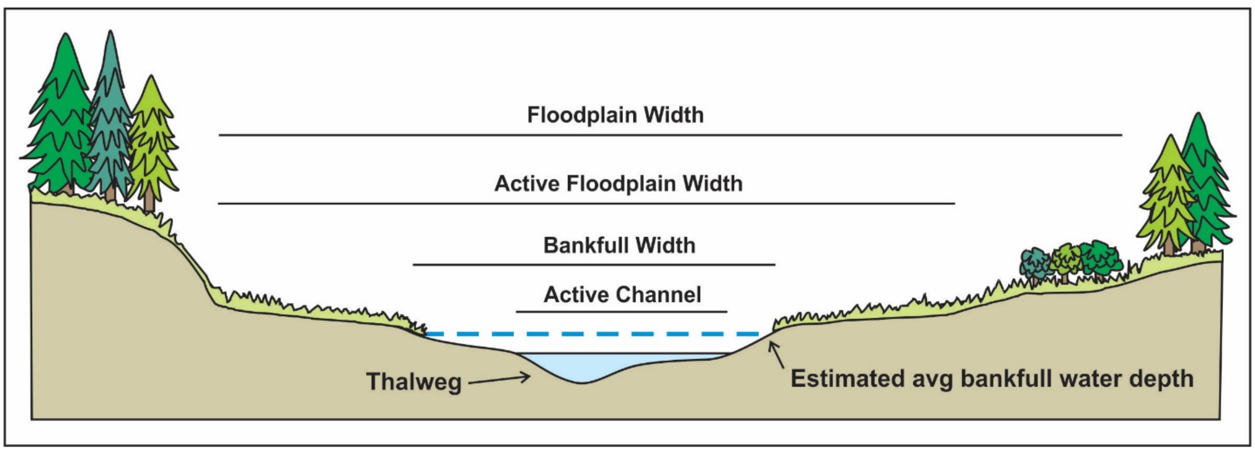

Figure B-2. Conceptual channel cross-section in a typical river valley.

In BC, the 200-year return period flood is used to define floodplain areas, with the exception of the Fraser River, where the 1894 flood of record is used, corresponding to an approximately 500-year return period (EGBC 2017). The 200-year flood is the annual maximum river flood discharge (and associated flood elevation) that is exceeded with an annual exceedance probability (AEP) of 0.5% or 0.005. While flooding is typically associated with higher return events, such as the 200-year return period event, lower return period events (i.e., more frequent and smaller magnitude events) have the potential to cause flooding if the banks of the channel are exceeded. A flood event that has the potential to cause damage to property and/or loss of life is considered a *hazardous flood*.

Flood maps provide information on the hazards associated with defined flood events, such as water depth, velocity, and duration of flooding, and the probability of occurrence. These maps are used as a decision-making tool for local and regional governments during floods or for planning purposes.

Flood risk combines the probability of a hazardous flood occurring and the consequences to elements at risk. Flood mitigation measures have the potential to reduce the risk associated with hazardous floods. These measures can be broadly defined as structural such as flood protection infrastructure (e.g., dikes or diversions) or non-structural such as emergency response, resiliency and land-use planning. Identifying and prioritizing flood-prone areas is an important step towards improving flood management planning within the TRW.

B.1.3. Terminology

This appendix refers to the following key definitions[1]:

- **Annual Exceedance Probability (AEP):** chance that a flood magnitude is exceeded in any year. For example, a flood with a 0.5% AEP has a one in two hundred chance of being exceeded in any year. AEP is increasingly replacing the use of the term ‘return period’ to describe flood recurrence intervals.
- **Clear-water floods:** riverine and lake flooding resulting from inundation due to an excess of clear-water discharge in a watercourse or body of water such that land outside the natural or artificial banks which is not normally under water is submerged.
- **Consequence:** damage or losses to an element-at-risk in the event of a specific hazard.
- **Flood Construction Level (FCL):** a designated flood level plus freeboard, or where a designated flood level cannot be determined, a specified height above a natural boundary, natural ground elevation, or any obstruction that could cause flooding.
- **Flood mapping:** delineation of flood lines and elevations on a base map, typically taking the form of flood lines on a map that show the area that will be covered by water, or the elevation that water would reach during a flood event. The data shown on the maps, for more complex scenarios, may also include flow velocities, depth, or other hazard parameters.
- **Flood setback:** the required minimum distance from the natural boundary of a watercourse or waterbody to maintain a floodway and allow for potential bank erosion.
- **Hazardous flood:** a flood that is a source of potential harm.

[1] CSA (1997); EGBC (2012, 2017).

- **Risk**: a measure of the probability of a specific flood event occurring and the consequence
- **Steep-creek floods:** rapid flow of water and debris in a steep channel, often associated with avulsions and bank erosion and referred to as debris floods and debris flows.
- **Strahler stream order:** is a classification of stream segments by its branching complexity within a drainage system and is an indication of the significance in size and water conveying capacity at points along a river as described in Section B.2.1.
- **Waterbody:** ponds, lakes and reservoirs.
- **Watercourse:** creeks, streams and rivers.

B.1.4. Approach Overview

Historical flood events that have occurred within the TRW are generally due to riverine flooding from rainfall, snowmelt and glacial runoff processes. However, flooding can also be triggered from other mechanisms such as: ice or large woody debris jams; undersized watercourse crossings; structural encroachments into flood-prone areas; channel encroachment due to bank erosion; wind- or landslide-generated waves; failure of engineered structures; or, landslide, glacial, moraine or beaver dam outbreak floods.

The focus of the clear-water flood hazard assessment for the TRW is on riverine and lake flooding from precipitation (rainfall or snowmelt driven melt) within natural watercourses and lakes and does not consider flooding due to other mechanisms such as failure of engineered structures (e.g., dams and dikes), or overland urban/sewer-related flooding. Methods for assessing landslide-dam outbreak flooding are summarized in Appendix D and were prioritized separately to clear-water flood hazard areas.

Historical floodplain maps have been developed for select areas of the TRW based on the designated flood as represented by the 200-year return period event or AEP of 0.5% (MFLNRO, 2016). These floodplain maps are the basis for this prioritization study, along with a review of historical flood events and a prediction of floodplain extents for natural watercourses and lakes in the TRW where historical floodplain mapping is unavailable. The floodplain maps and predicted floodplain extent are shown on the web application accompanying this report.

Table B-1 summarizes the approaches used to identify and characterize clear-water flood hazard areas. In this study, flood areas were identified from the following spatial sources (Figure B-3):

1. Inventory of historical flood event locations.
2. Existing historical and third-party floodplain mapping.
3. Prediction of floodplain extents for streams, rivers and lakes.

Table B-1. Summary of clear-water flood identification approaches.

Approach	Area of TRW Assessed	Application
Geohazard process type identification	All mapped watercourses	Classification of each watercourse segment as dominantly subject to clear-water floods, debris floods, or debris flows.
Historical flood event inventory	All watercourses and waterbodies prone to clear-water flooding	Identification of creeks and rivers with historical precedent for flooding and location of 2018 spring freshet events. The historical flooding locations are approximate locations where known landmarks adjacent to a watercourse were flooded, or specific impact to structures (roads, houses) was reported in media.
Existing floodplain mapping	All watercourses and waterbodies prone to clear-water flooding where existing information was available.	Identification of floodplain extents from publicly available historical mapping and 3rd party data sources.
Floodplain extent predication for lakes and streams	All lakes and streams without existing floodplain mapping and a Strahler stream order of 4 or greater	Identification of low-lying areas adjacent to streams using a topographic elevation offset applied to mapped centrelines.
	All watercourses and waterbodies without existing floodplain mapping and a Strahler stream order of 3 or less	Identification of low-lying areas adjacent to streams using a 30 m horizontal buffer applied to mapped centrelines.
Lake level prediction	All lakes with active gauge stations	Lake levels or elevations predicted for the 200-year return period event (AEP of 0.5%)

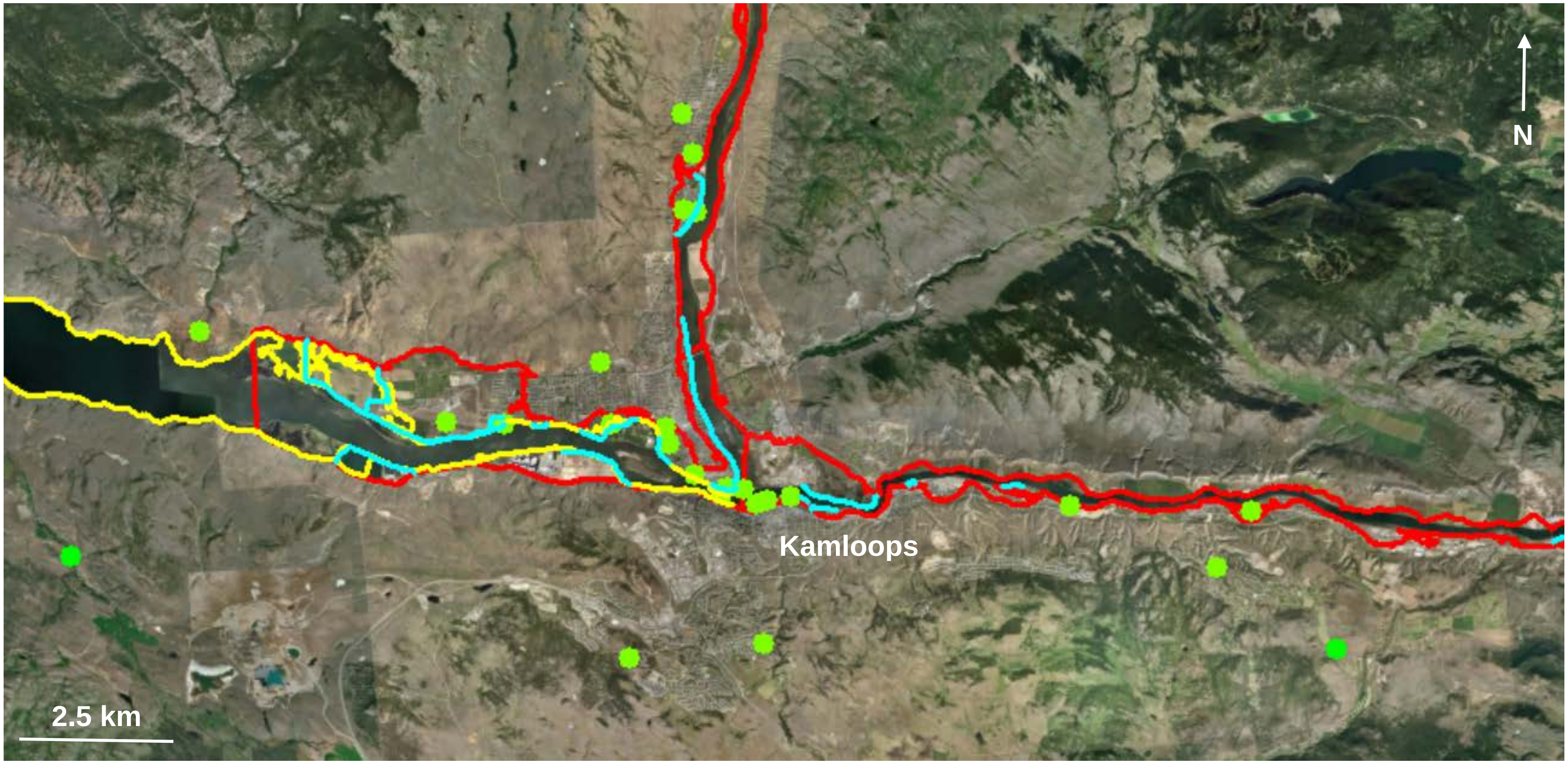

Figure B-3. Example spatial sources used to identify clear-water flood hazards in the TRW including historical floodplain mapping (red line), predicted lake levels for the 200-year flood event (yellow line) and past flood event locations (green dots). Locations of known flood protection structures (blue line) were inventoried but not prioritized. Refer to Section B.2.6 for a description of the predicted floodplain extents for streams and lakes without existing floodplain mapping.

B.2. CLEAR-WATER FLOOD GEOHAZARD CHARACTERIZATION

The following sections describe methods and data sources used to identify and characterize clear-water flood geohazard areas as summarized in Table B-1.

B.2.1. Stream Network

BGC's proprietary River Network Tools (RNT™) is a web-based application for analysis of hydrotechnical geohazards associated with rivers and streams. The basis for RNT is a digital stream network that is used to evaluate catchment hydrology, including delineating catchment areas and analysing flood frequencies over large geographical areas. RNT incorporates hydrographic data with national coverage from Natural Resources Canada's (NRCan's) National Hydro Network (NHN) at a resolution of 1:50,000 (NRCan, 2016). The publicly available stream network is enhanced by BGC-proprietary algorithms within the RNT database to ensure the proper connectivity of the stream segments even through complex braided sections. Modifications to the stream network within the RNT are made as necessary based on review of satellite imagery (e.g., Google Earth™) at approximately 1:10,000 scale.

In the RNT, the stream network is represented as a series of individual segments that includes hydraulic information such as:

- A water flow direction
- The upstream and downstream stream segment connections
- A local upstream catchment area for each stream segment (used to calculate total catchment area)
- A Strahler stream order classification (Strahler, 1952)
- A local channel gradient, which is determined using a topographic dataset to assess the elevation differential between the upstream and downstream limit of the segment.

Strahler stream order is used to classify stream segments by its branching complexity within a drainage system and is an indication of the significance in size and water conveying capacity at points along a river (Strahler, 1952). Strahler order 4 and higher streams are typically larger streams and rivers (e.g., Thompson River), while Strahler order 3 and lower streams are typically smaller, headwater streams (e.g., Sicamous Creek). An illustration of Strahler stream order classification is shown in Figure B-4 and described conceptually for the TRW in Table B-2. Strahler stream order was used to determine the method applied to predict the potential floodplain extents for streams and rivers within the study area as described in Section B.2.6.

BGC supplemented these data with 1:50,000-scale CanVec digital watercourse linework to represent lakes and reservoirs and 1:20,000 scale GeoBase digital elevation models (DEMs; NRCan, January 25, 2016) to generate catchment areas and a local stream gradient for each segment in RNT. Dam locations were represented using the inventory provided by the BC Ministry of Forests, Lands and Natural Resource Operations (MFLNRO, 2017a).

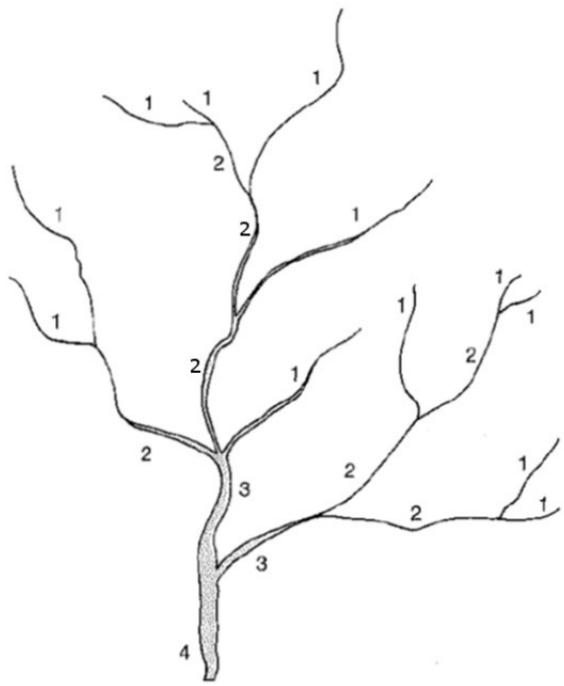

Figure B-4. Illustration showing Strahler stream order (Montgomery, 1990).

Table B-2. Strahler order summary for the TRW stream network.

Strahler Order	Description	% of TRW Stream Segments	TRW Examples
1 – 3	Small, headwater streams generally on steeper slopes and typically subject to steep-creek processes (debris floods/ flows). Channel may be dry for a portion of the year. They are tributaries to larger streams and are typically unnamed.	85	Ashton Creek, Hummingbird Creek, Sicamous Creek
4 – 6	Medium stream or river. Generally, less steep and lower flow velocity than headwater streams.	13	Hefley Creek, Knouff Creek, Bessette Creek, Salmon River
7+	Large river. Larger volumes of runoff and potentially debris conveyed then from smaller waterways.	2	Barriere River, Clearwater River, North and South Thompson Rivers

RNT also contains hydrometric data collected from Water Survey of Canada (WSC) stations across Canada. An estimation of flood discharge magnitude and frequencies for multiple return periods (2-year up to the 1 in 200-year event) are determined for each stream segment using a flood frequency analysis (FFA) approach as described in Section B.2.7. In RNT, flood quantiles are either pro-rated from a nearby single gauge or estimated by regional FFA from multiple gauges. A total of 391 WSC gauges stations are located within the TRW (ECCC, July 16, 2018). Of these gauges, 51 are active and 340 are discontinued stations. Of the 51 active stations, 37 are also used for real-time flood monitoring (Figure B-5).

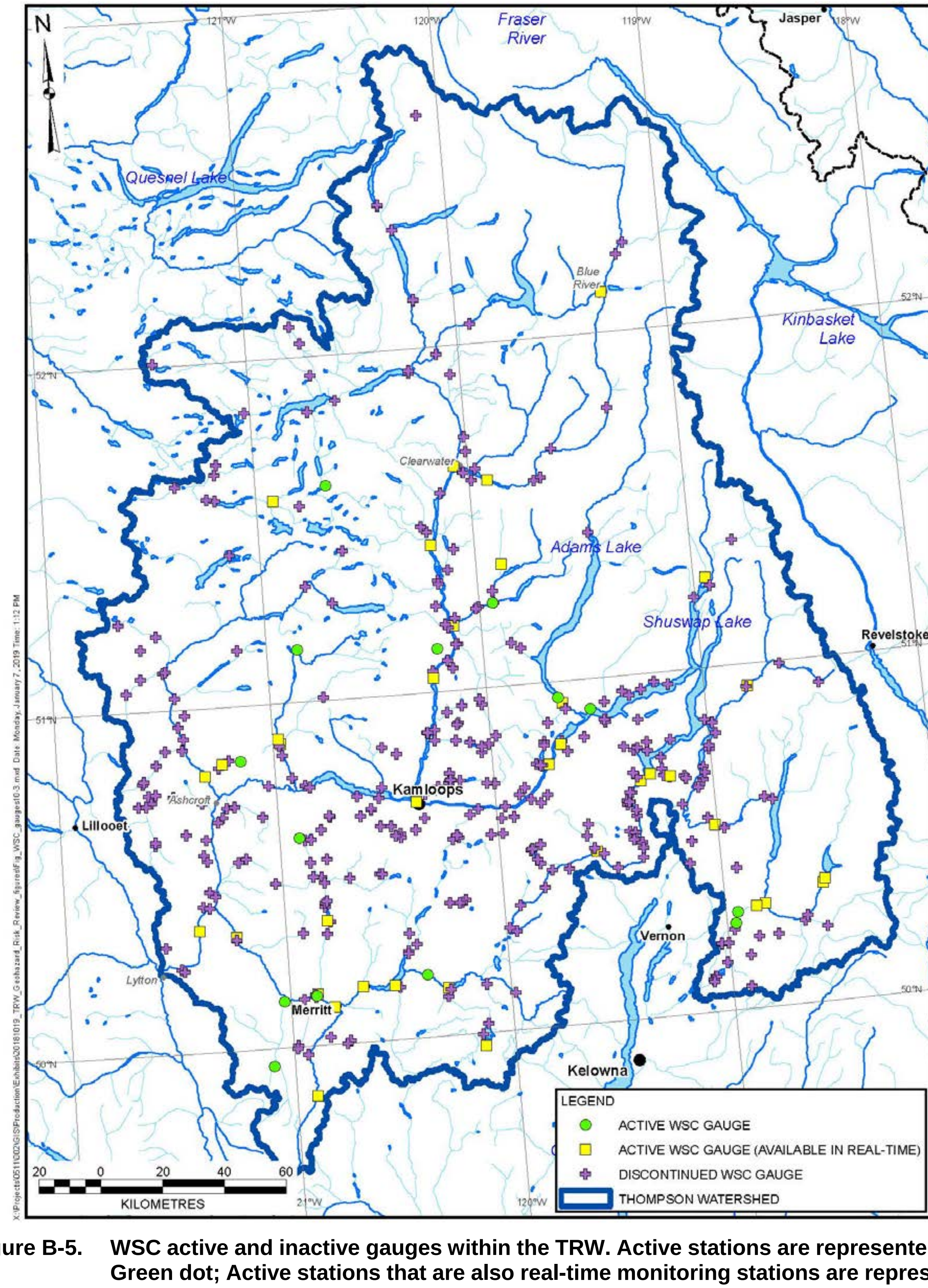

Figure B-5. **WSC active and inactive gauges within the TRW. Active stations are represented by a Green dot; Active stations that are also real-time monitoring stations are represented by a Yellow square; and Discontinued stations are represented by a Purple cross.**

B.2.2. Geohazard Process Type

Every mapped stream segment in the TRW, from small tributary creeks to large rivers, was assigned a predicted process type (flood, debris-flood or debris flow) based on statistical analysis of Melton Ratio[2] and watershed length[3]. These terrain factors are a useful screening-level indicator of the propensity of a creek to dominantly produce clear-water floods, debris floods or debris flows (Wilford et al., 2005; Jakob et al., 2015; Holm et al., 2016). The typical watershed characteristics that differentiate between these processes are shown in Table B-3. The web map displays every stream segment in the TRW and its associated predicted geohazard process type (clear-water flood, debris flood or debris flow).

Table B-3. Class boundaries using Melton ratio and total stream network length.

Process	Melton Ratio	Stream Length (km)
Clear-water flood	< 0.2	all
Debris flood	0.2 to 0.5	all
	> 0.5	> 3
Debris flow	> 0.5	≤ 3

The advantage of a statistically-based classification is that it can be applied to large regions. However, classification reliability is lower than detailed studies, which typically combine multiple lines of evidence such as statistical, remote-sensed, and field observation data. In this study, process type identification should be considered more reliable for creeks with mapped fans than those without mapped fans.

Classifying every stream segment in the TRW into one of three likely process-types (i.e., clear-water, debris-flood or debris flow hazards) also does not recognize that there is a continuum between clear-water floods and steep-creek processes that is not accounted for in morphometrics. A site may be transitional between two process-types, for example, a longer watershed that would be classified as debris flood could still produce debris flows if there's a landslide-inducing processes in a hanging valley near the fan apex. To capture this uncertainty, a probabilistic approach[4] was also used to determine the likelihood that a stream segment falls within each of the three categories, as shown for one site in Figure B-6. Results of the probabilistic analysis were considered in the classification of clear-water flood hazards interpreted as transitional between clear-water and debris flood process types, and can help inform more detailed hazard assessments in future.

[2] Melton ratio is watershed relief divided by the square root of watershed area (Melton, 1957).

[3] Stream network length is the total channel length upstream of a given stream segment to the stream segment farthest from the fan apex or watershed outlet.

[4] An ensemble method that applies learning algorithms to construct a set of classifiers based on the results from six different statistical models (Logistic Regression, Linear Discriminant Analysis, KNN, SVM, Random Forest, Naïve Bayes) was used to re-classify the new data points by taking a (weighted) vote of their predictions. The models are assumed to be independent from each other and their results combined are expected to have a higher accuracy than any of the models on its own (Dietterich, 2000).

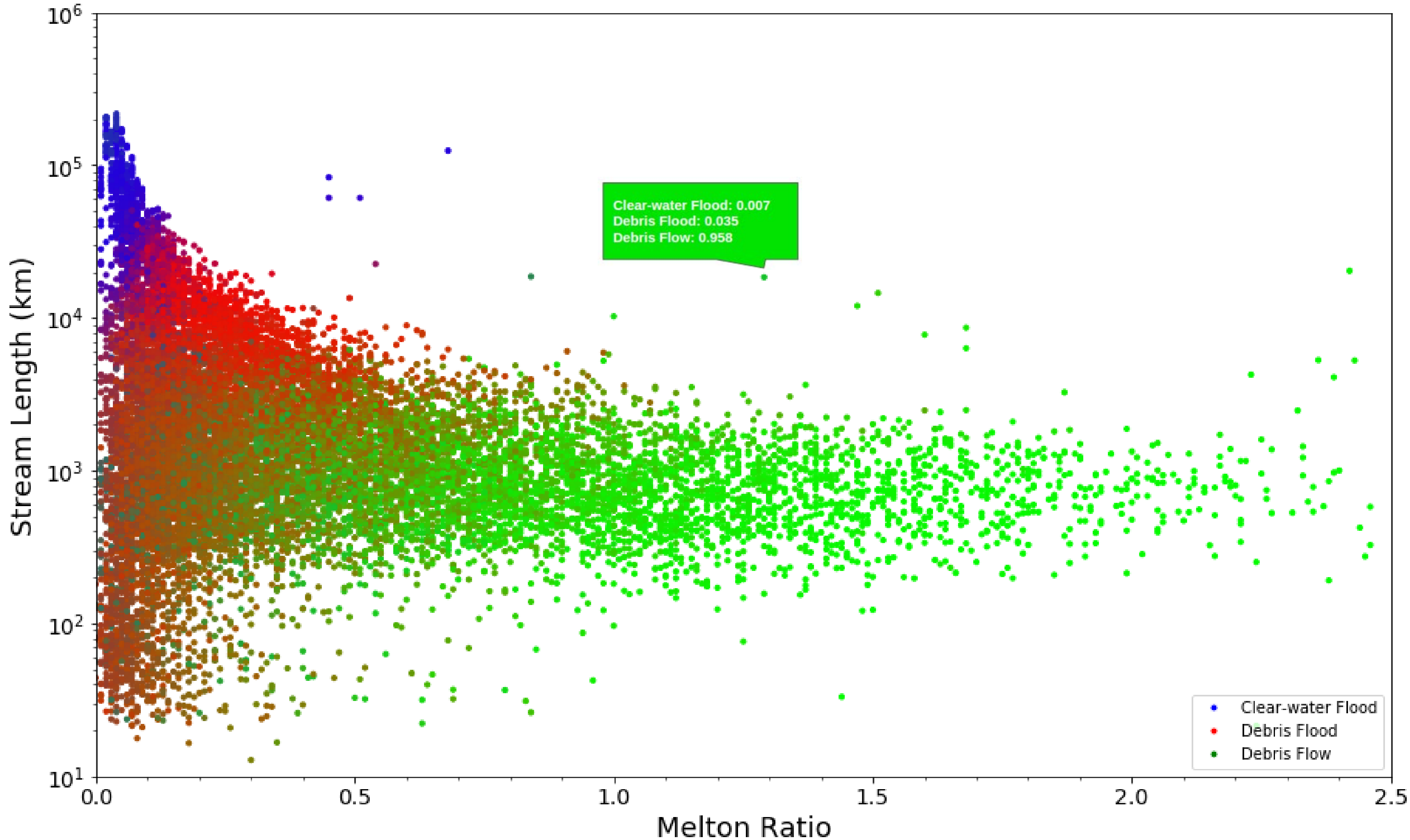

Figure B-6. Geohazard process-types identified for a subset of the TRW stream segments based on stream length (km) and Melton Ratio. Probabilities associated with the identified process type are shown for one predicted debris flow site.

B.2.3. Alluvial Fan Inventory

A fan inventory was developed for the TRW as part of the steep creek geohazard identification process (refer to Appendix C). The boundaries of alluvial fans were used to define fan geohazard areas prioritized in this study. A total of 108 out of the 1150 mapped fans were identified as intersecting streams with an identified clear-water flood process-type in the study area. However, these fans were prioritized using methods described in the steep creek appendix and were therefore not considered in the clear-water flood prioritization.

B.2.4. Historical Flood Event Inventory

BGC compiled a historical flood, steep creek, and landslide dam inventory across the TRW and digitized the locations of historical events from Septer (2007), DriveBC (Ministry of Transportation and Infrastructure (MoTI), n.d.), and 2018 freshet-related floods and landslides sources (e.g., media reports). BGC also considered the hazard sites identified in the Community to Community Forum between FBC and the TRW stakeholders (Fraser Basin Council, February 14, 2018). Historical flood events such as the event shown in Figure B-7 were used to confirm flood-prone low-lying terrain outside of the historical floodplain maps. Clear-water flood hazard areas were intersected with the flood event inventory compiled by BGC to identify areas with greater potential susceptibility to flooding. Geohazard ratings were increased a category (e.g., low to moderate) for clear-water hazard areas that intersected a past flood event location.

Figure B-7. Flood event of June 2, 1972 when dikes along the North Thompson River failed and sent flood water into the Oak Dale Trailer Park in Westsyde, near Kamloops BC. (CFJC Today, June 2, 2017).

A vertical column located in Riverside Park's High Water Plaza adjacent to the banks of the South Thompson River in Kamloops BC, provides a visual reminder of four past significant flood events; including the largest flood event on record in 1894. The four events from bottom to top on the column include 1999, 1948, 1972, and 1894 (Figure B-8).

Figure B-8. High water mark monuments adjacent to the South Thompson River in Kamloops BC. (CFJC Today, June 1, 2017).

The historical flooding locations presented on the web map are approximate locations where known landmarks adjacent to a watercourse were flooded, or specific impact to structures (roads, houses) was reported in media. For example, a certain park flooding in Kamloops, or a house being inundated by gravel from a debris flood. Flooding events are indicated as a point location and therefore do not represent the full extent of flooding on a watercourse (e.g., Figure B-3). Additional details on the historical flood event inventory are provided in Appendix G.

B.2.5. Existing Floodplain Mapping

B.2.5.1. Historical Mapping Sources

The BC government provides publicly-available information on the location of floodplains, floodplain maps and supporting data (MFLNRO, 2016). A provincial floodplain mapping program began in BC in 1974, aimed at identifying flood risk areas. This was in part due to the large Fraser River flood of 1972, which resulted in damage in the BC Interior (particularly on the North Thompson River near Kamloops, BC).

From 1975 to 2003, the Province managed development in designated floodplain areas under the Floodplain Development Control Program. From 1987 to 1998, the rate of mapping increased through the Canada/British Columbia Agreement Respecting Floodplain Mapping. The agreement provided shared federal–provincial funding for the program and included provisions for termination of the agreement as of March 31, 2003. This mapping was generally focused on major rivers as summarized in Table B-4. While the maps are now outdated, their use is promoted by the MFLNRO as often representing the best floodplain mapping information available (EGBC, 2017).

The historical floodplain maps typically show both the extent of inundation and flood construction levels (FCLs) based on the 0.5% AEP or 200-year return period event and include a freeboard allowance. At select locations, the 5% AEP or 20-year return period flood elevation (including a freeboard allowance) was also provided for septic tank requirements under the Health Act at the time. Flood levels associated with the 0.5% AEP (including a freeboard allowance) have been used to establish design elevations for flood mitigation works and to inform local floodplain management policy and emergency preparedness. The historical flood maps do not consider the occurrence and location of flood protection measures in the map extents.

Historical floodplain mapping within the TRW is, on average, 30 years old and as a result does not:

- Reflect the full data record available for hydrometric stations within the watershed since the mapping was conducted. Estimates of the 200-year return period flood have likely changed since there are now an additional 20+ years of hydrometric records.
- Reflect potential changes in channel planform and bathymetry (e.g., aggradation and bank erosion as well as channel changes and avulsion paths formation), or development within the floodplain that could alter the extent of inundation.
- Accuracy is limited to the resolution of the input data. Mapping predates high resolution LiDAR surveys and hydraulic analysis was generally limited to 1-dimensional (1D) analysis.
- Consider climate change impacts on flooding (directly by predicted changes in rainfall and/or snowmelt and indirectly by changes in vegetation cover through wildfires and/or insect infestations).
- Consider the presence of flood protection measures such as dikes or embankments, if applicable, and does not consider flood scenarios associated with failure of these structures (e.g., dike breaches, which would result in different flood inundation patterns, depths and velocities than if water levels rose in the absence of dikes).

The quality and accuracy of the historical floodplain mapping was not evaluated as part of this prioritization study. Further, freeboard and flood protection measures such as dike protections have not been evaluated or considered in the geohazard or consequence ratings applied in this project.

Table B-4. Summary of historical floodplain mapping within the TRW.

Site No.[1]	Watercourse (Area)	District	Approximate Floodplain Area (km^2)	Approximate Floodplain Length (km)	Floodplain Map Year	Flood Protection Measures?	Recorded Historical Flood Events	Comments
1	Thompson River (Kamloops Area)	TNRD	35.2	12	1976, 2004	Yes	1894, 1928, 1948, 1972, 1990, 1997, 1999, 2012	City of Kamloops updated floodplain maps in 2004. Portion of Tk'emlups te Secwepemc reserve land had floodplain mapped in 2004. The 2004 mapping was accepted by the Province as the official floodplains (BCREA, October 2015).
2	North Thompson (Vavenby to Kamloops)	TNRD	210.8	120	1982	Yes	1894, 1928, 1948, 1972, 1990, 1997, 1999, 2012	TNRD is currently undertaking official community plan in North Thompson. The river is prone to ice jams.
3	South Thompson River (Kamloops to Chase)	TNRD	39.6	50	1976, 2004	Yes	1894, 1928, 1948, 1972, 1990, 1997, 1999, 2012	City of Kamloops updated floodplain maps in 2004. A portion of Tk'emlups te Secwepemc reserve land had floodplain mapped in 2004. The 2004 mapping was accepted by the Province as the official floodplains (BCREA, October 2015).
4	Shuswap River (Mara Lake to Mabel Lake)	RDNO	62.9	50	1980, 2012	Yes	1983, 1990, 1997, 1999, 2012, 2018	Flooding at the northern extent of Shuswap River is influenced by Mara Lake levels. In 1990 and 1997 some of the flood events were debris flows and debris floods in tributaries adjacent to floodplain triggered by intense rainfall. There is frequent flooding of Highway 97A near Grindrod. City of Enderby completed floodplain mapping for the Shuswap River in 2012 (FBC, February 14, 2018).
5	Nicola/Coldwater Rivers (Nicola Lake to Spences Bridge)	TNRD	53.0	78	1989	Yes	1894, 1922, 1954, 1974, 1980, 1984, 1991, 1997, 2002, 2017, 2018	Debris and sediment pile up at the mouth of Nicola River at Spences Bridge. LiDAR was collected in 2016 for City of Merritt. Stump Lake previously flooded in 2017 and TNRD is assessing options to manage Stump Lake water levels. Many of the areas in Nicola/Merritt Valley were impacted by 2017 and 2018 flooding resulting in temporary installation of emergency protection structures (e.g., Guichon Creek). First Nations completed a 2015 hydrological study and has funds for mitigation planning (FBC, February 14, 2018).
6	Eagle River (Malakwa to Sicamous)	CSRD	34.0	35	1979	Yes	1967, 1972, 1982, 2012	Flooding at the western extent of Eagle River is influenced by lake levels on Shuswap and Mara Lakes. The costs for flooding damage in Sicamous area (including steep creeks on Sicamous and Hummingbird Creeks) totaled approximately $3.8M (Public Safety Canada, n.d.). Sicamous completed a hydrological connectivity study and applied for flood mitigation funding for Sicamous Creek.

Site No.[1]	Watercourse (Area)	District	Approximate Floodplain Area (km^2)	Approximate Floodplain Length (km)	Floodplain Map Year	Flood Protection Measures?	Recorded Historical Flood Events	Comments
7	Salmon River (Falkland to Salmon Arm)	CSRD	47.6	50	1991/1992, 2011	No	1894, 1972, 1999, 2018	Flooding at the northern extent of Salmon River is influenced by lake levels on Shuswap Lake. Adams Lake Indian Band is currently conducting climate modelling for Chase Creek, Salmon River, and others. Lower reaches around Salmon Arm have updated floodplain mapping (2011).
8	Shuswap River, Bessette & Duteau Creeks	RDNO	43.4	20	1998	Yes	1983, 1997, 1999, 2012, 2018	Flooding at the northern extent of Shuswap River is influenced by Mabel Lake levels and the Shuswap Falls dam. Regional District of North Okanagan applied for structural mitigation upgrade funding. Village of Lumby secured funding for floodplain mapping in 2017. In May 2017, approximately 7.7 km of creek banks and earthworks were installed for emergency flood response.
9	Bonaparte River (Cache Creek)	TNRD	35.0	35	1996	Yes	1866, 1875, 1880, 1990, 1997, 1999, 2015, 2017, 2018	Flooding in 1990 caused approximately $100,000 in damage (Septer, 2007). 40% of Bonaparte River catchment was burned in 2017 Elephant Hill wildfire (SNT 2017). Existing floodplain mapping limited to Cache Creek and could be extended to Ashcroft. Cache Creek has secured funding for flood mapping studies with anticipated completion Spring 2019 (FBC, February 14, 2018).
10	Seymour River at Seymour Arm[2]	CSRD	12.7	8	1989	No	Unknown – no historical accounts	Provincial floodplain designation has been withdrawn and mapping information is not accessible on iMapBC (Government of BC, 2016). No additional information was available on the reason why the map was withdrawn.
11	Spius Creek	TNRD	0.8	2	1989	No	1997	Developed as part of Nicola/Coldwater Rivers floodplain maps but identified as unique floodplain in digital floodplain dataset. Fire-related disturbance/aggradation event prior to 1960.

Notes:
1. Refer to **Figure B-9** for floodplain location.
2. Floodplain map indicated as withdrawn from Government of BC website [accessed July 11, 2018]. BGC contacted the Ministry of Environment for the reason the map was removed but did not receive a response at the time of writing.

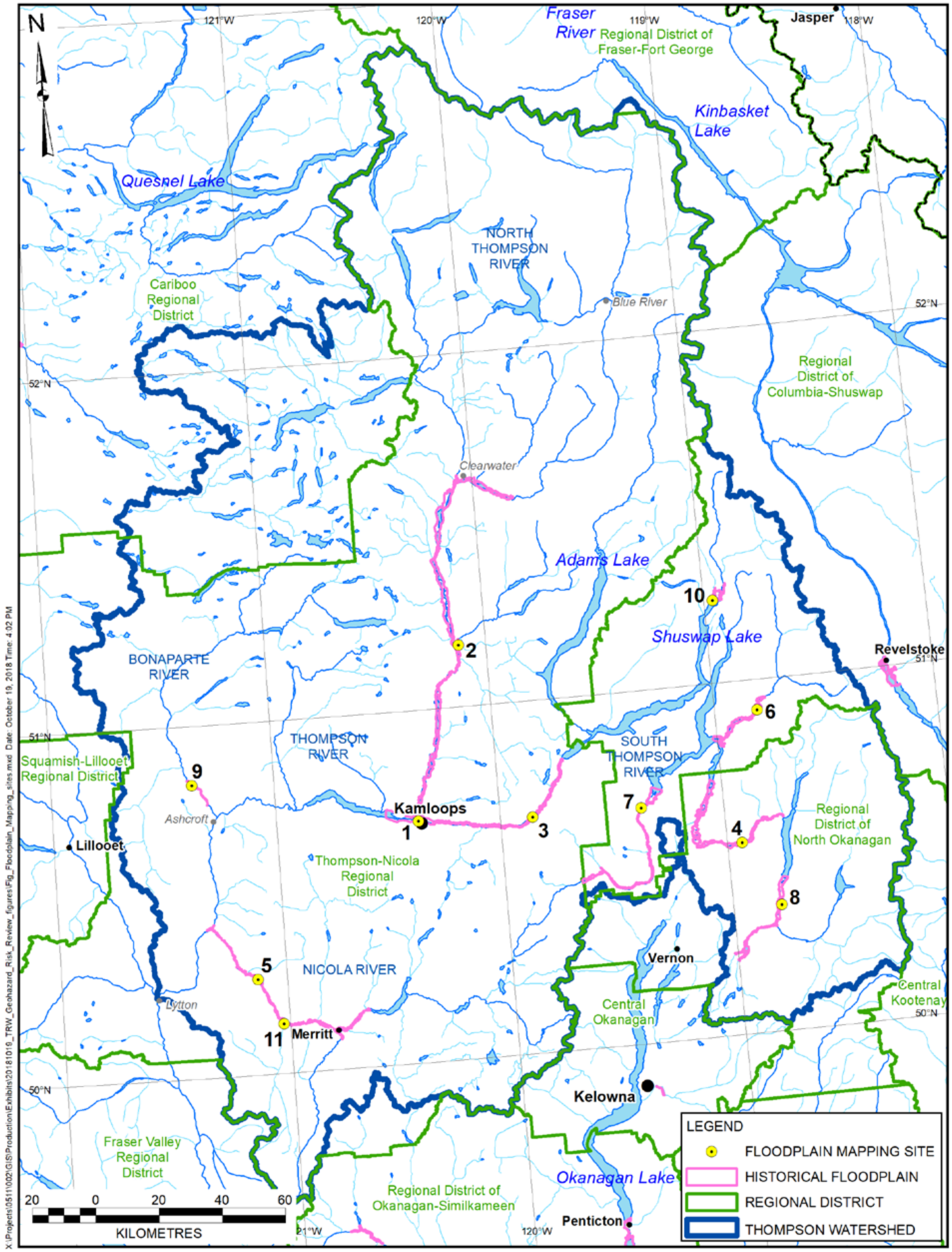

Figure B-9. Historical floodplain mapping in the TRW.

B.2.5.2. Third-party Mapping Sources

BGC is aware of the following floodplain mapping completed by third parties (private consultants) that post-dates historical mapping. The mapping shown in bold was available in geospatial (GIS) format and incorporated into this study:

- **City of Kamloops (updated 2004; CoK, April 17, 2017[5])**
- **City of Salmon Arm (updated November 14, 2011)**
- **Village of Lumby (awarded 2017; MoTI, March 22, 2017)**
- **City of Enderby (updated 2012; FBC, February 14, 2018).**
- Village of Cache Creek (awarded 2017; MoTI March 27, 2017, anticipated Spring 2019).

As a result of the limited existing floodplain mapping available within the TRW, BGC developed an approach to predict floodplain extents for locations where historical floodplain mapping was not available as described in Section B.2.6.

B.2.6. Floodplain Extent Prediction

A topographic analysis was conducted to provide a screening-level estimate of floodplain extent, in areas where historical floodplain mapping was unavailable. Two approaches were used to predict the potential floodplain extent for mapped watercourses and varied depending on the size of the watercourse. These approaches included:

1. A vertical offset model to identify potential low-lying areas for lakes and larger watercourses (Strahler order 4 or higher).
2. A horizontal buffer model to identify potential low-lying areas for smaller watercourses (Strahler order 3 or lower).

The difference in approaches for larger and smaller watercourses was an artifact of the resolution of the spatial data compiled, as described in the sections below.

B.2.6.1. Vertical Offset Model for Lakes and Larger Watercourses

A GIS-based approach was used to identify geographical low-lying areas adjacent to mapped watercourses and lakes within the TRW to represent potential flood inundation extents for watercourses without existing historical floodplain or 3rd party mapping information. This approach was modified from Zheng et al., (2018) and applied to each lake and watercourse with a Strahler stream order classification of 4 or higher.

The surrounding valley topography for each watercourse was represented using a watershed-wide DEM as described in Section B.2.1 and intersected with the RNT stream network to identify the geographical location of the watercourses. A 4.0 m vertical offset was applied to the base stream elevation for each mapped watercourse to represent an elevated stream surface relative to the surrounding topography (Figure B-10). In the absence of existing floodplain mapping, this

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[5] City of Kamloops updated extent and depth for 20 and 200-year floodplain map in 2004. Results of the update were accepted by the Province as the official floodplains for the City (BC Real Estate Association, 2015).

surface represents a “high-water level” estimate used to define topographic low-lying areas adjacent to watercourses that are potentially subject to flood inundation.

The offset modelling results were compared to existing floodplain mapping in the region (e.g., Figure B-11). A 4.0 m offset was selected by comparing automated results to floodplain extents generated from previous hydraulic modelling conducted within the watershed (e.g., City of Salmon Arm, November 14, 2011) as shown on Figure B-11. Vertical offset modelling results for the Salmon Arm floodplain were also consistent with flood hazard maps derived from a coarse scale (90 m grid cell resolution), global physical flood model developed by FM Global (2018).

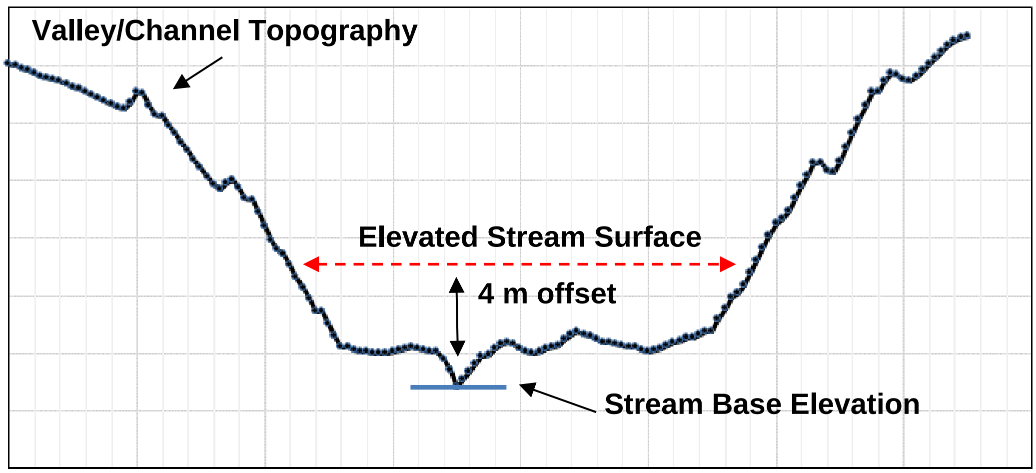
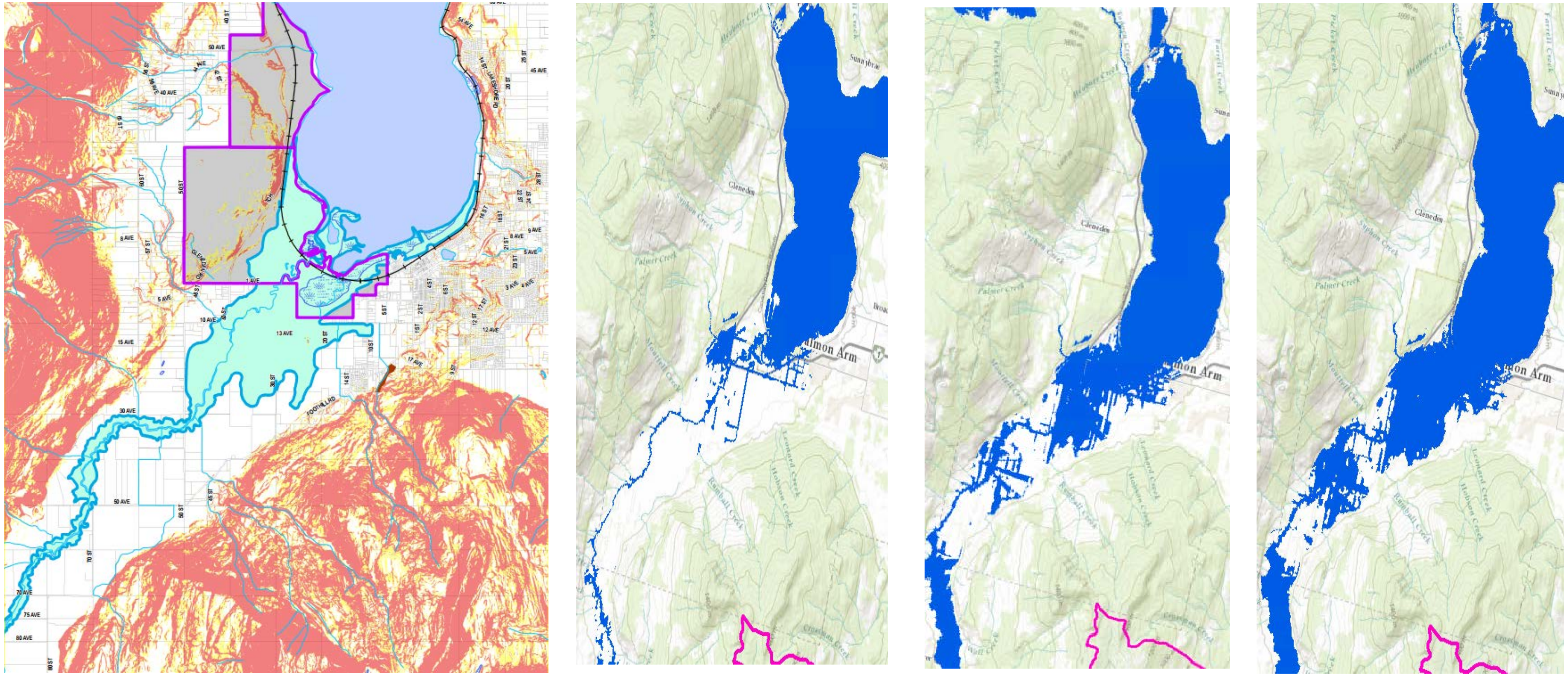


Figure B-10. Vertical topographic offset modelling conceptual sketch.

As a result of the comparison shown in Figure B-11, the 4 m offset model was assumed to be valid at a screening-level for application to other areas of the TRW. These results were used as a proxy for the ‘0.5% AEP” flood extent in the absence of existing mapping. However, they should not be considered a specific representation of a flood return period and do not replace hydraulic modelling or detailed floodplain mapping.

The quality of the results also relies on the ability of the DEM data to capture topographic features that influence the extent of the floodplains and is typically better suited for wider floodplains. Section B.2.6.2 describes the approach taken for smaller streams (less than Strahler order 3).



Salmon Arm (2011) 200-year floodplain (light blue) **1 m offset** **4 m offset** **5 m offset**

Figure B-11. Comparison of BGC vertical offset modelling results using various vertical offsets (1, 4, 5 m) to the City of Salmon Arm (November 14, 2011) 200-year floodplain.

B.2.6.2. Horizontal Buffer Model for Smaller Watercourses

As smaller watercourses are relatively narrow in terms of channel width, a higher degree of topographic data resolution is required to represent the channel geometry in a terrain model. Because of the challenge aligning the stream network with the watershed-wide DEM, a horizontal offset (or buffer) was used to identify potential flood inundation extents for smaller watercourses rather than a vertical offset.

A horizontal buffer of 30 m was applied to the stream network using ArcGIS to create a buffer polygon around the Strahler order 3 or lower stream segments in the TRW. This buffering distance was selected by BGC to approximate the riparian zone for smaller watercourses and approximates minimum setback distances for infrastructure from natural streams (as established in MWLAP, 2004; EGBC, 2017). BGC emphasizes that this buffered zone is an uncertain representation of setback and flood hazard extent. Specifically, floodplain setback is defined based on distance from the visible high-water mark of any lake, river, stream to any development (Figure B-12), whereas the buffer was measured from stream centerline in the absence of high water mark locations because the stream network in RNT is only represented as a linear feature. An example of the horizontal buffer applied to Strahler order 3 or lower stream segments is shown in Figure B-13.

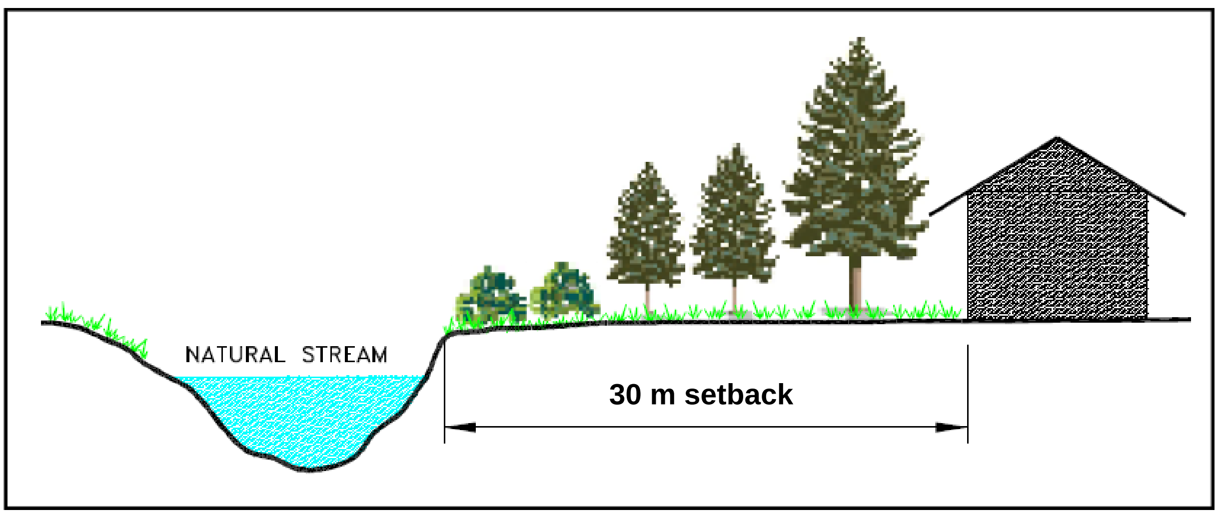


Figure B-12. Setback distance for natural streams applied as a 30 m horizontal buffer to the stream network for smaller watercourses. The horizontal buffer used by BGC does not represent the distance from the top of the bank of the watercourse.

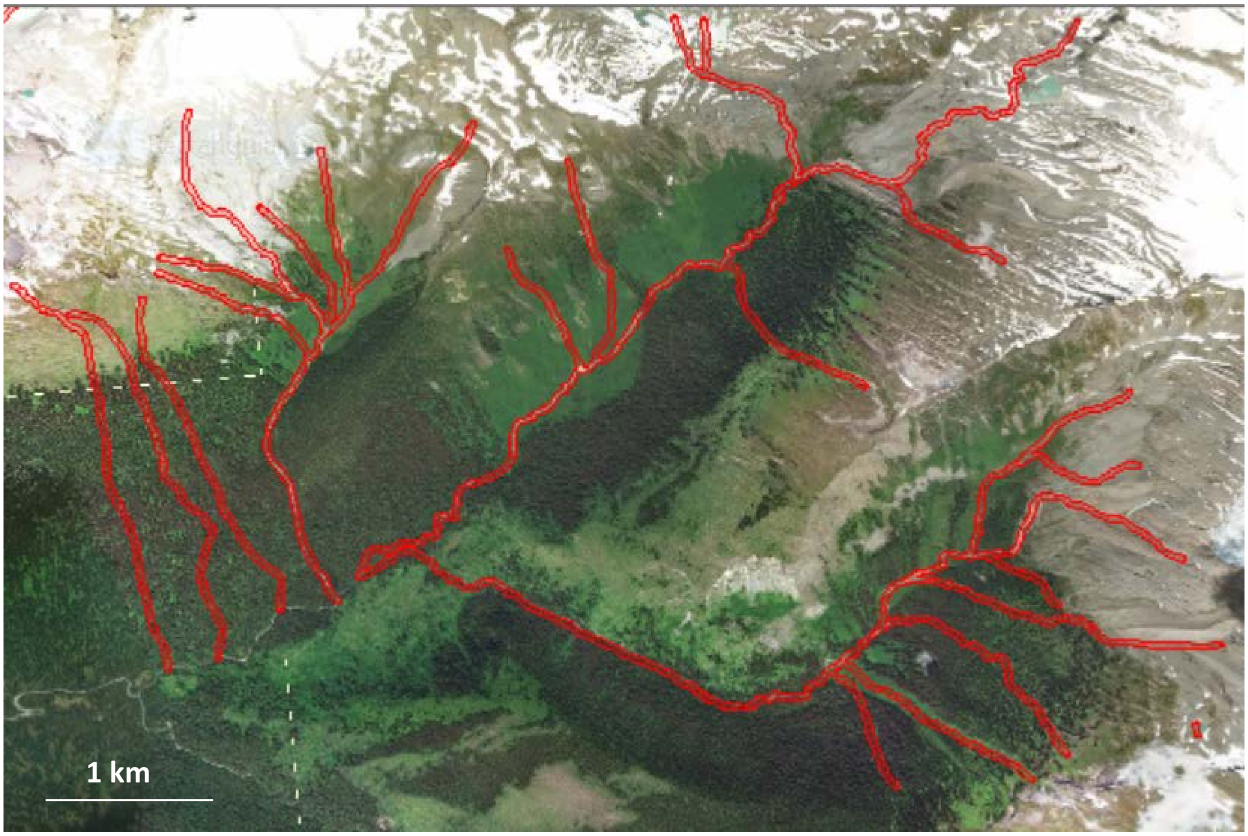


Figure B-13. Example of 30 m horizontal topographic buffer results for Strahler order 3 or lower stream segments in the TRW to identify potential low-lying areas.

B.2.7. Flood Frequency Analysis (FFA)

B.2.7.1. Watercourses

FFA is used to estimate the flood discharge magnitudes and frequencies at a location along a watercourse. An FFA is automatically generated for each stream segment using information and data from hydrometric gauge stations that are contained within RNT™ and are connected to the stream network. FFAs are based on either an analysis of several hydrometric gauge stations with similar catchment and hydrological characteristics (regional analysis) or a prorated analysis, based on the catchment area, using a single station located on the same watercourse. Screening-level flood discharge quantiles were generated for every stream segment within the TRW and assigned to clear-water flood hazard polygons at the farthest downstream stream segment in the polygon. Because RNT is applied as a screening level tool to predict flows over a large geographical area, the flow estimates have the following limitations:

- Gauges on regulated rivers (i.e., rivers where flows are controlled by a dam) are not used in the FFA; and flow regulation is not accounted for watercourses with flow controlled by dams.
- Attenuation from the many lakes, wetlands and marshes in the TRW may not be accounted for in the flow estimates. Peak flow values may be overestimated in catchments

that contain these features. This can only be resolved via detailed rainfall/snowmelt-runoff modeling.

- Peak flow estimates do not account for potential outburst floods from ice jams, glacial or moraine-dammed lakes, beaver dams, landslide dams (see Appendix E), which may be of substantial magnitude in some locations.
- The stream network dataset does not reflect recent changes to drainage alignments due to natural river migration or artificial alterations, which could impact calculated catchment areas and the selection of stream segments available for analysis.
- The stream network does not include stormwater infrastructure and drainage ditches.
- Regional FFAs typically under-estimate peak flows for smaller watersheds (< 25 km^2), as such catchments are rarely gauged and runoff processes are not necessarily scalable compared to larger catchments.

Implication of these uncertainties include under or overestimation of flow discharge at a given return period. While important to consider for more detailed floodplain mapping, they are not addressed further in this study and are not expected to affect relative site priority rankings at the screening level of current study.

B.2.7.2. Lake Levels

An FFA approach was also used to estimate the lake elevation associated with the 200-year flood event for four lakes within the TRW including:

1. Kamloops Lake
2. Shuswap Lake
3. Nicola Lake
4. Aberdeen Lake

These lakes were selected because: (1) each has a WSC gauge station with a minimum of 15 years of historical water level data and (2) a reference elevation for the station was available from WSC to correlate the predicted 200-year water level to an elevation contour that could be used to represent the lake flood hazard area. Of the 391 WSC gauges stations located in the TRW, 30 stations are installed on lakes, four are active and 26 are discontinued (Figure B-14; Table B-5). As described below, both Nicola Lake and Aberdeen Lake have regulated dams on the lakes as described in Section B.2.8 (MFLNRO, 2017a).

Historical water levels were obtained from the WSC HYDAT database (ECCC, July 16, 2018). A generalized extreme value (GEV) distribution was fitted to the annual maximum series to estimate either the 200-yr flood level or elevation. For lakes with more than one WSC station on the lake (e.g., Kamloops Lake and Shuswap Lake), the highest estimated lake elevation was used to represent the potential flood hazard area in proximity to the lake. Annual lake level data for the *Kamloops Lake near Kamloops* (08LF085) station is presented in Figure B-15 as an example.

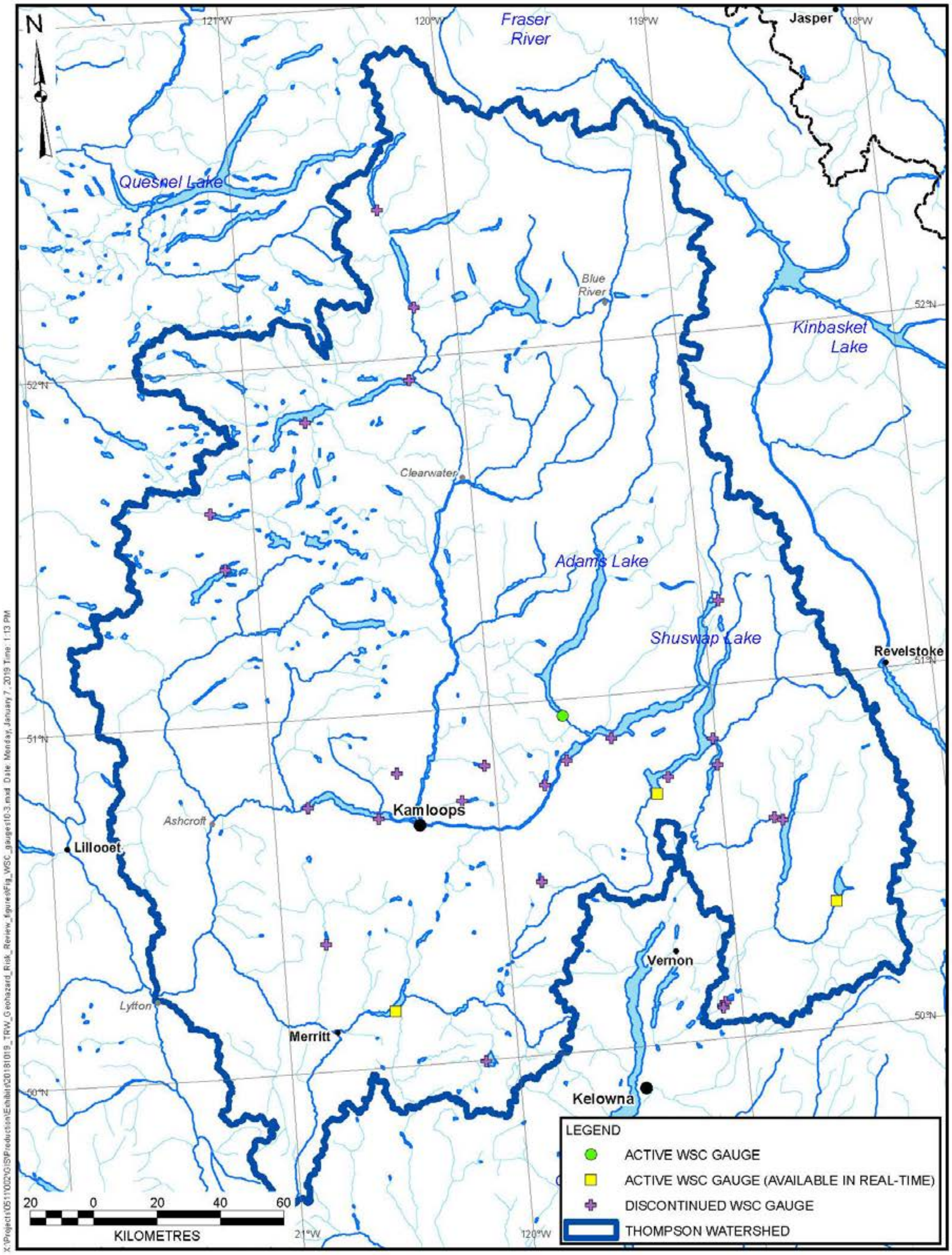


Figure B-14. WSC gauges located on lakes including active stations (green dot), active real-time monitoring stations (yellow square) and discontinued stations (purple cross).

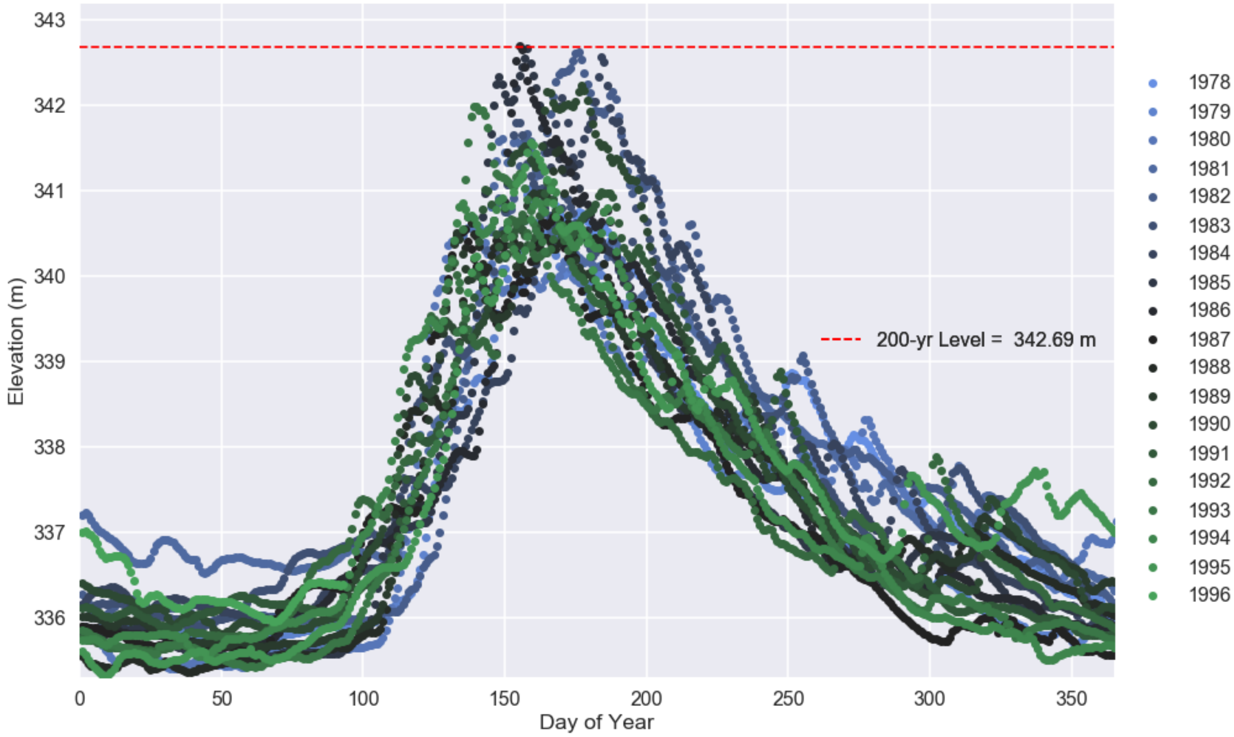


Figure B-15. Kamloops Lake near Kamloops (08LF085) historical lake levels.

Nicola Lake outflows are regulated by the Nicola Lake Dam, a 4 m high dam that was first constructed in 1927 for irrigation and flood control and later reconstructed in 1985 to 1986 (Nichols, July 1998). The 200-year flood elevation of 627.4 metres above sea level (masl) estimated for Nicola Lake is consistent with the 627.9 masl FCL[6] (including 0.6 m freeboard) for Nicola Lake (TNRD 2012).

Aberdeen Lake outflows are regulated by the Aberdeen Lake Dam – a 10 m high structure operated by Regional District of North Okanagan (RDNO). The dam is part of the Duteau Creek water supply system, which provides water for the City of Vernon (GVW, 2017). Duteau Creek watershed includes seven earthen dams forming the Aberdeen Plateau Reservoirs, which are comprised of: Grizzly, Aberdeen and Haddo Lakes. The 200-year water surface elevation presented in Table B-5 for Aberdeen Lake is estimated at 1,279.0 masl. Reservoir management structures and policies have a considerable impact on the hydrology of waterbodies they regulate. The frequency analysis performed in this study does not consider management practices of the reservoirs and are based solely on recorded lake levels.

[6] Flood construction level (FCL) refers to the *designated flood level* based on the provincial floodplain mapping plus 0.6 m of freeboard.

Table B-5. Summary of WSC hydrometric stations located on lakes within the TRW, estimated 200-yr lake levels and documented flood construction levels (FCL).

No	Station Number	Station Name	Latitude°	Longitude	Station Status	Real Time Station	Start of Record	End of Record	Record Length	200-yr Elev. (masl)[1]	200-yr Level[2] (m)	FCL[3] (m)
1	08LF085	Kamloops Lake near Kamloops	50.707	-120.534	DISCONTINUED	FALSE	1978	1996	19	342.7	-	346.2
2	08LF046	Kamloops Lake at Savona	50.753	-120.847	DISCONTINUED	FALSE	1947	1978	32	344.5	-	346.2
3	08LE070	Shuswap Lake at Salmon Arm	50.709	-119.284	ACTIVE	TRUE	1951	2016	41	349.7	-	351.0
4	08LE047	Shuswap Lake near Sorrento	50.881	-119.465	DISCONTINUED	FALSE	1923	1979	57	349.3	-	351.0
5	08LE053	Shuswap Lake near Sicamous	50.851	-119.012	DISCONTINUED	FALSE	1923	1974	21	349.9	-	351.0
6	08LE109	Shuswap Lake at Canoe	50.755	-119.229	DISCONTINUED	FALSE	1986	2010	25	345.0	-	351.0
7	08LE071	Shuswap Lake at Seymour Arm	51.239	-118.928	DISCONTINUED	FALSE	1961	1979	19	-	5.9	351.0
d	08LG046	Nicola Lake near Quilchena	50.158	-120.525	ACTIVE	TRUE	1933	2015	66	627.4	-	627.9
9	08LC043	Aberdeen Lake at the Outlet	50.105	-119.073	DISCONTINUED	FALSE	1968	1986	19	1,279.0	-	-
10	08LE057	Little Shuswap Lake at Chase	50.828	-119.674	DISCONTINUED	FALSE	1949	1987	39	-	5.2	350.2
11	08LC041	Sugar Lake Reservoir at the Outlet	50.358	-118.538	ACTIVE	TRUE	1970	2014	45	-	11.0	604.72
12	08LD003	Adams Lake near Squilax	50.954	-119.675	ACTIVE	FALSE	1949	2015	67	-	-	3.0
13	08LA010	Mahood Lake near Clearwater Station	51.938	-120.241	DISCONTINUED	FALSE	1950	1984	33	-	3.1	-
14	08LA011	Canim Lake near Canim Lake	51.842	-120.730	DISCONTINUED	FALSE	1944	1979	35	-	2.4	-
15	08LA012	Clearwater Lake near Clearwater Station	52.143	-120.192	DISCONTINUED	FALSE	1950	1995	46	-	2.9	-
16	08LA014	Hobson Lake near Clearwater Station	52.425	-120.326	DISCONTINUED	FALSE	1960	1983	24	-	14.6	-
17	08LC044	Haddo Lake at the Outlet	50.094	-119.084	DISCONTINUED	FALSE	1968	1986	19	-	7.1	-
18	08LE068	Monte Lake near Monte Lake	50.492	-119.833	DISCONTINUED	FALSE	1957	1975	19	-	1.4	-
19	08LE079	Niskonlith Lake near Shuswap	50.764	-119.783	DISCONTINUED	FALSE	1932	1950	19	-	3.0	-
20	08LF075	Green Lake near 70 Mile House	51.442	-121.142	DISCONTINUED	FALSE	1969	1995	27	-	1.6	-
21	08LG031	Mamit Lake near Merritt	50.363	-120.809	DISCONTINUED	FALSE	1934	1953	20	-	2.9	-
22	08LG034	Pennask Lake near Quilchena	49.999	-120.145	DISCONTINUED	FALSE	1920	1975	34	-	1.0	-
23	08LA017	Horse Lake near 100 Mile House	51.602	-121.192	DISCONTINUED	FALSE	1969	1984	16	-	2.1	-
24	08LB053	Paul Lake near Kamloops	50.739	-120.157	DISCONTINUED	FALSE	1945	1954	10	-	-	-
25	08LB066	Heffley Lake near Heffley Creek	50.833	-120.045	DISCONTINUED	FALSE	1960	1968	8	-	-	-
26	08LB082	McQueen Lake at the Outlet	50.830	-120.438	DISCONTINUED	FALSE	1984	1991	8	-	-	-
27	08LC032	Shuswap River below Skookumchuk Rapids	50.611	-118.775	DISCONTINUED	FALSE	1955	1956	2	-	-	-
28	08LC037	Mara Lake near Sicamous	50.776	-119.004	DISCONTINUED	FALSE	1961	1974	14	-	-	351.1
29	08LC038	Mabel Lake at the Outlet	50.603	-118.738	DISCONTINUED	FALSE	1970	1979	10	-	-	3.0
30	08LC047	Grizzly Swamp near Haddo Lake	50.089	-119.083	DISCONTINUED	FALSE	1978	1986	9	-	-	-

Notes:
1. Reference elevation for the station was available from WSC to correlate the predicted 200-year water level to a vertical datum: CGVD28.
2. Local unreferenced vertical datum from WSC.
3. Flood construction level (FCL) expressed as an elevation (masl) including 0.6 m of freeboard above the *designated floodplain level* or distance above the natural lake boundary where available.

The estimated 200-year lake levels were also compared to the floodplain extents predicted from the vertical and horizontal offset (buffer) models used by BGC to capture potential low-lying areas adjacent to streams and lakes as described in Section B.2.6. As a representative example, Figure B-16 provides a comparison of the following three approaches used to represent the potential lake flooding hazard area at Shuswap Lake including the:

- 200-year return period water level frequency analysis
- 4 m vertical offset model
- 30 m horizontal buffer model.

As shown in Figure B-16, the three approaches provide similar simulation of flood extents for Shuswap Lake; however, the vertical offset model performs better to capture the potential flood hazard area at the southern end of the lake where the terrain is relatively flat compared to using a straight horizontal buffer. In this study, the potential lake flooding hazard area is represented by the 200-year water level for the four lakes that were analyzed using historical lake level data. For all other lakes, extents from the 4 m vertical offset model were used with the assumption that the results are appropriate to use as a proxy for the ‘0.5% AEP” flood extent.

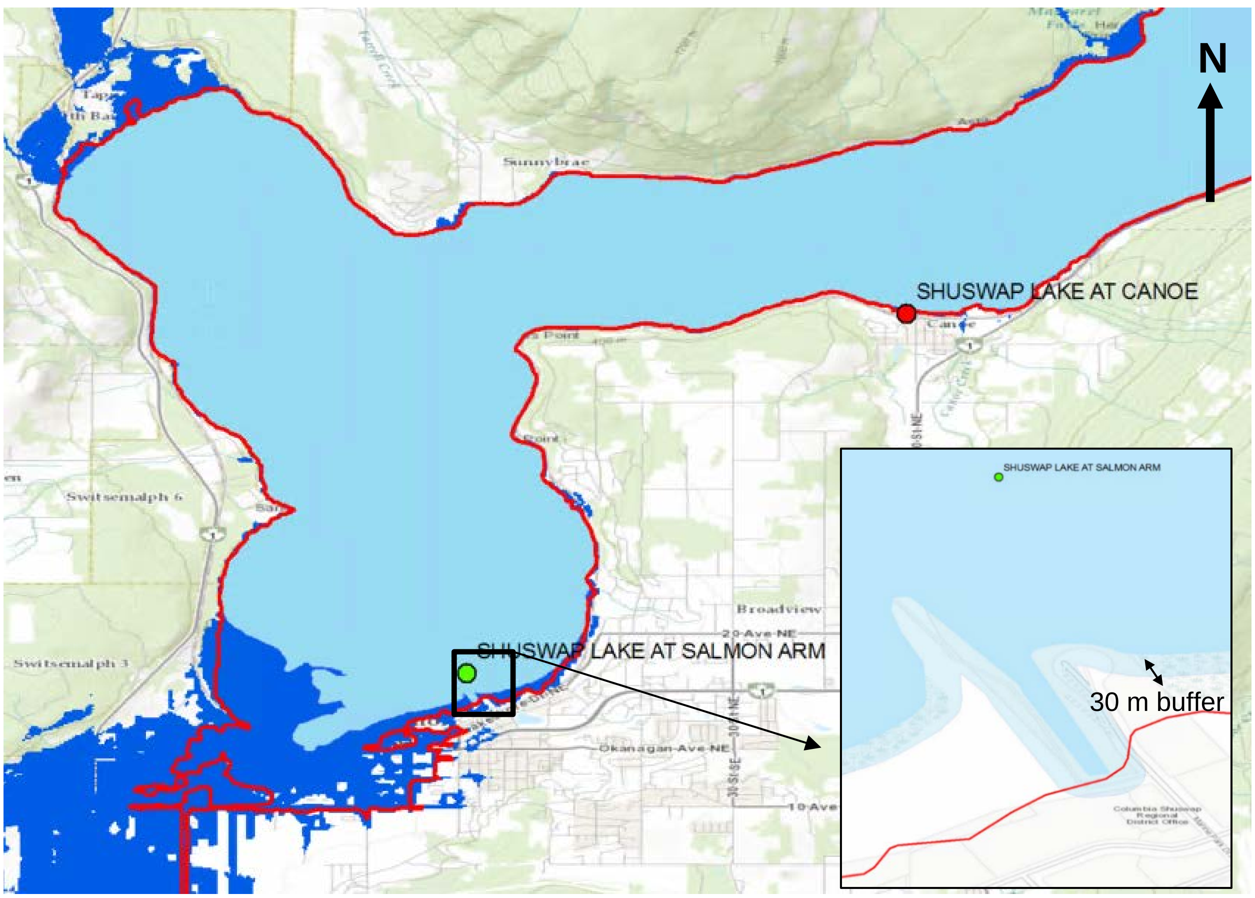


Figure B-16. Comparison of the Shuswap Lake at Salmon Arm (08LE070) estimated 200-yr water level elevation of 349.7 m (red line) to the results of a 30 m horizontal buffer applied to the lake boundary (light blue area) and a 4 m vertical offset model (dark blue area) applied to represent the potential lake flooding hazard area.

B.2.8. Regulated Dams and Flow Regulation

Within the TRW, there are currently 453 dams out of the 1,965 inventoried dams in BC that are regulated under the *Water Sustainability Act* (SBC, 2014). Most of these dams occur on smaller watercourses within the TRW and flows are generally unregulated. Although flow regulation due to the occurrence of dams has an impact on flood hydrology and could potentially reduce the magnitude of flood events, the impact of regulation on flows is outside the scope of this study.

Regulated dams require a water licence issued under the *Act* and must meet the requirements specified in the Dam Safety Regulation (40/2016). A total of 96 dams are classified as low consequence dams, which are exempt from portions of the Regulation (Figure B-17). A total of 403 of the 453 dams are active and regulated; 24 of which have a dam height greater than 7.5 m based on the BC inventory (Table B-6; MFLNRO, 2017a).

The web map displays all the inventoried dams in the TRW to support subsequent detailed flood hazard studies within the TRW and should consider the potential flood hazards from high consequence dams such as the list provided in Table B-6.

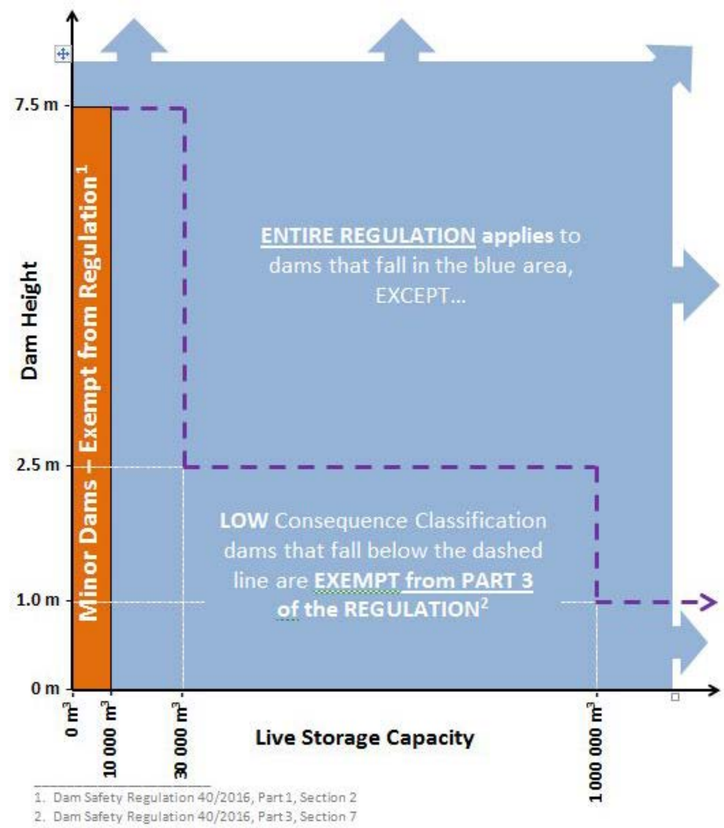


Figure B-17. Dam height (m) versus dam live storage capacity (m^3) as defined by the Dam Safety Regulation (40/2016), which along with the dam failure consequence classification determines which portion of the Regulation applies to the dam.

BGC notes that two dams constructed as part of BC Hydro's Shuswap Falls generating station (Figure B-18), influence the hydrology of the Shuswap River and should be consider for subsequent flood studies on these waterbodies. These dams include:

- Sugar Lake Dam, a 98 m long and 13 m high concrete buttress dam constructed in 1929 which impounds the 2,100 ha Sugar Lake Reservoir
- Wilsey Dam, a 40 m long and 30 m high concrete dam located 31 km downstream of the Sugar Lake Dam, which provides power generation at Shuswap Falls (Figure B-19).

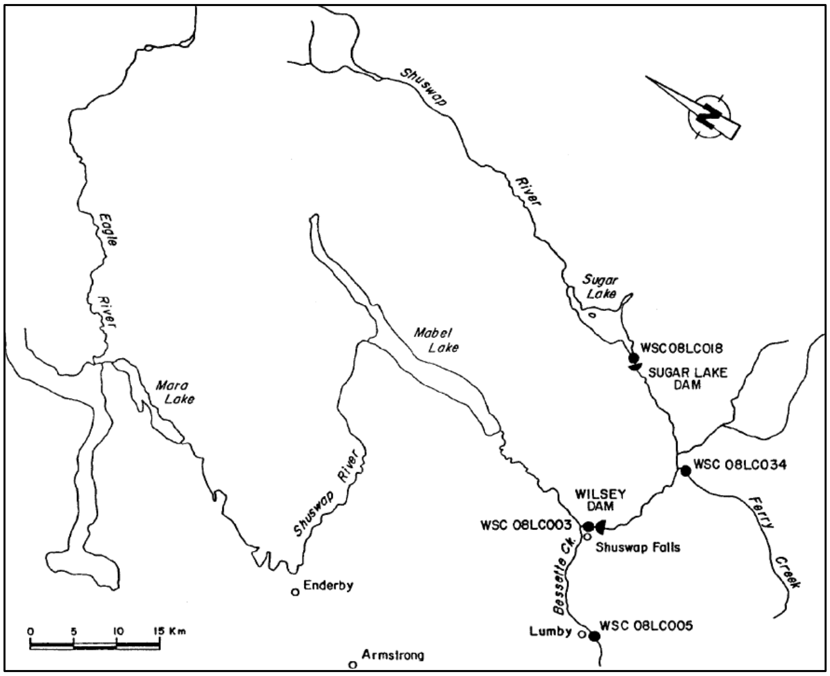


Figure B-18. Location of Wilsey and Sugar Lake Dams.

Figure B-19. Wilsey Dam on the Shuswap River near Lumby (Vernon News, July 3, 2018).

Table B-6. Summary of regulated dams with a height greater than 7.5 m in the TRW (MFLNRO, 2017a).

Dam Name	Dam Crest Information			Owner	Status	Waterbody
	Elevation (masl)	Length (m)	Height (m)			
Wilsey Main Dam	67	40	29.6	BC Hydro	Active	Shuswap River
Highland Valley Raw Water Dam	1,455	396	21.3	TECK	Active	-
Grizzly Saddle Dam	1,290	335	16.2	RDNO	Active	Grizzly Lake
Grizzly Main Dam	1,290	199	14.0	RDNO	Active	Grizzly Lake
Vance Creek	1,663	230	13.5	RDNO	Active	Vance Creek
Sugar Lake Dam	216	98	13.4	BC Hydro	Active	Shuswap River
Yook Lake Dam	-	865	12.0	GVRD	Breached	Yook Lake
Charcoal Creek Dam	926	103	12.0	China Valley Ranch	Active	Charcoal Creek
Tadpole Lake South Dam	40	200	11.7	City of West Kelowna	Active	Tadpole Lake
North Silver Star Lake Dam	1,508	120	11.3	City of Armstrong	Active	North Silver Star Lake
Sun Peaks Dam	1,755	486	11.0	Sunpeaks	Active	McGillvary Lake
Little O.K. lake Dam	1,554	305	10.7	Fish & Wildlife	Active	Little OK Lake
Hector Creek Dam	1,379	140	10.7	Pooley Ranch	Active	Hector Creek
Scuitto Lake Cut-Off Dam	-	-	10.6	Campbell Creek	Active	Scuitto Lake
Botanie Lake Dam	1,114	65	10.3	Lytton First Nation	Active	Botanie Lake
Aberdeen Lake Dam	1,281	449	10.2	RDNO	Active	Aberdeen Lake
Charles Lee Creek Dam	922	50	10.0	Tk'emlups Indian Band	Active	Charles Lee Creek
Haddo Lake Dam	1,271	320	10.0	RDNO	Active	Haddo Lake
North Silver Star Saddle Dam	1,508	205	9.0	City of Armstrong	Active	North Silver Star Lake
Duteau Creek Intake	661	110	8.2	RDNO	Active	Duteau Creek
Buse Lake (Upper) Dam	-	123	8.0	Jack Kenneth Douglas	Active	Buse Lake
Tranquille Lake Dam	-	137	8.0	BC Wilderness	Active	Tranquille Lake
Canoe Creek (East Fork) Dam	-	-	7.8	City of Salmon Arm	Active	Canoe Creek

Dam Name	Dam Crest Information			Owner	Status	Waterbody
	Elevation (masl)	Length (m)	Height (m)			
Sucker Lake Dam	-	180	7.5	Douglas Lake	Active	Sucker Lake

B.2.9. Flood Protection Measures

Although flood protection measures, such of dikes, can reduce the flood risk to people and infrastructure, they rarely eliminate the risk. The residual risk (e.g., flood risk with consideration of risk reduction measures) can be substantial and potentially catastrophic if, for example, the dikes have a high probability of failure due to inadequate maintenance or due to a flood event that exceeds the design capacity. A dike cannot offer the same level of protection to a facility as building out of the maximum credible flood zone. The provincial database for flood protection works includes structural works (MFLRNO, 2017b) and appurtenant structures (MFLRNO, 2017c). The database was developed through a provincial, GPS-based mapping project in 2004 and facilities shown in the database are regulated under the provincial *Dike Maintenance Act* (RSBC, 1996). As defined in the *Act*, a dike is “embankment, wall, fill, piling, pump, gate, floodbox, pipe, sluice, culvert, canal, ditch, drain, or any other thing that is constructed, assembled, or installed to prevent the flooding of land”.

The web map displays the inventoried flood protection works in the TRW. However, no condition assessment, ground-truthing, survey or detailed evaluation of the infrastructure was completed as part of the prioritization study, and the presence of such infrastructure was not accounted for in the prioritization. It is further noted that there may be additional structures not captured by the provincial database.

B.2.10. Flood Conveyance Infrastructure

Although flood conveyance infrastructure such as culverts affect flood hydrology, assessment of this effect is outside the scope of this study. However, the location of culvert and road structures were included on the web map to support future detailed flood hazard studies within the TRW. Since no single dataset exists for watercourse crossings in the TRW, information was compiled from two MoTI databases to display on the web page including:

1. Culverts (MoTI, 2017a).
    - Point dataset for culverts or half-round flumes less than 3 m in diameter that are used to transport or drain water under or away from a road and/or Right of Way (RoW).
    - The majority of the data points are for culverts not on specific watercourses and many of the locations of culverts that are on specific watercourses do not align well with the stream network dataset described in Section B.2.1. Data on culvert parameters required for hydraulic analyses is typically not available.
2. Road Structures (MoTI, 2017b).
    - Polyline dataset for bridges, culverts (≥ 3 m), retaining walls (perpendicular height greater than 2 m), sign bridges and tunnels/snowsheds that are located on a road

and/or RoW that is owned and/or maintained by MoTI. The database includes structure names and reference numbers to the Bridge Management Information System (BMIS) but does not provide specifications for the structures.

The dataset is only for MoTI-owned infrastructure as included in the Road Features Inventory (RFI; MoTI 2017c), and significant gaps exist for municipal, rail and industry-owned infrastructure.

B.3. GEOHAZARD RATING

Hazard sites were prioritized based on the relative likelihood that an event will occur, impact an element at risk and result in some level of undesirable consequence. The largest floodplain polygons in proximity to elements at risk were divided into approximately 10 km long units and intersected with electoral boundaries where appropriate to provide a relatively consistent area for comparing ratings.

B.3.1. Hazard Likelihood

Frequency analysis estimates how often geohazard events occur, on average. Frequency can be expressed either as a return period or an annual probability of occurrence. As described, floodplain maps are typically based on the designated flood as represented by the 0.5% AEP event. Therefore, the 200-year flood event likelihood was used to prioritize clearwater flood sites across the TRW, which corresponds to a representative AEP of 0.5% or a “low” geohazard likelihood as summarized in Table B-7.

Table B-7. Annual Exceedance Probability (AEP) ranges and representative categories.

Geohazard Likelihood	AEP Range (%)(1)	Representative AEP	Representative Return Period (years)
Very High	>10%	20%	5
High	>10% - <3.3%	5%	20
Moderate	>3.3% - 1%	2%	50
Low	>1% - <0.33%	0.5%	200
Very Low	<0.33% - 0.1%	0.2%	500

(1) AEP ranges are consistent with those identified in EGBC (2018).

B.3.2. Consequence Rating

The main report presents a matrix used to assign consequence ratings to each hazard area based on the following two factors:

- Exposure of elements at risk to geohazards (exposure rating)
- Destructive potential of uncontrolled flows that could impact elements at risk (hazard intensity rating).

This section describes how these two factors were determined.

B.3.2.1. Hazard Exposure (Elements at Risk)

Elements at risk are things of value that could be exposed to damage or loss due to geohazard impact (geohazard exposure). This study assessed areas that both contained elements at risk and that were subject to geohazards. As such, identifying elements at risk was required to both define the areas to be assessed and to assign consequence ratings as part of risk prioritization. Section 3.0 of the main study report provides a complete list of elements at risk that were assessed in the study and the relative weightings applied to elements.

B.3.2.2. Hazard Intensity

Estimated flood depth was used as a measure of clear-water flood hazard intensity (destructive potential). In the absence of hydraulic modelling results for the study, a relationship between the flood event magnitude (Section B.2.7) and the maximum flood depth associated with the event was developed as shown in Table B-8. The categories of low, moderate and high flood depths are based on a similar flood risk prioritization study used to describe potential flood severity (Ebbwater, August 14, 2018). A discharge range for the categories was assigned based on experience by BGC from unrelated projects in the region. The results were used as a proxy for maximum flood depth and an estimate of potential flood severity.

Table B-8. Relative flood intensity criteria relating maximum flood depth to flood magnitude.

Average Flood Depth above Ground Surface (m)	Q_{200} discharge (m^3/s)	Hazard Intensity
< 0.1	< 10	Low
0.1 – 1	10 – 500	Moderate
>1	500+	High

Note:

Flood depth and discharge are not necessarily directly correlated as shown in this table. Flood event peak discharge was used as a proxy for flood depth. Thresholds shown for discharge were assigned based on experience by BGC from unrelated projects in the region. These thresholds are relative estimates and cannot replace the use of flood stage-damage curves for detailed flood consequence estimation.

The flood depth thresholds shown in Table B-8 are relative estimates and cannot replace the use of flood stage-damage curves for detailed flood consequence estimation (e.g., FEMA, May 2016). As well, the flood depths to not account for the occurrence of flood protection structures that could potentially alter the extent of flood inundation.

REFERENCES

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APPENDIX C
HAZARD ASSESSMENT METHODOLOGY: STEEP CREEKS

C.1. INTRODUCTION

C.1.1. Objectives

This appendix describes methods used by BGC to identify and characterize steep creek geohazards within the study area. The results form the basis to assign geohazard ratings to each alluvial fan identified as subject to steep creek hazards.

This appendix is organized as follows:

- Section C.1 provides background information and key terminology.
- Section C.2 describes methods and criteria used to identify steep creek geohazard areas.
- Sections C.3 and C.4 describe methods and criteria used to assign geohazard and hazard intensity (destructive potential) ratings, respectively.

Section 5.0 of the main report describes how geohazard and intensity ratings were used as inputs to prioritize each geohazard area.

C.1.2. What are Steep Creek Hazards?

Steep mountain creeks (here-in defined as having channel gradients steeper than 3°, or 5%) are typically subject to a spectrum of mass movement processes ranging from clear water floods to debris floods to hyper-concentrated flows to debris flows, in order of increasing sediment concentration. They can be referred to collectively as hydrogeomorphic[1] floods or processes because water and sediment are being transported, which causes local landscape changes. A continuum prevails between these processes in space and time, with floods transitioning into debris floods upon exceedance of bed shear stress thresholds and eventually debris flows through progressive sediment entrainment in channels steeper than approximately 15°. Conversely, dilution of a debris flow through partial sediment deposition on lower gradient (approximately less than <15°) channels, and tributary injection of water can lead to a transition towards hyper-concentrated flows and debris floods and eventually floods. Some steep creeks can be classified as hybrids, implying variable hydrogeomorphic processes. Creeks classified as subject to debris flows may also be subject to floods and debris floods at lower return periods, or debris flows may transition to debris floods in the lower runout zone and after the main debris surge. Those classified as subject to debris floods may be subject to clear water floods but are only under specific circumstances subject to debris flows.

Figure C-1 summarizes the different hydrogeomorphic processes by their appearance in plan form, velocity and sediment concentration.

[1] Hydrogeomorphology is an interdisciplinary science that focuses on the interaction and linkage of hydrologic processes with landforms or earth materials and the interaction of geomorphic processes with surface and subsurface water in temporal and spatial dimensions (Sidle & Onda, 2004).

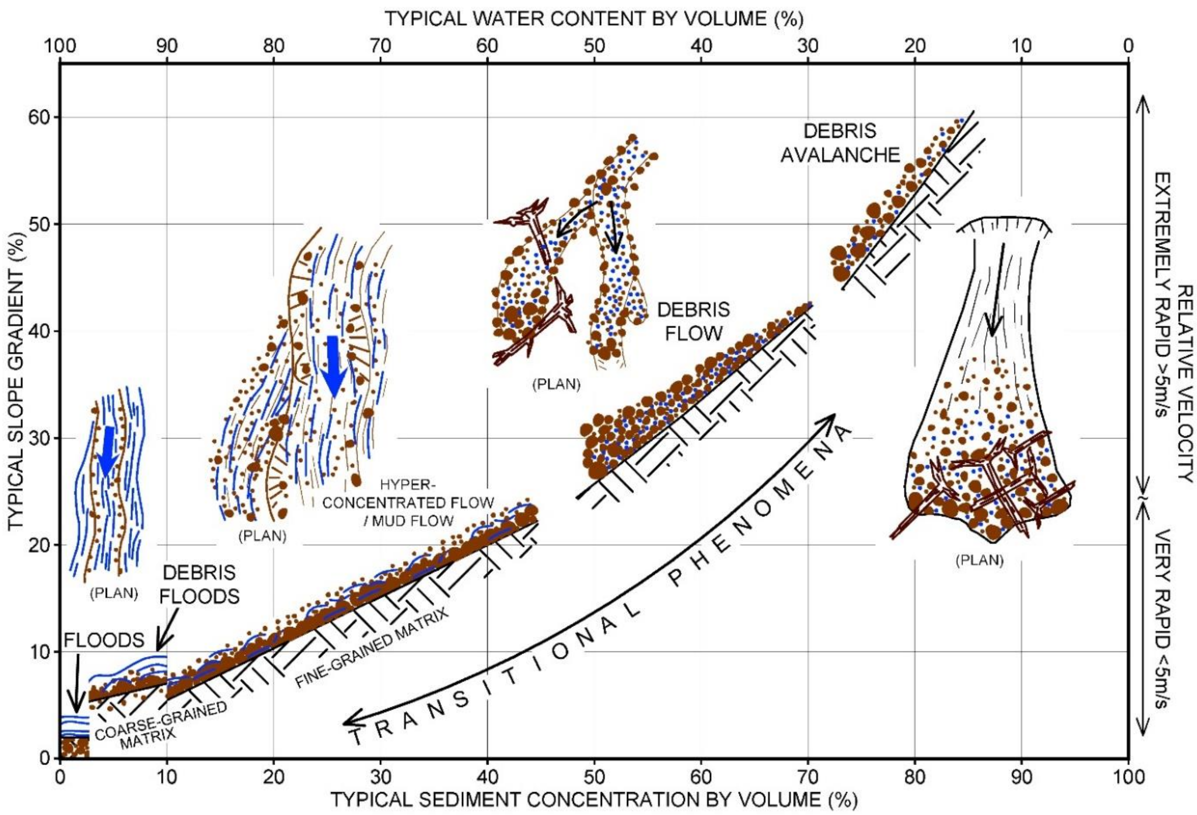

Figure C-1. Hydrogeomorphic process classification by sediment concentration, slope velocity and planform appearance.

C.1.2.1. Steep Creek Watersheds and Fans

A steep creek watershed consists of hillslopes, small feeder channels, a principal channel, and an alluvial fan composed of deposited sediments at the lower end of the watershed. Figure C-2 provides a typical example of a steep creek in the TRW.

Every watershed is unique in the type and intensity of mass movement and fluvial processes, and the hazard and risk profile associated with such processes. Figure C-3 schematically illustrates two fans side by side. The steeper one on the left is dominated by debris flows and perhaps rock fall near the fan apex, whereas the one on the right with the lower gradient is likely dominated by debris floods.

Figure C-2. A typical steep creek watershed and fan (Hummingbird Creek) located near Sicamous in the TRW, with Shuswap Lake in the foreground. The approximate watershed (which extends outside of the margins of the photo) and fan boundary are outlined in white and blue, respectively. Photo: BGC, taken on October 4, 2012.

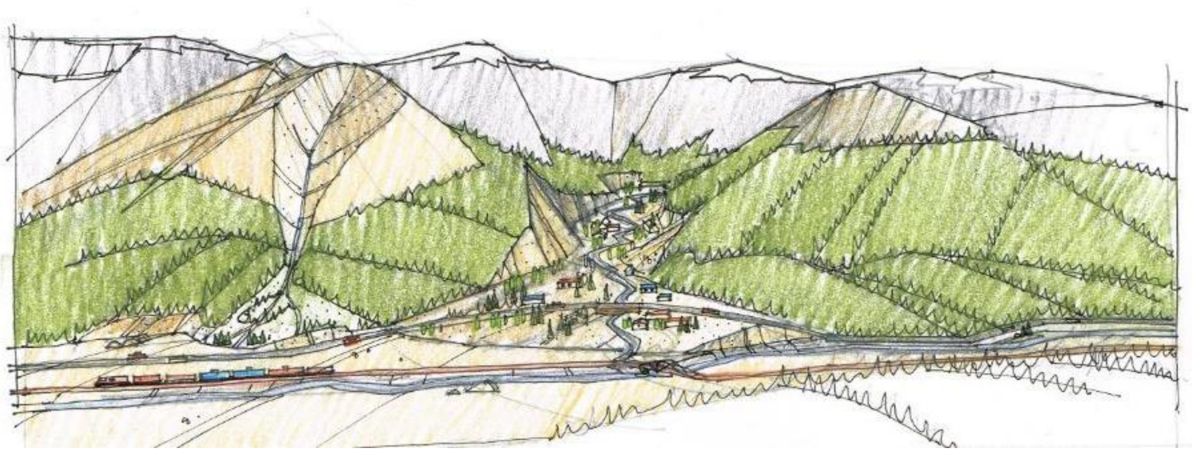

Figure C-3. Typical steep and low-gradient fans feeding into a broader floodplain. On the left a small watershed prone to debris flows has created a steep fan that may also be subject to rock fall processes. On the right a larger watershed prone to debris floods has created a lower gradient fan. Development and infrastructure are shown to illustrate their interaction with steep creek hazard events. Artwork: Derrill Shuttleworth.

Sediment transport in steep creeks occurs by a continuum of processes ranging from bedload and suspended load during floods and debris floods to the fluid landslide-like behavior of debris flows. In steep basins, most mass movements on hillslopes directly or indirectly feed into steep mountain channels from where they begin their journey downstream. Viewed at the scale of the catchment and over geologic time, distinct zones of sediment production, transfer, erosion, deposition, and avulsions may be identified within a drainage basin (Figure C-4). To understand the significance of these different modes of sediment transfer, it is useful to consider the characteristic anatomy of a steep channel system.

Steep mountain slopes deliver sediment and debris to the upper channels by rock fall, rock slides, debris avalanches, debris flows, slumps and raveling. Landslides may also create temporary dams that pond water, which can fail catastrophically. In these scenarios, a debris flow may be initiated in the channel that travels further than the original landslide. Debris flows and debris floods characteristically gain power and material as they move downstream and spread across an alluvial fan where the channel enters the main valley floor.

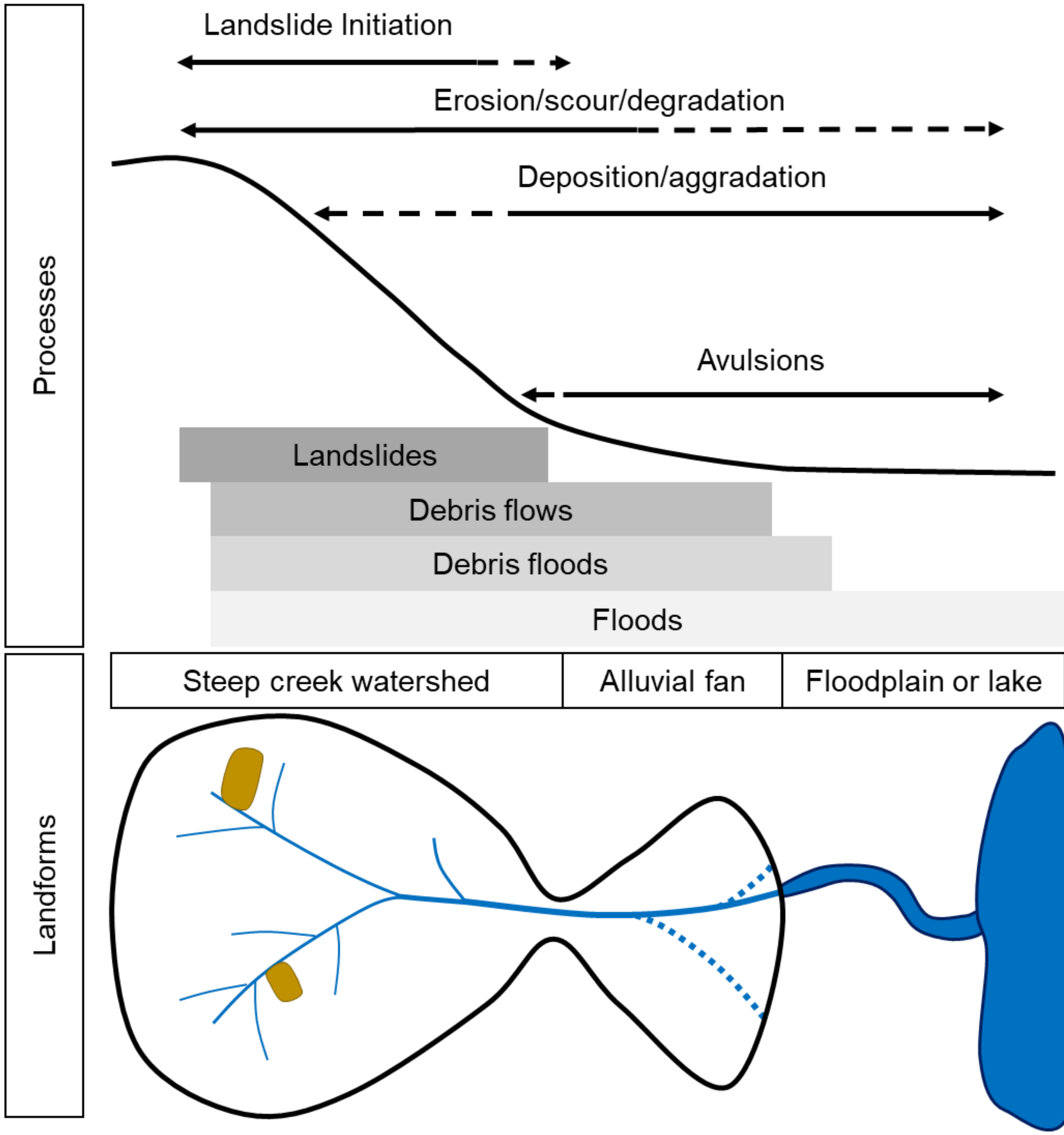

Figure C-4. Schematic diagram of a steep creek watershed system that shows the principal zones of distinctive processes and sediment behaviour. The alluvial fan is thought of as the long-term storage landform with a time scale of thousands to tens of thousands of years. Sketch developed by BGC from concepts produced by Schumm (1977), Montgomery & Buffington (1997), and Church (2013).

The alluvial fan represents a depositional landform at the outlet of a steep creek watershed. This landform is more correctly called a colluvial fan when formed by debris flows because debris flows are classified as a landslide process, and an alluvial fan when formed by clear-water floods or debris floods. For simplicity the term alluvial fan is used herein irrespective of geohazard type.

"Classic" alluvial fans are triangular in plan form but most fans have irregular shapes influenced by the surrounding topography.

The term "paleofan" is used to describe portions of fans interpreted as no longer active and entirely removed from channel processes (i.e., with negligible potential for channel avulsion and flow propagation) due to deep channel incision (Kellerhals & Church, 1990). Similar features common throughout the TRW are paraglacial fans, which are fans primarily deposited shortly after the landscape was deglaciated (Ryder, 1971a; Ryder, 1971b; Church & Ryder, 1972). These fans are commonly found overlying the broad terraces bordering large river systems in the TRW. Post-wildfire debris flows in the Bonaparte Valley and Cache Creek in 2018 (e.g., Figure C-5) have shown that paraglacial fans can still experience debris flows if the watershed stream is still connected to the alluvial fan. Thus, the term paleofan, which implies that the surface is inactive, was only applied to paraglacial fans if the stream had incised into the fan and removed the connection between the stream and the landform (e.g., Figure C-6).

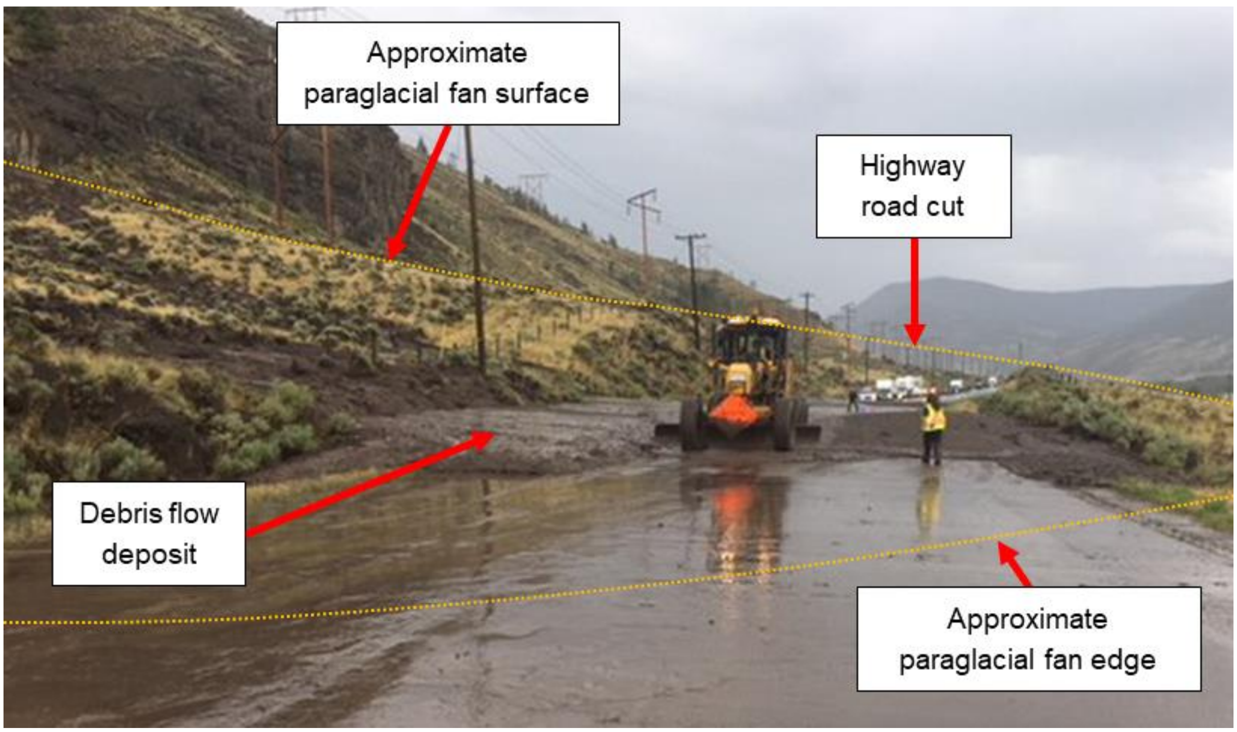

Figure C-5. Maintenance crews clearing a post-wildfire debris flow deposit on Highway 97 on August 3, 2018. Highway 97 cuts across the toe of this paraglacial fan approximately 1 km south of the junction with Highway 99. Photo: MOTI (2018).

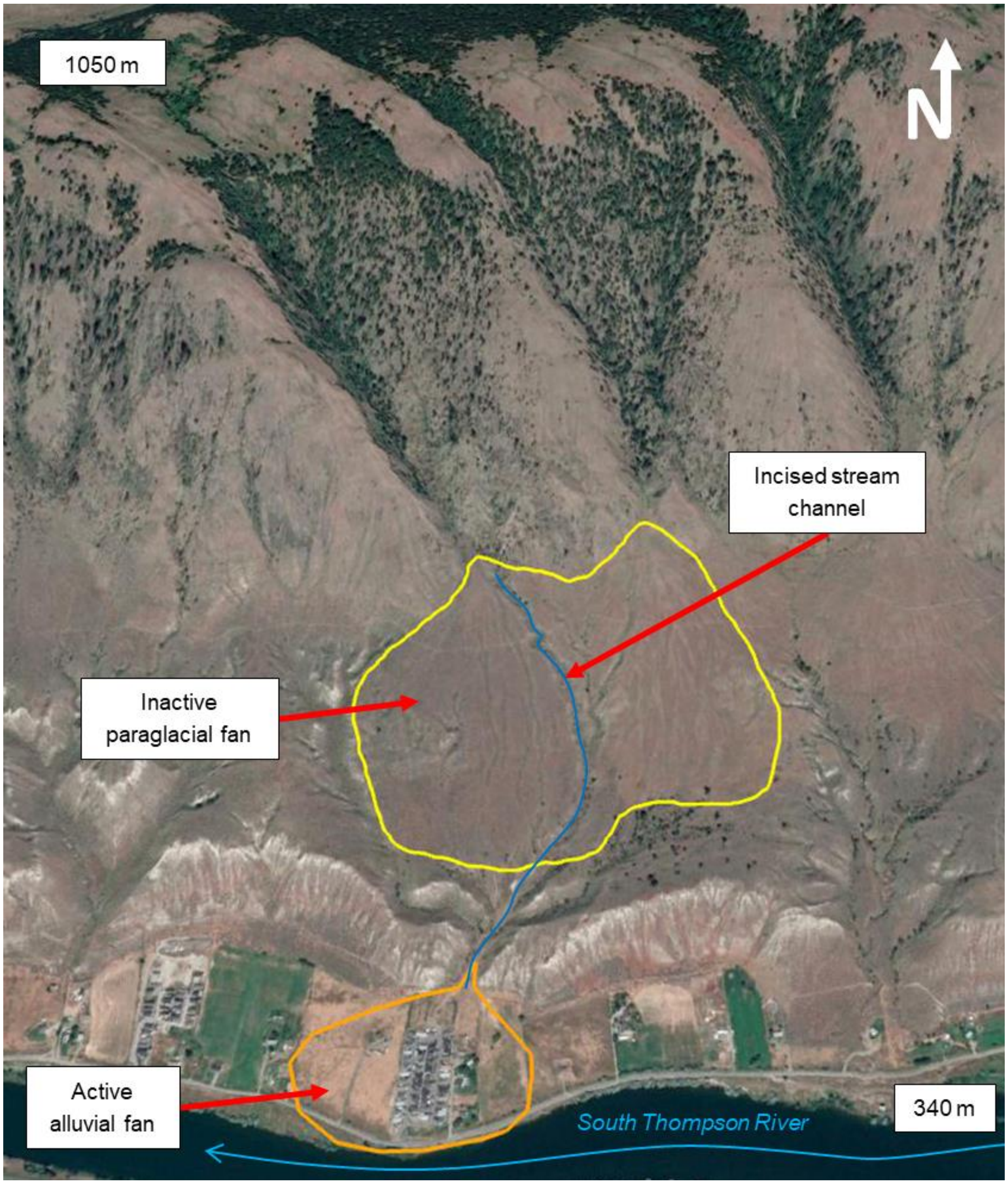

Figure C-6. A Google Earth image of an inactive paraglacial fan and active alluvial fan near Kamloops. The distinction of the paraglacial fan being classified as an inactive paleofan is due to the incised stream channel.

Redistribution of sediments from the upper steeper fan to the lower flatter fan, primarily through bank erosion and channel scour, is common. Stream channels on the fan are prone to avulsions, which are rapid changes in channel location, due to natural cycles in alluvial fan development and from the loss of channel confinement during hydrogeomorphic events (e.g., Kellerhals & Church, 1990; van Dijk et al., 2009; 2012; de Haas et al, 2017). If the alluvial fan is formed on the margin of a still water body (lake, reservoir, ocean), the alluvial fan is termed a fan-delta. These landforms differ from alluvial fans in that sediment deposition at the margin of the landform occurs in still water, which enhances in-channel sediment aggradation and increases the frequency and possibly severity of avulsions (van Dijk et al., 2009; 2012). In summary, alluvial fans are dynamic landforms that represent the approximate depositional extent of past hydrogeomorphic processes generated from a steep creek watershed and are the location of potential future hydrogeomorphic processes.

C.1.2.2. Debris Flows

'Debris flow', as defined by Hungr et al. (2014), is a very rapid, channelized flow of saturated debris containing fine grained sediment (i.e., sand and finer fractions) with a plasticity index of less than 5%. Debris flows originate from a single or distributed source area(s) from sediment mobilized by the influx of ground- or surface water. Liquefaction occurs shortly after the onset of landsliding due to turbulent mixing of water and sediment, and the slurry begins to flow downstream, 'bulking' by entraining additional water and channel debris.

Sediment bulking is the process by which rapidly flowing water entrains bed and bank materials either through erosion or preferential "plucking" until a certain sediment conveyance capacity (saturation) is reached. At this time, further sediment entrainment may still occur through bank undercutting and transitional deposition of debris, with a zero net change in sediment concentration. The volume of the flowing mass is thereby increased (bulked). Bulking may be limited to partial channel substrate mobilization of the top gravel layer, or – in the case of debris flows – may entail entrainment of the entire loose channel debris. Scour to bedrock in the transport zone is expected in the latter case.

Unlike debris avalanches, which travel on unconfined slopes, debris flows travel in confined channels bordered by steep slopes. In this environment, the flow volume, peak discharge, and flow depth increase, and the debris becomes sorted along the flow path. Debris-flow physics are highly complex and video recordings of events in progress have demonstrated that no unique rheology can describe the range of mechanical behaviours observed (Iverson, 1997). Flow velocities typically range from 1 to 10 m/s, although very large debris flows from volcanic edifices, often containing substantial fines, can travel at more than 20 m/s along much of their path (Major et al., 2005). The front of the rapidly advancing flow is steep and commonly followed by several secondary surges that form due to particle segregation and upwards or outwards migration of boulders. Hence, one of the distinguishing characteristics of coarse granular debris flows is vertical inverse grading, in which larger particles are concentrated at the top of the deposit. This characteristic behaviour leads to the formation of lateral levees along the channel that become part of the debris flow legacy. Similarly, depositional lobes are formed where frictional resistance from coarse-grained or large organic debris-rich fronts is high enough to slow and eventually stop the motion of the trailing liquefied debris. Debris-flow deposits remain saturated for some time after deposition but become rigid once seepage and desiccation have removed pore water.

Typical debris flows require a channel gradient of at least 27% (15°) for transport over significant distances (Takahashi, 1991) and have volumetric sediment concentrations in excess of 50%. Between the main surges a fluid slurry with a hyperconcentration (>10%) of suspended fines occurs. Transport is possible at gradients as low as 20% (11°), although some type of momentum transfer from side-slope landslides is needed to sustain flow on those slopes. Debris flows may continue to run out onto lower gradients even as they lose momentum and drain: the higher the fine grained sediment content, and hence the slower the sediment-water mixture will lose its water content, the lower the ultimate stopping angle. The silt-clay fraction is thus the most important textural control on debris-flow mobility. The surface gradient of a debris-flow fan approximates the stopping angle for flows issuing from the drainage basin.

Due to their high flow velocities, peak discharges during debris flows are at least an order of magnitude larger than those of comparable return period floods, and can be upwards of 50 to 100 times larger (Jakob & Jordan, 2001; Jakob et al., 2016). Further, the large caliber of transported sediment and wood means that debris flows are highly destructive along their channels and on fans.

Channel banks can be severely eroded during debris flows, although lateral erosion is often associated with the trailing hyperconcentrated flow phase that is characterized by lower volumetric sediment concentrations. The most severe damage results from direct impact of large clasts or coarse woody debris against structures that are not designed for the impact forces. Even where the supporting walls of buildings may be able to withstand the loads associated with debris flows, building windows and doors are crushed and debris may enter the building, leading to extensive damage to the interior of the structure (Jakob et al., 2012). Similarly, linear infrastructure such as roads and railways are subject to complete destruction. On fans, debris flows tend to deposit their sediment rather than scour. Therefore, exposure or rupture of buried infrastructure such as telecommunication lines or pipelines is very rare. However, if a linear infrastructure is buried in a recent debris deposit, it is likely that over time or during a significant runoff event, the tractive forces of water will erode through the debris until an equilibrium slope is achieved, and the infrastructure thereby becomes exposed. This necessitates understanding the geomorphic state of the fans being traversed by a buried linear infrastructure.

Avulsions are likely in poorly confined channel sections, particularly on the outside of channel bends where debris flows tend to superelevate. Sudden loss of confinement and decrease in channel slope cause debris flows to decelerate, drain their inter-granular water, and increase shearing resistance, which slow the advancing bouldery flow front and block the channel. The more fluid afterflow (hyperconcentrated flow) is then often deflected by the slowing front, leading to secondary avulsions and the creation of distributary channels on the fan. Because debris flows often display surging behaviour, in which bouldery fronts alternate with hyperconcentrated afterflows, the cycle of coarse bouldery lobe and levee formation and afterflow deflection can be repeated several times during a single event. These flow aberrations and varying rheological characteristics pose a particular challenge to numerical modelers seeking to create an equivalent fluid (Iverson, 2014).

C.1.2.3. Debris Floods

A 'debris flood' is "a very rapid surging flow of water heavily charged with debris in a steep channel" (Hungr et al., 2014). Transitions from floods to debris floods occur at minimum volumetric sediment concentrations of 3 to 10%, the exact value depending on the particle size distribution of the entrained sediment[2]. Because debris floods are characterized by heavy bedload transport, rather than by a more homogenous mixture of suspended sediments typical of hyperconcentrated flows (Pierson, 2005a), the exact definition of sediment concentration depends on how sediment is transported in the water column. Debris floods typically occur on creeks with channel gradients between 5 and 30% (3-17^{o}). More formally, BGC defines debris flood onset when at least the grain size corresponding to the D_{84} (the 84th percentile of all bedload grain sizes) is mobilized. When this occurs, most of the stream bed becomes mobile, and the mobile layer is a few D84 grains thick (Mackenzie, Eaton & Church, 2018).

The term "debris flood" is similar to the term "hyperconcentrated flow", defined by Pierson (2005a) on the basis of sediment concentration as "a type of two-phase, non-Newtonian flow of sediment and water that operates between normal streamflow (water flow) and debris flow (or mudflow)". Debris floods (as defined by Hungr et al., 2014) have lower sediment concentrations than hyperconcentrated flows (as defined by Pierson). Thus, there is a continuum of geomorphic events that progress from floods to debris floods to hyperconcentrated flows to debris flows, as volumetric sediment concentrations increase.

Due to their initially relatively low sediment concentration, debris floods can be more erosive along channel banks and beds than debris flows. Bank erosion and excessive amounts of bedload introduce large amounts of sediment to the fan where they accumulate (aggrade) in channel sections with decreased slope. In fact, debris floods can be initiated on the fan itself through rapid bed erosion and entrainment of bank materials, as long as the stream power is high enough to transport at least the D_{84}. Because typical long-duration storm hydrographs fluctuate several times over the course of the storm, several cycles of aggradation and remobilization of deposited sediments on channel and fan reaches can be expected during the same event (Jakob et al., 2016).

A second type of debris flows occurs when unusual geomorphic processes create a sudden onset of a debris flood. One trigger is transition from a debris flow when lower stream channel gradients are encountered. This includes landslide dam, beaver dam or glacial lake or moraine dam outburst floods as well as the failure of man-made dams (Jakob & Jordan, 2001; Jakob et al., 2016).

C.2. STEEP CREEK GEOHAZARD IDENTIFICATION

Steep creek geohazard identification for the TRW focused on the delineation of alluvial fans, as these are the landforms commonly occupied by elements at risk. The boundaries of alluvial fans

[2] The yield strength is the internal resistance of the sediment mixture to shear stress deformation; it is the result of friction between grains and cohesion (Pierson, 2005a).

define the steep creek geohazard areas prioritized in this study. Upstream watersheds were assessed to identify geohazard processes and determine geohazard ratings but were not mapped.

C.2.1. Fan Inventory

Fan[3] extents were manually delineated in an ESRI ArcGIS Online web map based on a review of previous mapping (Ministry of Environment and Climate Change Strategy, 2016; Lau, 2017), and from hillshade images built from the limited coverage of lidar Digital Elevation Models (DEM). At sites where lidar DEMs were not available, low resolution (approximately 25 m)[4] Canadian Digital Elevation Model (CDEM) terrain models and satellite imagery available within ArcGIS were used for terrain interpretation.

As noted in the scope of work (Main Report Section 1.2), the fan mapping focused on areas that contain existing buildings development, and 1,157 fans were mapped.

The accuracy of each fan's boundary and hazard rating depends, in part, on the resolution of the available terrain data. Lidar terrain models, where available, provide 1 m or better resolution (e.g., Figure C-7). Mapped fan boundaries, even where lidar coverage is available, are approximate, but contain higher uncertainty where lidar coverage was not available. For areas without lidar coverage, the minimum fan size and characteristics that can be mapped at regional scale with the available information is about 2 ha. Local variations in terrain conditions over areas of 1 to 3 ha, or over distances of less than about 200 m, may not be visible. Specific site investigations could alter the locations of the fan boundaries mapped by BGC.

[3] Defined in Appendix A (Section A.2.4).

[4] CDEM resolution varies according to geographic location. The base resolution is 0.75 arc second along a profile in the south-north direction and varies from 0.75 to 3 arc seconds in the east-west direction, depending on location. In the TRW, this corresponds to approximately 25 m grid cell resolution (Government of Canada, 2016).

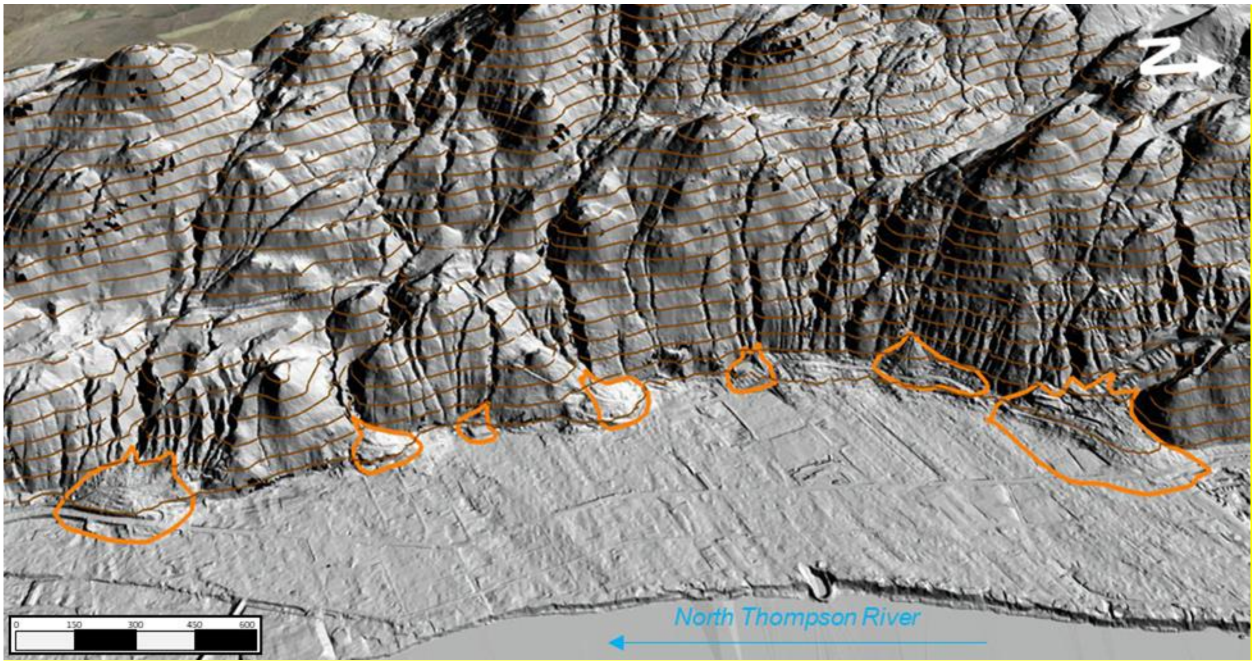

Figure C-7. Example of oblique lidar hillshade and 20 m contours showing small alluvial fans at the base of gullies in the Westsyde neighborhood of Kamloops. Lidar DEM provided by the City of Kamloops.

C.2.2. Geohazard Process Type Identification

BGC used two methods to assign geohazard processes: terrain interpretations and morphometric statistics. The statistically predicted process was applied to every stream segment in the entire study area, including both developed and undeveloped areas. These process types were considered alongside terrain interpretations to assign a dominant process type to each fan, as described below.

Steep creek process type assignment does not specifically contribute to the fan prioritization rating. However, it is important for more detailed assessment of flow magnitude and behavior, the choice of parameters for numerical modeling of flows, criteria used to estimate vulnerability and associated risk, and the design of risk reduction measures. Creeks classified as subject to debris flows may also be subject to floods and debris floods at lower return periods, or debris flows may transition to watery afterflows in the lower runout zone and after the main debris surge. Those classified as subject to debris floods may be subject to clear water floods but will generally not be subject to debris flows.

C.2.2.1. Terrain Interpretations

BGC interpreted the dominant fan-forming process types from the following information sources:

- The geomorphology of fans and their associated watersheds observed in the available imagery
- Field observations

- Records of previous events
- Review of statistically predicted process type for channel(s) intersecting the fan.

While a single process type was assigned to a given fan, many fans are subject to more than one process type. Fans classified as subject to debris flows are also subject to floods, though rarely debris floods. Those classified as debris flood fans are also subject to floods, as a debris flood is simply a flood in which the stream power allows full surface bed entrainment. Those classified as subject to clear-water floods were interpreted as not subject to debris floods or debris flows.

C.2.2.2. Morphometric Statistics

BGC applied the following approach to predict steep creek process type for all segments of every mapped creek within the study area, based on morphometric statistics:

1. Collect statistics on Melton Ratio[5] and watershed length[6] for each segment of each creek. These terrain factors are a good screening level indicator of the propensity of a creek to dominantly produce floods, debris floods or debris flow (Holm et al., 2016).
2. Use Analysis of Variance (ANOVA) to determine class boundaries that best predicted process types for fans where the process type is well understood based on previous study.
3. Apply class boundaries to predict process types for all stream segments in the study area, regardless of whether they intersect fans.

Figure C-8 plots the study creeks with respect to Melton Ratio and watershed length[7]. Although there is overlap, creeks with the highest Melton ratio and shortest watershed stream length are mostly prone to debris flows, and those with the lowest Melton ratio and longest watershed stream lengths are mostly prone to floods. Debris floods fall between these types. Table C-1 lists class boundaries used to define process types on each segment of each creek within the TRW. The results are shown on the web map as a layer coloring each stream by predicted process type.

[5] Melton ratio is watershed relief divided by the square root of watershed area (Melton, 1957).
[6] Stream network length is the total channel length upstream of a given stream segment to the stream segment farthest from the fan apex.
[7] The process type shown in the figure represents the process at the location of the fan apex. Many creeks subject to debris floods are also subject to debris flows on steeper creeks higher in the basin.

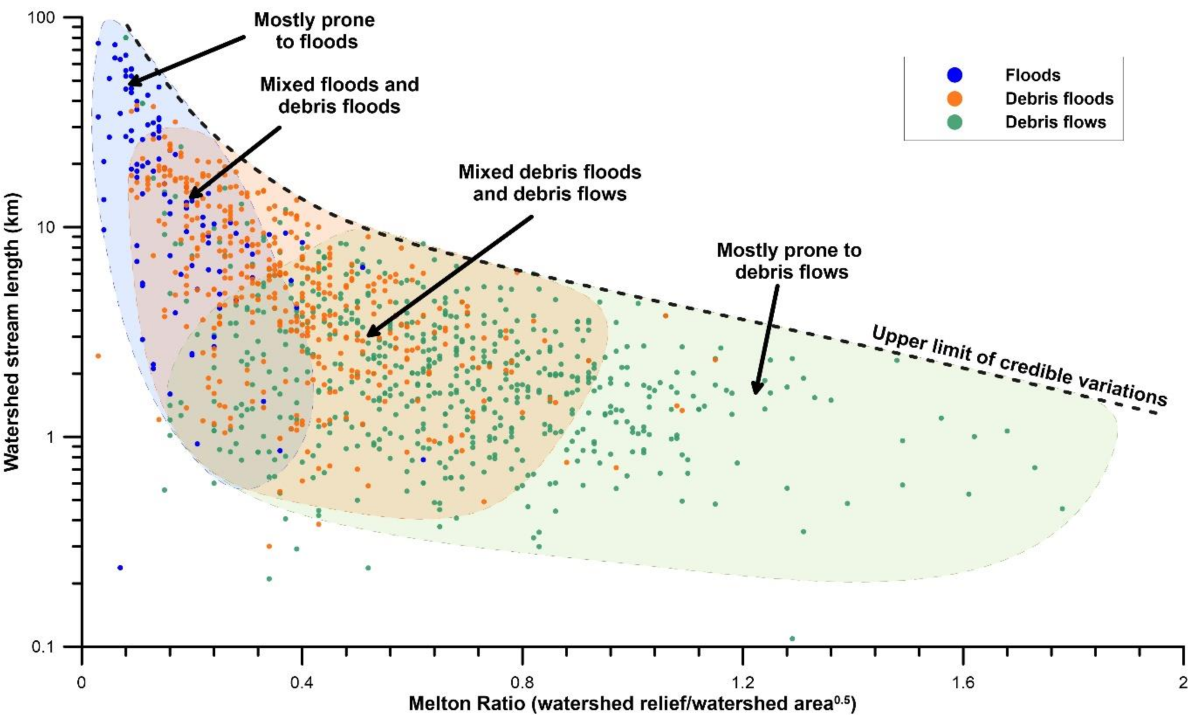

Figure C-8. Steep creek processes in the TRW as a function of Melton Ratio and stream length. Process boundaries are derived from this study and additional fans in Alberta and BC (Holm et el., 2016, Lau, 2017).

Table C-1. Class boundaries using Melton ratio and total stream network length.

Process	Melton Ratio	Stream Length (km)
Floods	< 0.2	all
Debris floods	0.2 to 0.5	all
	> 0.5	> 3
Debris flows	> 0.5	≤ 3

Steep creek process types predicted from watershed morphometry are subject to limitations. Creeks at the transition between debris flows and debris floods may generate either type of process and do not fall clearly into one category or another. The classification describes the potential dominant process type but does not consider the geomorphic or hydroclimatic conditions needed to trigger events. As such, channels may be classified as "debris flow" or "debris flood" without evidence for previous events. Some streams subject to lower frequency debris floods will be subject to higher frequency clearwater floods.

Watershed conditions that affect hydrogeomorphic process types cannot be considered using a purely statistical approach. For example, a fan could be located at the outlet of a gentle valley, but where a debris-flow tributary enters near the fan apex. In this situation, debris flows could run out onto a fan that is otherwise subject to floods or debris floods from the main tributary. Other exceptions include hanging valleys, where the lower channel sharply steepens below a gentle upper basin. It should further be understood that there is a continuum between each of the geohazard processes. As an example, a steep creek could have an event that has characteristics that fall between a debris flood and debris flow. Such events are commonly referred to as hyperconcentrated flows (Pierson, 2005b).

In summary, the major advantage of statistically based methods is that they can be applied to much larger regions than would be feasible to manually assess. However, interpretation of steep creek process types from multiple lines of evidence (statistical, remote-sensed, field observation) would result in higher confidence. Therefore, BGC also manually interpreted the dominant fan-forming process types for the prioritized study sites (where both a steep creek hazard and element(s) at risk were present).

C.3. GEOHAZARD RATING

BGC assigned geohazard ratings that considered the following two factors:

- Hazard likelihood: What is the likelihood of steep creek geohazard events large enough to potentially impact elements at risk (Section C.3.1)?
- Impact likelihood: Given a geohazard event occurs, how susceptible is the hazard area to uncontrolled flows that could impact elements at risk (Section C.3.2)?

This section describes methods to estimate both factors and combine them to arrive at a geohazard rating. Appendix E describes how the geohazard rating is then combined with a consequence rating to prioritize each creek. Note that paleofans were not attributed impact likelihood and geohazard ratings.

C.3.1. Geohazard Likelihood

Frequency analysis estimates how often geohazard events occur, on average. Frequency can be expressed either as a return period or an annual probability of occurrence. For example, if five debris floods have occurred within a 100-year period, the average return period is 20 years and the annual probability is the inverse, so 0.05, or a 5% chance that a debris flood may occur in any given year. While a single geohazard likelihood rating was assigned for prioritization, BGC notes that events of different frequencies and magnitudes can occur on any given steep creek. The magnitude of a geohazard event refers to the volume of sediment deposited on a fan, peak discharge, or both.

BGC assigned a geohazard likelihood rating to each fan based on terrain analysis, with reference to recorded events and past assessments. Professional experience and judgement was applied to estimate the most frequent event of sufficient magnitude to have credible potential for consequences.

The terrain analysis approach assigns a single, “typical” event frequency to each fan based on surface evidence for previous events, recorded events, and reference to previous work.

Table C-2 lists the relative hazard likelihood ratings and corresponding annual frequency and return period ranges assigned to each fan. Note that frequency is the inverse of return period (higher frequency events have a smaller return period).

Table C-2. Annual Exceedance Probability (AEP) ranges and representative categories.

Geohazard Likelihood	AEP Range (%)(1)	Representative AEP	Representative Return Period (years)
Very High	>10%	20%	5
High	>10% - <3.3%	5%	20
Moderate	>3.3% - 1%	2%	50
Low	>1% - <0.33%	0.5%	200
Very Low	<0.33% - 0.1%	0.2%	500

(1) AEP ranges are consistent with those identified in EGBC (2018).

Hazard frequency estimates were based on surface evidence for geomorphic activity within the basin and fan, as shown by the examples in Figure C-9 and Figure C-10. As such, they correspond to events large enough to produce visible surface evidence. Dense tree cover, for example, could obscure small events that would not be detected at the scale of study. Accordingly, the ratings are relative measures.

Table C-3 lists the fan and basin characteristics used to assign hazard frequency categories.

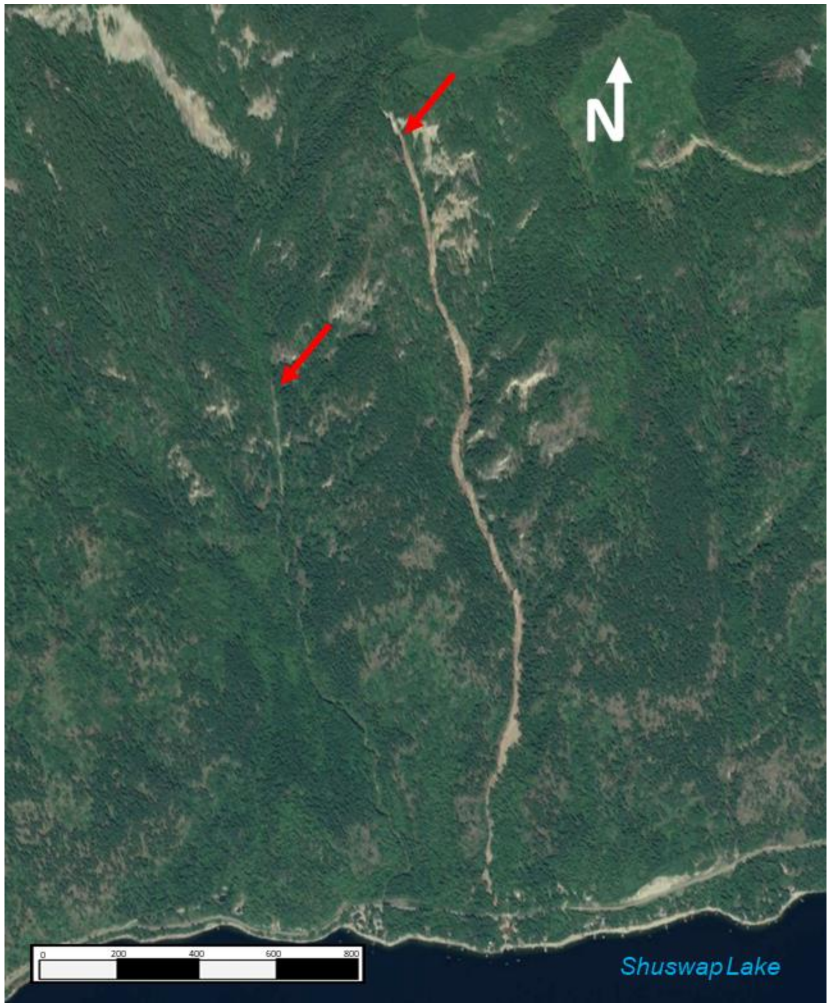

Figure C-9. Example of evidence for recent landslide or in-channel debris flow initiation within the basin of Hart Creek (left) and Robinson Creek (right), east of Paradise Point.

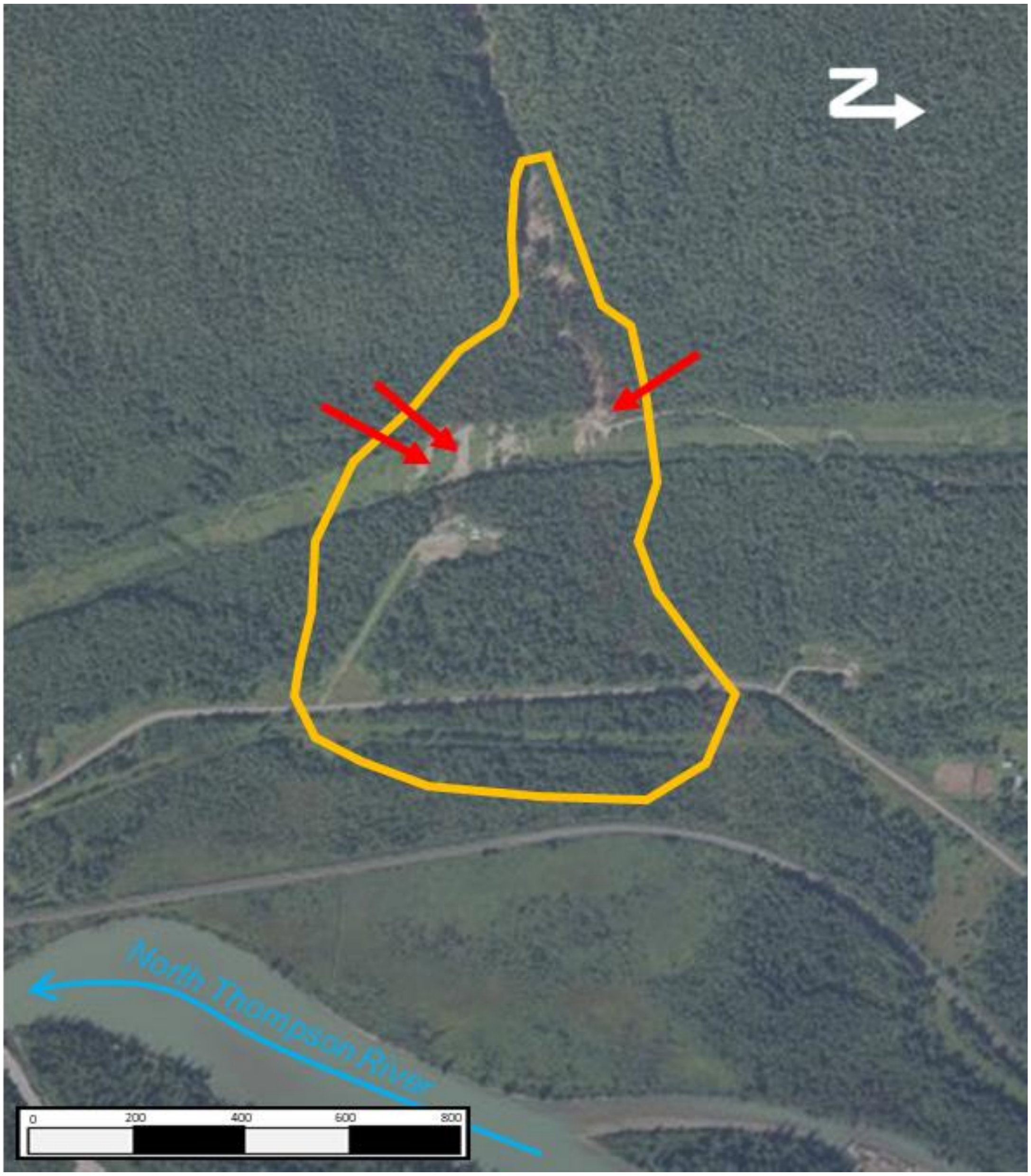

Figure C-10. Example of evidence (red arrows) for recent (early 2000s) debris flow deposit on an unnamed fan north of Avola. The approximate alluvial fan boundary is shown in orange.

Table C-3. Relative hazard likelihood criteria for steep creek fans.

			Typical Basin Activity Characteristics									
			Very Low		**Low**		**Moderate**		**High**		**Very High**	
			Debris Flood Creek	**Debris Flow Creeks**	**Debris Flood Creek**	**Debris Flow Creeks**	**Debris Flood Creeks**	**Debris Flow Creeks**	**Debris Flood Creeks**	**Debris Flow Creeks**	**Debris Flood Creeks**	**Debris Flow Creeks**
			Small watershed with no identifiable source areas. Dominantly a bedrock-controlled main channel. Supply limited watershed	No identifiable source areas; absence of fresh landslide scars or channel deposits; low AAR[2]; supply-limited watershed.	Few tributaries with few identifiable sediment sources; little or no sediment sources along main channel; supply limited watershed; mostly bedrock-controlled main channel with little alluvium; mature tree growth to margin of active channel; tree line close to watershed peak elevations.	Poorly defined source areas; absence of fresh landslide scars or channel deposits; low AAR[2]; supply-limited watershed.	Some tributaries with identifiable sediment sources; deciduous tree bordering active channel; 1/3 of watershed above treeline; some active sediment sources along main channel; variable channel width; partially bedrock-partially alluvial channel; supply unlimited watershed.	Well-defined source areas; presence of some fresh landslide scars in soil or rock and some channel deposits; moderate active-area-ratio (AAR[2]); usually supply-limited watershed.	Many tributaries with abundant identifiable sediment sources in tributaries; deciduous tree bordering active channel; 2/3 of watershed above treeline; numerous highly active sediment sources along main channel (i.e., debris slides, debris avalanches, raveling in lacustrine, glaciofluvial, or morainal sediments); wide and debris-rich alluvial channel; supply unlimited watershed.	Numerous, well-defined, actively producing source areas in tributaries and along main channel; channel choked with debris; abundant fresh landslide scars in soils and rock; fresh channel deposits; high active area ration (AAR[2]); supply-unlimited watershed.	Most tributaries with abundant identifiable sediment sources in tributaries; deciduous tree bordering active channel; 2/3 of watershed above treeline; numerous highly active sediment sources along main channel (i.e., debris slides, debris avalanches, raveling in lacustrine, glaciofluvial, or morainal sediments); wide and debris-rich alluvial channel; supply unlimited watershed.	Numerous, well-defined, actively producing source areas in tributaries and along main channel; easily entrained materials along incised channels (e.g., talus, glacial deposits, volcanics); channel choked with debris; abundant fresh landslide scars in soils and rock; fresh channel deposits; high active area ratio (AAR[2]); supply-unlimited watershed.
Fan Activity Characteristics	**Very High**	Obvious fresh deposits in mainstem; channels, lobes or levees of previous events easily discernible; swaths of bare sediment or low (<2 yr) pioneer vegetation, multiple active channels	n/a[1]		n/a[1]		High		Very High		Very High	
	High	Obvious fresh deposits in mainstem; channels, lobes or levees of previous events easily discernible; swaths of bare sediment or low (<2 yr) pioneer vegetation	n/a[1]		n/a[1]		High		High		Very High	
	Moderate	Partially vegetated mainstem; channels, lobes or levees of previous events well visible; swaths of young (<50 yr) deciduous or coniferous vegetation on fan.	Low		Low		Moderate		High		High	
	Low	Vegetated mainstem; channels, lobes or levees of previous events difficult to discern; mature (>50 yr) vegetation on fan.	Very Low		Low		Low		Moderate		Moderate	
	Very Low	Raised paleo fans. Vegetated fan with no clear channels.	Very Low		Very Low		Low		Low		Moderate	

Notes:

1. A combination of higher fan activity and lower basin activity is considered not credible.
2. AAR[2] stands for "Active Area Ratio" and is a ratio of the total area of sediment sources to the total basin area (Jakob and Bovis, 1996). It provides a measure of degree of instability, normalized by basin area. A high AAR value implies abundant sediment sources which in turn results in a higher frequency of debris flows as those watersheds will produce debris flows whenever a critical hydroclimatic threshold is exceeded. AAR were not quantified for this assignment but were assessed qualitatively during terrain analysis.

BGC notes that wildfires in steep mountainous terrain are often followed by a temporary period of increased geohazard activity. The period of increased geohazard activity is most pronounced within the first three to five years after the fire (Cannon & Gartner, 2005; DeGraff et al., 2015). After about three to five years following fire, vegetation can reestablish on hillslopes and loose, unconsolidated sediment mantling hillslopes and channels may have been eroded and deposited downstream. A second period of post-fire debris-flow activity is possible about ten years following a fire, when long duration storms with high rainfall totals or rain-on-snow events cause landslides that more easily mobilize due to a loss of cohesion caused by tree root decay (Degraff et al., 2015; Klock & Helvey, 1976; Sidle, 1991; 2005). This second period of heightened debris-flow activity is rare, and post-wildfire debris flows are most predominant immediately following the fire and continuing for up to about three to five years. Detailed post-wildfire geohazard assessment was outside the scope of work, and the likelihood of geohazards is subject to change following future wildfires.

C.3.2. Geohazard Impact Likelihood

BGC assigned an impact likelihood rating to each fan that considered the relative spatial likelihood that geohazard events, given they occur, result in uncontrolled flows that could impact elements at risk. This rating is assigned as an average for the fan. It is not an estimate of spatial probability of impact for specific elements at risk, which would vary depending on their location within the fans. This section describes methods to determine this rating.

BGC used two methods to estimate impact likelihood: terrain interpretations for prioritized study sites (SectionC.3.2.1) and steep creek susceptibility modelling for all streams identified as being subject to steep creek hazards[8] (Section C.3.2.2). Previous assessments and event records were also referenced where available. Both approaches were combined in criteria to assign impact likelihood ratings. The methods described in this section are applicable for regional scale assessment but do not replace quantitative estimates of spatial probability of impact to specific elements at risk, as would be completed for detailed hazard and risk analysis.

C.3.2.1. Terrain Interpretations

BGC used terrain interpretations of channel avulsion as a proxy to assess avulsion potential at each fan, where uncontrolled flow outside the active channel is assumed to have higher potential to impact elements at risk. Terrain interpretation was undertaken based on a combination of LiDAR data, when available, and satellite imagery.

Avulsion refers to a sudden change in stream channel position on a fan due to partial or complete blockage of the existing channel by debris or due to exceedance of bankfull conditions. During an event, part or all of a flow may avulse out of the existing channel and travel across a different portion of the fan. Table C-4 lists criteria used to rate avulsion potential as Very High, High, Moderate, Low, or Very Low, based on channel confinement and surface evidence for previous

[8] For clearwater flood, impact likelihood was estimated only based on terrain interpretation.

avulsions. Fans where reports or evidence for past avulsion events were available were generally assigned a “Very High” or “High” rating. BGC notes that fan-deltas (fans that form in standing water bodies, such as large lakes) have an inherently higher avulsion potential than terrestrial (land-based) alluvial fans due to channel back-filling effects from the stream-water body interface. As such, these fans were typically assigned a “Very High” or “High” rating, as long as the channel was not entrenched (highly dissected) into the fan. Fan deltas with steeper gradients are likely to be less influenced by lake level and were assigned an avulsion rating based on fan characteristics.

Channel confinement level was based on estimated bank height and the presence of locations where confinement could be reduced during an event (e.g., channel bends, changes in channel gradient, channel constrictions at road crossings). Surface evidence for previous avulsions included vegetation and the presence of relict channels, lobes and deposits on the fan surface (e.g. Figure C-11). These features are readily detectable on lidar hillshades; interpretations are less certain for areas without lidar coverage.

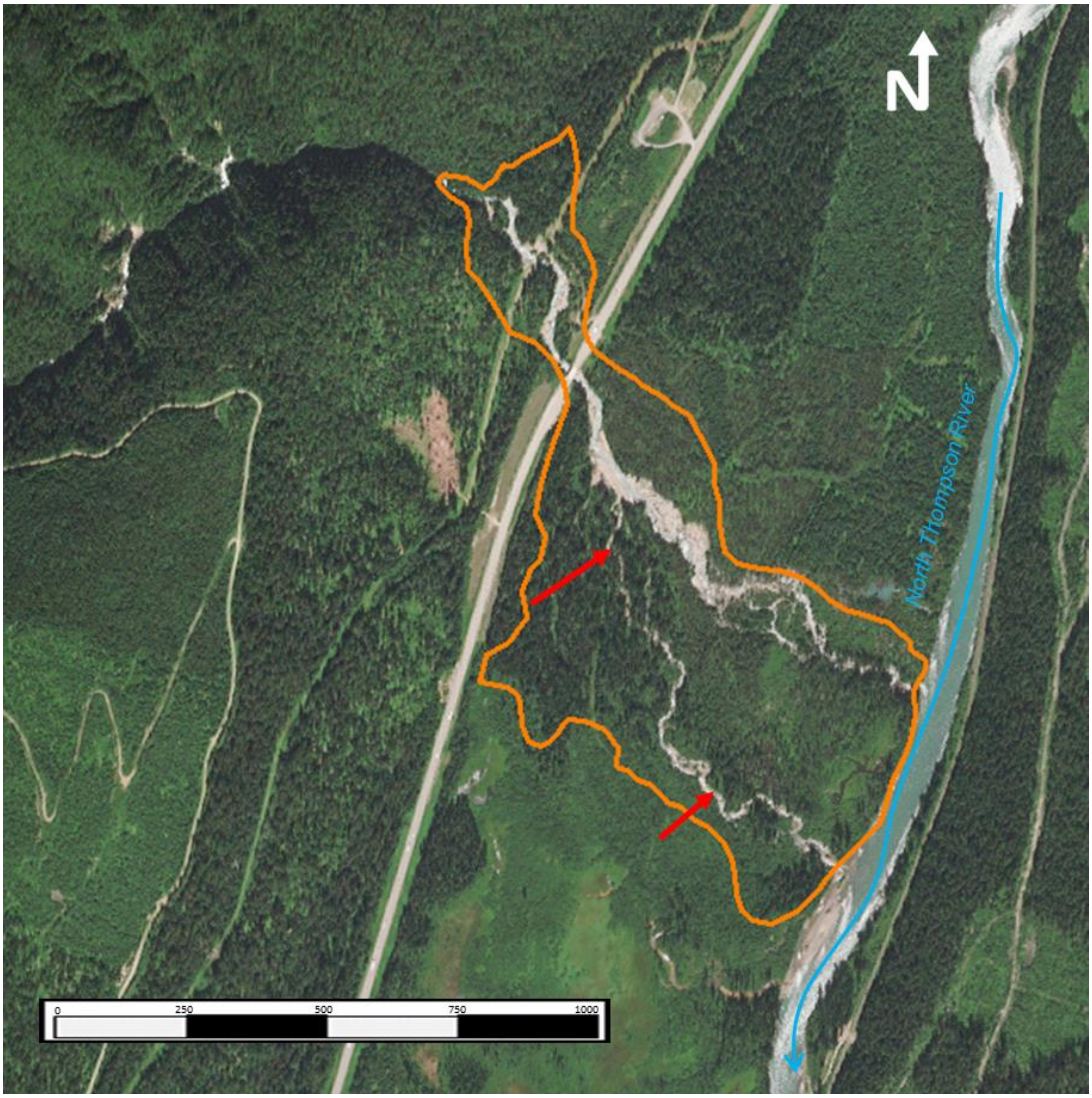

Figure C-11. Example of evidence for high avulsion potential on Miledge Creek, located north of Blue River. The approximate fan boundary is shown in orange.

Table C-4. Avulsion potential criteria.

Surface Evidence of Previous Avulsions[2]			Channel Confinement[1]: Very High	Channel Confinement[1]: High	Channel Confinement[1]: Moderate	Channel Confinement[1]: Low	Channel Confinement[1]: Very Low
			Deeply incised, straight channel; no obvious locations where confinement could be reduced during an event (e.g., channel bends, changes in channel gradient, channel constrictions).	Obvious (likely >15 m high) channel banks on LiDAR hillshade; no obvious locations where confinement could be reduced during an event (e.g., channel bends, changes in channel gradient, channel constrictions).	Obvious (likely 5-15 m high) channel banks on LiDAR hillshade; some presence of locations where confinement could be reduced during an event (e.g., channel bends, changes in channel gradient, channel constrictions or areas of potential blockage).	Minor or transient channel banks visible on LiDAR hillshade (likely < 5 m high), or obvious presence of locations where confinement could be reduced during an event (e.g., channel bends, changes in channel gradient, channel constrictions).	Multiple channels visible on LiDAR hillshade. Minor or transient channel banks visible on LiDAR hillshade (likely < 5 m high), or obvious presence of locations where confinement could be reduced during an event (e.g., channel bends, changes in channel gradient, channel constrictions).
Surface Evidence of Previous Avulsions[2]	Very strong	Multiple obvious fresh avulsion paths exist. swaths of bare sediment or low (<2 yr) pioneer vegetation exist on previous avulsion paths.	n/a[3]	n/a[3]	n/a[3]	Very High	Very High
	Strong	Obvious fresh avulsion paths exist. swaths of bare sediment or low (<2 yr) pioneer vegetation exist on previous avulsion paths.	n/a[3]	n/a[3]	High	High	Very High
	Moderate	Relict channels on fan surface are well visible; swaths of young (<50 yr) deciduous or coniferous vegetation exist in previous avulsion paths.	n/a[3]	n/a[3]	Moderate	High	High
	Poor	Relict channels on fan surface exist but are vegetated and difficult to discern.	n/a[3]	Low	Low	Moderate	High
	Very Poor	No clear relict channels can be identified.	Very Low	Very Low	Low	Low	Moderate

Notes:

1. Channel confinement is a rating applied at the fan level of detail that primarily considers the natural channel. Channel constrictions at road crossings were identified as potential avulsion mechanisms (where existing). However, quantitative analysis of channel conveyance at bridge and culvert crossings was outside the scope of work.
2. Fans with no surface evidence or record of previous avulsions were assigned to the “Low” avulsion susceptibility category. Fans with recorded previous avulsion events were assigned to the “High” category.
3. A combination of high channel confinement and higher or moderate evidence of avulsion is unlikely.

C.3.2.2. Susceptibility Modelling

Debris flow or debris flood susceptibility mapping based on terrain interpretation alone is limited by the availability of surface evidence for past events, which may be hidden by development or obscured by progressive erosion or debris inundation. To address this limitation, BGC used a semi-automated approach based on the River Network Tool™ (RNT)[9], morphometric statistics (Section C.2.2.2), and the Flow-R model[10] developed by Horton *et al*. (2008, 2013) to identify debris flow or debris flood hazards and model their runout susceptibility. Others that have modelled debris flow susceptibility using comparable approaches include Blahut et al. (2010), Baumann et al. (2011), and Blaise-Stevens and Behnia (2016). This approach allowed estimation of potential debris flow or debris flood hazard extent on every fan within the study area, including both developed and undeveloped areas. The results were used to apply a baseline impact likelihood rating to each fan, as described in Section C.3.2.4.

<u>Flow-R Software</u>

FLOW-R propagates landslides across a surface defined by a digital elevation model (DEM). Sections of the freely available Canadian Digital Elevation Model (CDEM) at 20 m resolution were used in the current project. Flow-R simulates flow propagation based on both spreading algorithms and simple frictional laws. The source areas were identified as stream segments associated with debris flow or debris flood processes, based on the morphometric statistics presented in Section C.2.2.2. Both spreading algorithms and friction parameters need to be calibrated by back-analysis of past events or geomorphological observations (e.g., fans along Shuswap Lake).

Flow-R can calculate the maximum susceptibility that passes through each cell of the DEM, or the sum of all susceptibilities passing through each cell. The former is calculated in Flow-R using the “quick” calculation method and is used to identify the area susceptible to landslide processes. The “quick” method propagates the highest source areas, and iteratively checks the remaining source areas to determine if a higher energy or susceptibility value will be modelled. The latter is calculated in Flow-R using the “complete” method and can be used to identify areas of highest relative regional susceptibility. The complete method triggers propagation from every cell in the source segments.

For this study, the sum of susceptibilities using the “complete” method was calculated once the final model parameters had been calibrated. Although the absolute value of susceptibility at a given location has no physical meaning, areas of higher relative regional susceptibility account for both larger source zones (increasing the number of potential debris flows that reach a

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[9] The RNT was used to extract segments corresponding to the creeks within the study area and to supply watershed parameters (i.e., Melton Ratio, watershed length).

[10] "Flow-R" refers to "Flow path assessment of gravitational hazards at a Regional scale". See http://www.flow-r.org

susceptibility zone), as well as increased control of topographic features (i.e., incised channels or avulsion paths within alluvial fans).

BGC used the following steps to complete debris flow/flood susceptibility modelling using Flow-R:

- For model calibration purposes, BGC first completed susceptibility modelling at several steep creeks outside the study area, in the Town of Canmore. Steep creeks in this area have been previously assessed by BGC at a higher level of detail than any creeks within the TRW (Holm et al., 2018). As such, the Canmore-area creeks provided a good starting point to calibrate the model.
- BGC calibrated the Flow_R model parameters by attempting to reproduce the extent of fans in the Cache Creek area and in the region between Salmon Arm and Three Valley Gap.
- Finally, BGC applied the model to map debris flow and debris flood susceptibility on all creeks in the stream network, within the TRW. The results were further compared to terrain analyses and a database of past road closures (BC MoTI, 2018).

As explained previously, Flow-R parameters were calibrated separately in two regions within the TRW (Cache Creek area and Salmon Arm/Three Valley Gap area), to account for physiographic and climatic differences. The two regions correspond approximately to the eastern mountainous zone (including Cariboo Mountain, Northern Kootenay Mountains, Northern Shuswap Highland, Shuswap River Highland, Central Columbia Mountain, Northern Okanagan Basin and Northern Okanagan Highland) and the interior plateau (including Quesnel Highland, Cariboo Plateau, Cariboo Basin, Northern Thompson Upland, Tranquille Upland, Thompson Basin, Pavilion Ranges, Shuswap Basin, Guichon Upland, Nicola Basin, Western Okanagan Upland and Hozameen Range). Table C-5 and

Table C-6 show the Flow-R calibrated parameters for debris flows and debris floods, respectively. The debris flow and debris flood scenarios were modelled separately.

Table C-5. Calibrated debris flow parameters used in Flow-R.

Selection	FLOW-R Parameter	Value	
		Cache Creek Area	**Salmon Arm – Three Valley Gap Area**
Directions algorithm	Holmgren (1994) modified	dh = 2 exponent = 1	dh = 2 exponent = 12
Inertial algorithm	weights	Gamma (2000)	Gamma (2000)
Friction loss function	travel angle	9°	7°
Energy limitation	velocity	< 15 m/s	< 15 m/s

Table C-6. Calibrated debris flood parameters used in Flow-R.

Selection	FLOW-R Parameter	Value	
		Cache Creek Area	**Salmon Arm – Three Valley Gap Area**
Directions algorithm	Holmgren (1994) modified	dh = 2 exponent = 1	dh = 2 exponent = 1
Inertial algorithm	weights	Gamma (2000)	Default
Friction loss function	travel angle	5°	3°
Energy limitation	velocity	< 15 m/s	< 15 m/s

Flow-R results are displayed on the web map and generally correspond well to the extent of known debris flow or debris flood events and fan boundaries within the study area (Figure C-12). Within each affected area, the summed susceptibility values follow a negative exponential distribution (Figure C-13). They were classified into zones of very low, low, moderate, and high relative susceptibility based on comparison to fans with the clearest evidence of the extent of previous events, including avulsion channels and deposits visible on lidar imagery. Zones of the DEM with summed susceptibility values lower than a threshold corresponding to the 70th percentile were attributed 'very low' regional susceptibility (i.e., 'very low' susceptibility include the majority of areas covered by Flow-R simulations). Zones of 'low' regional susceptibility were defined between the 70th and 85th percentile (the 85th percentile corresponding approximately to the mean susceptibility value); 'moderate' and 'high' susceptibility were defined between the 85th and 95th percentile, and greater than the 95th percentile, respectively (Figure C-13). Portions of alluvial fans not encompassed by susceptibility modelling were interpreted as having 'very low' regional susceptibility where modern fan morphometry encouraged flow away from the unaffected area, or not affected by debris flows/floods where deep channel incision indicated paleofans.

BGC notes that regional scale modelling contains uncertainties and should be interpreted with caution. Susceptibility modelling is not suited for detailed risk analyses or risk control design, which require modelling of flow extent, depth and velocity for specific hazard scenarios. Average impact likelihood ratings do not apply to any specific element at risk on a fan. BGC highlights the following specific limitations:

- Susceptibility modelling on creeks without mapped fans contain much higher uncertainty.
- Some areas mapped as susceptible to debris flows or debris floods may not have credible potential for events due to factors not considered in screening level modelling, such as lack of sediment supply.
- Modelling was only completed for creeks within the mapped stream network. Because debris flows can also initiate in areas without mapped streams, additional debris flow hazard areas exist that were not mapped.
- Debris flow and debris flood susceptibility model calibration was optimized for flow propagation on the fan. Susceptibility modelling in the upper basin should be considered a proxy for debris sources, not necessarily an accurate representation of actual source areas.

- Flow-R provides estimates of debris flow propagation in watersheds from user-specified source areas as well as in the corresponding inundation areas on fans, which is the focus of this study. Propagation is simulated using parameters calibrated at regional scale. As such, it is not supposed to be used for detailed runout simulations. In addition, the model is not physics-based (it is an empirical model) and not attached to any specific return period. Thus, it cannot inform on return period-specific runout distance, nor does it provide flow depths and velocity estimates which are necessary to calculate debris flow intensities.

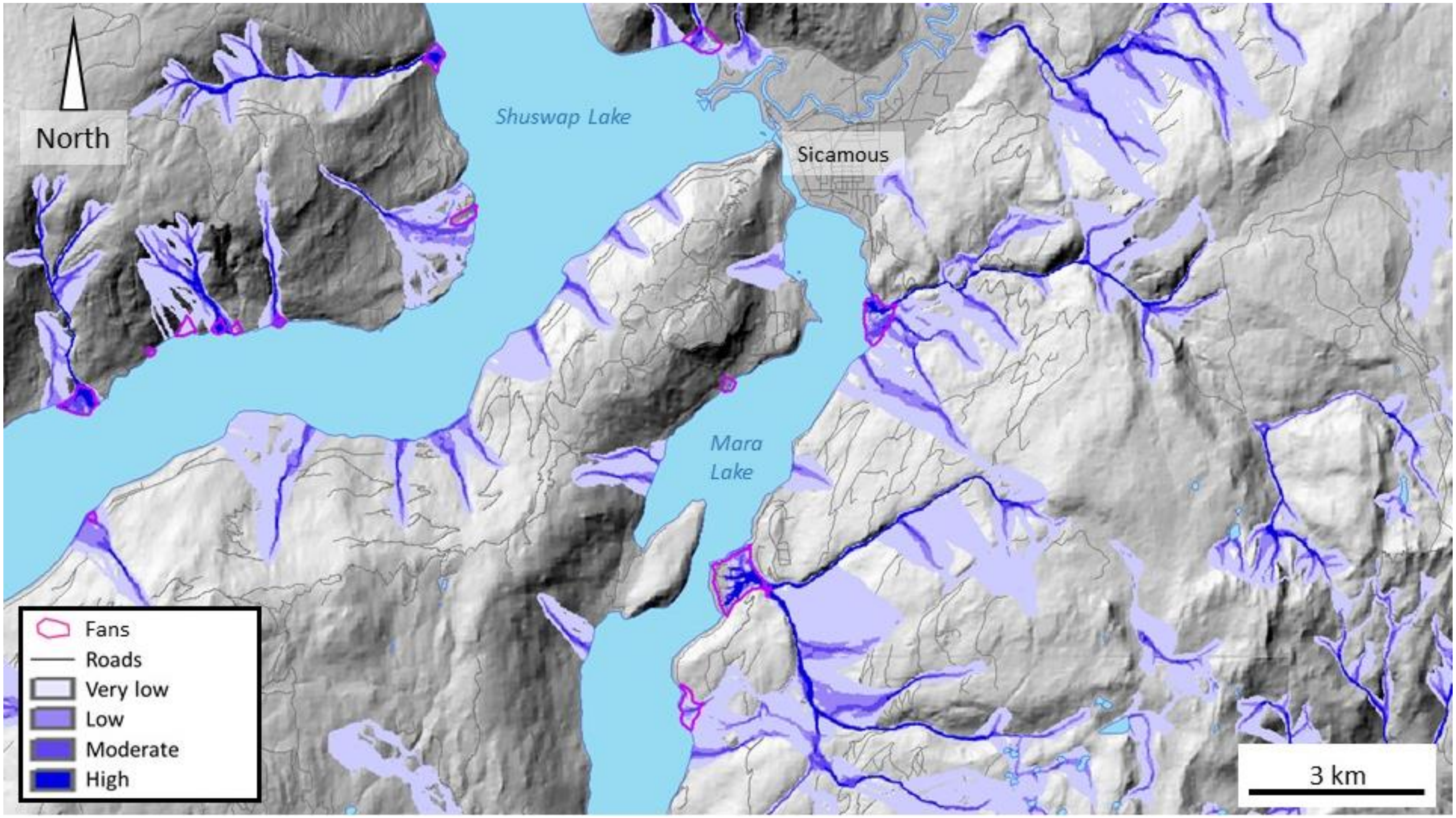

Figure C-12. Debris flood susceptibility map for a section of the study area showing the spatial distribution of the four different susceptibility classes. Note that this is a susceptibility map, and as such an individual debris flood event will very unlikely occupy the same area as shown in this figure.

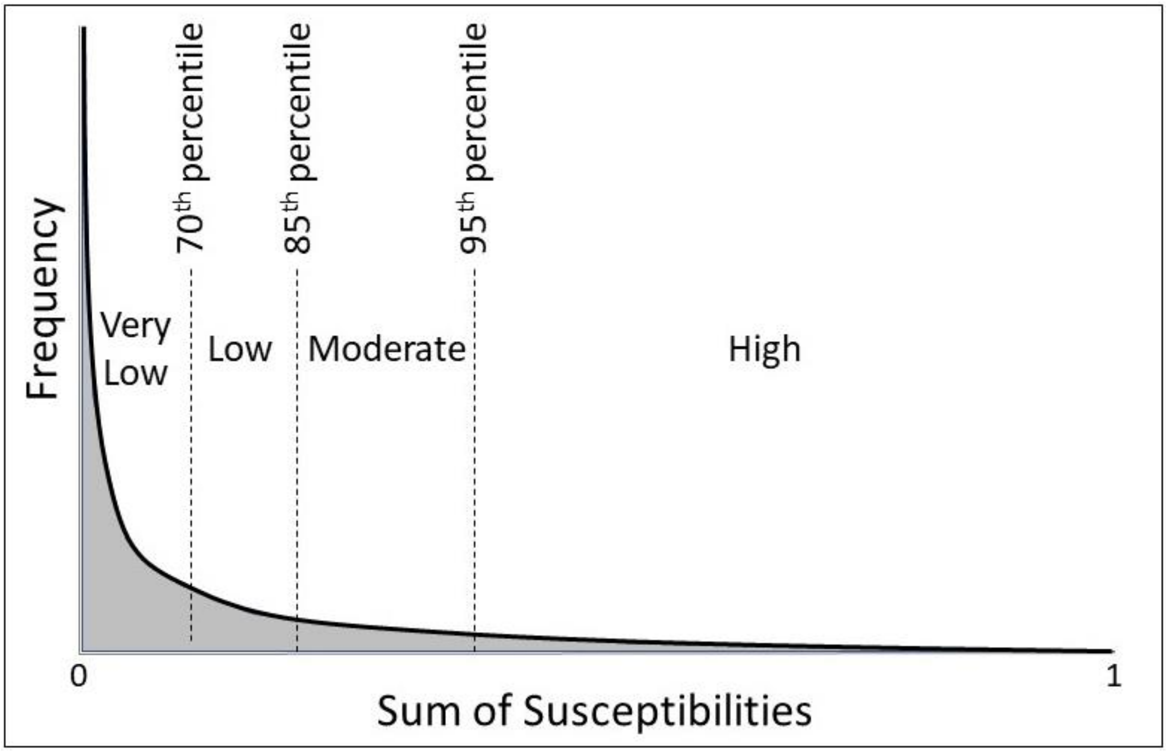

Figure C-13. Illustration of the negative exponential distribution of summed susceptibilities and the percentiles used to define zones of very low, low, moderate and high susceptibility.

C.3.2.3. Landslide Dam Outbreak Floods

Some steep creek watersheds are prone to landslide dam outbreak floods (LDOFs), which could have the potential to trigger major flooding, debris floods or debris flows. As part of the TRW geohazard risk assessment, LDOF hazards on stream and rivers with Strahler orders greater than 6 were evaluated as part of the landslide dam assessment (Appendix D).

Table C-7 lists criteria used to estimate the potential for LDOFs in upper basins. Ratings were assigned as Very High, High, Moderate, Low or Very Low based on evidence of past landslide dams, presence of large landslide scars with the potential to travel to the valley floor and presence of channel sections potentially susceptible to blockage (e.g., channel constrictions). LDOF potential is expected to be a factor potentially increasing avulsion potential; therefore, it is considered in the impact likelihood rating (see Section C.3.2.4). However, LDOFs are a distinct population of events from “conventional” debris flows and debris floods. This rating serves as a flag for consideration of more specific analyses to address this type of geohazard.

Table C-7. Landslide dam outbreak flood potential criteria.

Relative Frequency	Landslide Dam Outbreak Flood Potential
Very High	Extensive evidence of past landslide dams, presence of large landslide scars with the potential to travel to the valley floor, channel sections potentially susceptible to blockage (e.g., channel constrictions)
High	Evidence of past landslide dams, presence of large landslide scars with the potential to travel to the valley floor, channel sections potentially susceptible to blockage (e.g., channel constrictions)
Moderate	Minimal evidence of previous landslide dams, presence of potential landslides with the potential to travel to the valley floor, presence of channel sections potentially susceptible to blockage (e.g., channel constrictions)
Low	No evidence of previous landslide dams, presence of potential landslides with the potential to travel to the valley floor, presence of channel sections potentially susceptible to blockage (e.g., channel constrictions)
Very Low	Absence of evidence of larger landslides reaching the valley floor, no evidence of previous landslide dams

Evidence for LDOF potential was gathered from lidar and satellite imagery. Figure C-14 shows an example of a potential landslide dam located north of Clearwater. Note that other landslide dams may not be visible at the resolution of Figure C-14; the interpretation is based on the combination of characteristics noted above. These basins are identified on the web application and in results for consideration in future more detailed assessment.

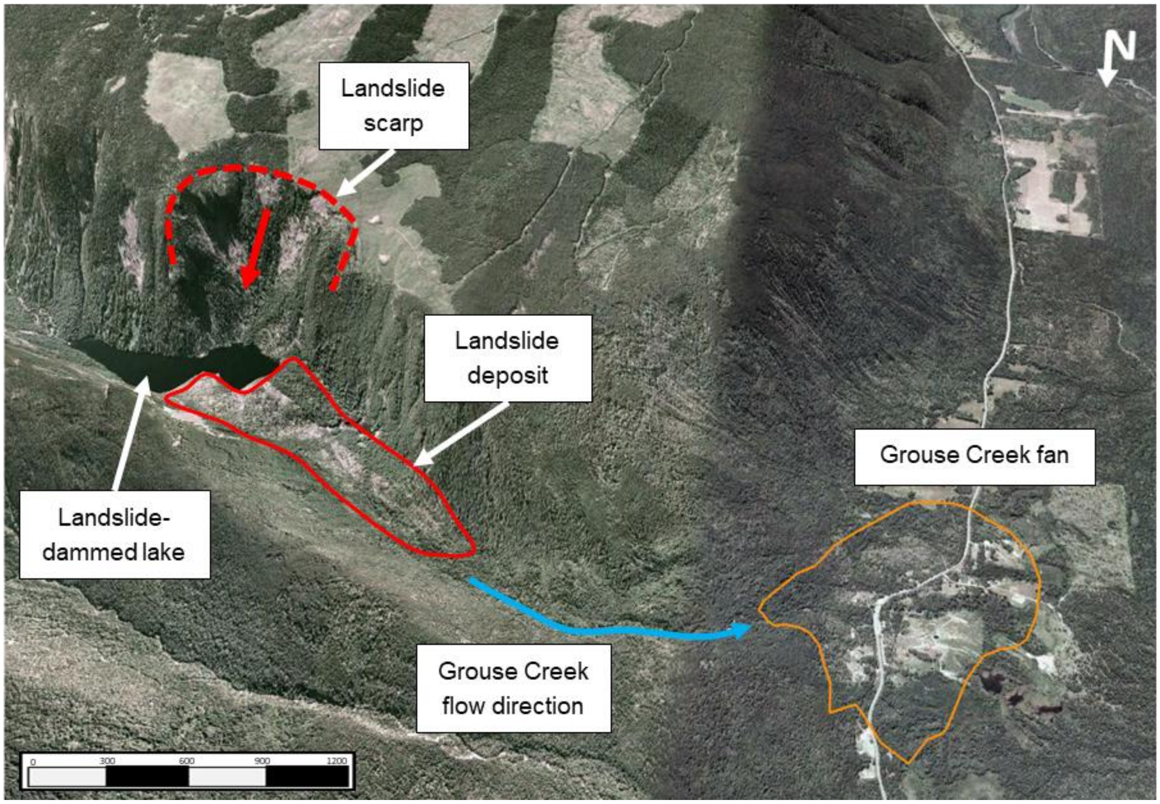

Figure C-14. Example for evidence for a landslide dam outbreak flood potential in Grouse Creek basin, north of Clearwater. The age of the landslide is unknown.

C.3.2.4. Impact Likelihood Rating

Table C-8 and Table C-9 provide impact likelihood criteria, which are based on both susceptibility modelling and terrain interpretation. Consistently with the regionalization of the TRW used in Section C.3.2.2 for Flow-R parameter calibration, separate impact likelihood criteria were defined for the two regions. In each region, the impact likelihood rating was first calculated as the proportion of "moderate" and/or "high" susceptibility zones included within the area of each fan. If required, this baseline was then adjusted based on terrain interpretation of evidence for past avulsion. The impact likelihood rating was further adjusted to flag the fans where there is a possibility of major flooding events associated with potential landslide dam outbreak events, as explained in Section C.3.2.3. For clearwater floods, impact likelihood was estimated based on avulsion potential (Table C-4) and adjustments for evidence of past avulsion and possibility of landslide dam outbreak events.

Table C-8. Summary of criteria used for impact likelihood rating in the region corresponding to the interior plateau of the TRW.

Impact Likelihood Rating	Criteria*
Very Low	Fan area is rated Very Low susceptibility; no evidence of past avulsion
Low	Less than 5% of fan area is rated Moderate or High susceptibility; none to poor evidence of past avulsion
Moderate	Less than 5% of fan area is rated Moderate or High susceptibility, and moderate evidence of past avulsion; OR 5 to 30% of fan area is rated Moderate or High susceptibility, and poor evidence of past avulsion
High	More than 30% of fan area is rated High susceptibility; OR 5 to 30% of fan area is rated Moderate or High susceptibility, and moderate evidence of past avulsion
Very High	More than 30% of fan area is rated High susceptibility, and moderate to strong evidence of past avulsion; OR 5 to 30% of fan is rated Moderate or High susceptibility, and strong evidence of past avulsion

Note:

* The impact likelihood rating was increased by a factor of 1 if the landslide dam outbreak flood potential criteria are "moderate"; and by a factor of 2 if they are "high' or "very high".

Table C-9. Summary of criteria used for impact likelihood rating in the region corresponding to the eastern mountains of the TRW.

Impact Likelihood Rating	Criteria*
Very Low	Fan area is rated Very Low susceptibility; no evidence of past avulsion
Low	Less than 5% of fan area is rated Moderate or High susceptibility; none to poor evidence of past avulsion
Moderate	Less than 5% of fan area is rated Moderate or High susceptibility, and moderate evidence of past avulsion; OR 5 to 40% of fan area is rated Moderate or High susceptibility, and poor evidence of past avulsion
High	More than 40% of fan area is rated High susceptibility; OR 5 to 40% of fan area is rated Moderate or High susceptibility, and moderate evidence of past avulsion
Very High	More than 40% of fan area is rated High susceptibility, and moderate to strong evidence of past avulsion; OR 5 to 40% of fan is rated Moderate or High susceptibility, and strong evidence of past avulsion

Note:

* The impact likelihood rating was increased by a factor of 1 if the landslide dam outbreak flood potential criteria are "moderate"; and by a factor of 2 if they are "high' or "very high".

C.3.3. Geohazard Rating

Table C-10 presents a qualitative geohazard rating assigned to each area. It combines the hazard likelihood (Table C-3) and impact likelihood ratings (Table C-8) and provides a relative estimate of the likelihood for events to occur and result in flows outside the main channel. For example, a fan estimated to have a high likelihood of events that could result in consequences, and where large proportions of the fan are highly susceptible to impact, would be assigned a high geohazard rating.

Table C-10.Geohazard rating.

Geohazard Likelihood	**Geohazard Rating**				
Very High	M	H	H	VH	VH
High	L	M	H	H	VH
Moderate	L	L	M	H	H
Low	VL	L	L	M	H
Very Low	VL	VL	L	L	M
Impact Likelihood	Very Low	Low	Moderate	High	Very High

C.4. GEOHAZARD INTENSITY

In a detailed steep creek analysis, destructive potential is characterized based on intensity, which is quantified by parameters such as flow depth and velocity. At a regional scale, these parameters are difficult to estimate, because they are specific to individual watersheds. To address this limitation, at the scale of the TRW, and in the context of the current prioritization study, BGC used peak discharge as a proxy for flow intensity.

C.4.1. Peak Discharge Estimation

Clearwater flood, debris flood and debris flow processes can differ widely in terms of peak discharge. Debris floods typically have peak discharges comparable to that of a flood but can have much larger quantities of sediment transported during an event (Hungr et al., 2014). In rare cases, debris floods can have peak discharges up to 2 to 3 times larger than floods if the event is associated with an outburst flood from a landslide dam breach (Jakob & Jordan, 2001). If the creek is subject to debris flows, the peak flow may be much higher (as much as 50 times) than the flood peak discharge (Jakob & Jordan, 2001). Figure C-15 shows a hypothetical cross-section of a steep creek, including:

- Peak flow for the 2-year return period (Q_2)
- Peak flow for the 200-year return period flood (Q_{200})
- Peak flow for debris flood (Q_{max} debris flood)
- Peak flow for debris flow (Q_{max} debris flow).

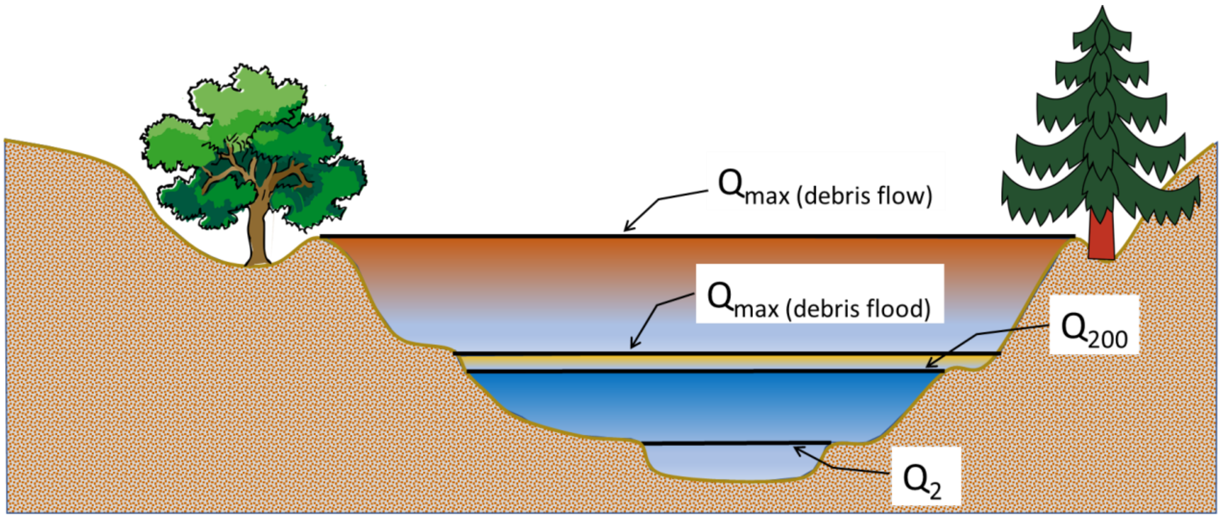

Figure C-15. Steep creek flood profile showing peak flow levels for different events.

Peak discharge for clearwater flood fans was calculated using flood frequency analysis (FFA), employing an internally developed tool called the River Network Tool (RNT™). The clear-water flood appendix (Appendix B) provides further information on RNT™ and discusses limitations and uncertainties.

Debris flood peak discharge was estimated as twice the peak discharge of a clearwater flood in the same creek, in order to account for a bulking effect[11] (Jakob and Jordan, 2001). Debris flow peak discharge was estimated using a regional, statistically based approach described further below.

Like clear-water floods and debris floods, debris flows follow a F-M relationship, where larger events occur more rarely. F-M relationships for debris flows are difficult to compile because of the scarceness of direct observations, the discontinuous nature of event occurrence, and the obfuscation of field evidence due to progressive erosion or debris inundation. Detailed F-M analyses involve a high level of effort for each creek that is outside the current scope of work.

However, when a number of reliable F-M curves have been assembled, regional relations can be developed. These relations can then be applied to watersheds for which detailed studies are unavailable, unaffordable or impractical due to lack of dateable field evidence. The number of watersheds with detailed F-M analyses is increasing, but at present is still limited.

In this assessment, BGC used F-M curves developed by Jakob et al. (2016) from creeks in southwestern British Columbia and Bow Valley, Alberta that have received detailed geohazard investigations (where the magnitude refers to sediment volume rather than peak discharge) (Holm et al., 2018). Individual F-M curves were normalized by dividing sediment volume by fan area and

[11] In reality, at a specific return period, debris flood peak discharge is not necessarily significantly higher (i.e., > 10%) than clearwater flood peak discharge; here, the bulking factor is used as proxy to account for typically higher destructive potential.

then plotted collectively versus return period. A logarithmic best-fit curve was then fit to the data. Figure C-16 shows the resulting F-M curves for debris flows in southwestern British Columbia and the Bow Valley, Alberta.

BGC cautions against the indiscriminate use of regionally based F-M curves, especially in watersheds where multiple geomorphic upland processes are suspected, or where drastic changes (mining, major landslides) have occurred in the watershed that are not yet fully responded to by the fan area. These site-specific factors could result in data population distributions that violate underlying statistical assumptions in the regional F-M curves.

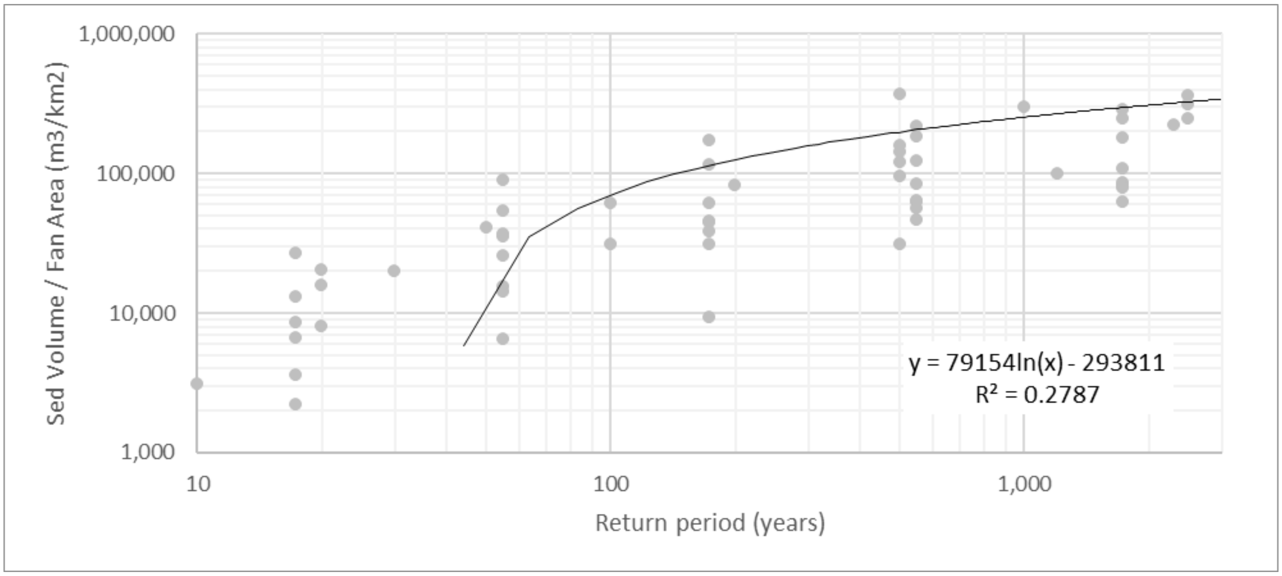

Figure C-16. F-M curve for debris flows in southwestern British Columbia and Bow Valley, Alberta, using data from sixteen study creeks. Curves are truncated at the 40-year return period (Jakob et al., 2016).

The regional F-M relationship (Equation C-1, derived from Figure C-16) was developed by BGC from the detailed study[12] of sixteen creeks in southwestern BC, as follows:

$$V_S = A_f[79{,}154\ln(\mathrm{T}) - 293{,}811] \quad \text{[Eq. C-1]}$$

BGC predicted sediment volumes (V_s) for each study fan with area (A_f) of the TRW study area for an average return period (T) of 200 years. Results are provided on Cambio Communities based on the best fit line for the regional F-M curve.

[12] BGC December 2, 2013a/b; December 18, 2013; 2014, October 23, 2015; January 22, 2015; April 21, 2015; November 23, 2015; May 31,2017; June 2018; April 6, 2018; September 25, 2018; Cordilleran Geoscience 2008 and 2015; Clague et al. 2003; and Michael Cullen Geotechnical Ltd. and Cordilleran Geoscience 2015.

Having determined sediment volume, three published empirical relations for granular debris flows were considered to estimate peak flow (or discharge) on each study debris flow creek interpreted. These relations are as follows:

$M = 13 * Q^{1.33}$ (Mizuyama et al., 1992) [Eq. C-2]

$M = 28 * Q^{1.11}$ (Jakob and Bovis, 1996) [Eq. C-3]

$M = (10 * Q)^{6/5}$ (Rickenmann, 1999) [Eq. C-4]

where M is the debris flow volume in m^3 and Q is peak discharge in m^3/s. The above equations were solved iteratively for Q using the sediment volumes (M) derived using Equation F-1. The average of the above peak flow relations is reported for each creek in the tables in their respective section below, where applicable.

C.4.2. Hazard Intensity Rating

Peak discharge estimates obtained based on the methods described in Section C.4.1 were analyzed statistically and integrated into an intensity rating system, where the Very Low to Very High classes were defined using percentiles (Table C-11). It should be noted that debris flow peak discharge estimate are based on a regional approach using FM data from case studies outside of the TRW study area, which may result in overestimation of peak discharge. To address this issue, we estimated that debris flow peak discharge could not exceed the peak discharge of a clearwater flood in the same creek by more than 50 times. Paleofans were not attributed intensity rating.

Table C-11. Summary of criteria used for intensity rating. The percentage criteria related to peak discharge estimates at all study fans.

Hazard Intensity Rating	Criterion
Very Low	< 20th percentile
Low	20th to 50th percentile
Moderate	50th to 80th percentile
High	80th to 95th percentile
Very High	95th to 100th percentile

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APPENDIX D
HAZARD ASSESSMENT METHODOLOGY: LANDSLIDE-DAM FLOODS

D.1. INTRODUCTION

D.1.1. Objectives

This study follows a systematic approach to 1) define the extent of the landslide-dam flood hazard study area, 2) perform landslide-dam flood geohazard characterization, and 3) assign geohazard and consequence ratings to prioritize landslide-dam flood prone watercourses in proximity to developed areas within the Thompson River Watershed (TRW). The assessment considers landslide-dam flood hazards within the TRW along the Thompson River and its main tributaries. The effects of landslides and floodwaters impacting lakes and potentially creating landslide-generated tsunamis are excluded from this study. Uncertainties associated with each step in the assessment are described in each section.

This appendix discusses inputs to the risk prioritization completed for all geohazards in this study. BGC recommends that the reader review Section 5.0 (Risk Prioritization) of the main document prior to reading this appendix. The appendix is organized as follows:

- Section D.1 provides background information and a historical overview of landslide-dam flooding within the TRW.
- Section D.2 provides an overview of the assessment workflow.
- Section D.3 describes methods used to identify landslide-dam flood prone watercourses.
- Sections D.4 to D.6 describe methods used to assign geohazard ratings.

D.1.2. Landslide-dam Floods

A landslide-dam flood is a flooding event that can occur when a landslide blocks the flow of a watercourse (e.g. stream or river) leading to the impoundment of water on the upstream side of the dam and potentially the rapid release of the impounded water due to catastrophic dam failure. For this part of the project, the ‘geohazard’ is landslide-dam flooding (both upstream inundation floods and downstream outburst floods). The formation and failure of a landslide dam is a complex geomorphic process because it involves the interaction of multiple geomorphic hazards. Major elements of the process are shown in Figure D-1.

Landslide dams are most frequently formed in geologically active mountainous regions, such as the Canadian Cordillera, because these areas contain more abundant landslide sources, and more abundant watercourses prone to blockage (Clague & Evans, 1994).

Landslide dam flooding requires that the dam, once formed, persists long enough to impound water. A dam which quickly erodes or otherwise fails does not produce upstream or downstream flooding. A stable dam may persist for hundreds or thousands of years and result in essentially permanent impoundment and upstream impacts. Alternatively, downstream impacts may be realized in cases where a landslide dam persists long enough to temporarily impound hazardous volume of water, yet ultimately fails catastrophically, releasing the impounded water, potentially leading to downstream impacts. Stability is function of multiple variables such as dam geometry, structure, material, and particle size distribution (Costa & Schuster, 1988; Korup & Tweed, 2007).

Landslide dam failure case studies by Ermini et al. (2006); Costa and Schuster (1988); and Peng and Zhang (2012) show that the failure rate is at least 80% within one year of landslide-dam formation, for cases not breached intentionally by humans. The most common modes of failure are from overtopping, seepage piping, displacement waves (caused by landslides into the landslide dam lake), and erosion of the downstream face of the dam (Hermanns, 2013; Korup & Tweed, 2007; Peng & Zhang, 2012).

The extent of upstream flooding is a function of the height of the dam, the gradient, morphology of the river valley, longevity of the dam, and rate of flow for the impounded watercourse (Peng & Zhang, 2012; Clague & Evans, 1994; Costa & Schuster, 1988). If landslide-dam fails and an outburst occurs, the magnitude of downstream flooding is controlled by the maximum discharge during the outburst event and the outburst volume (Evans, 1986) as well as the downstream channel and floodplain morphology. For example, a wide floodplain allows a flow to attenuate, while a narrow and steep channel will likely preserve a very high discharge for a longer distance downstream.

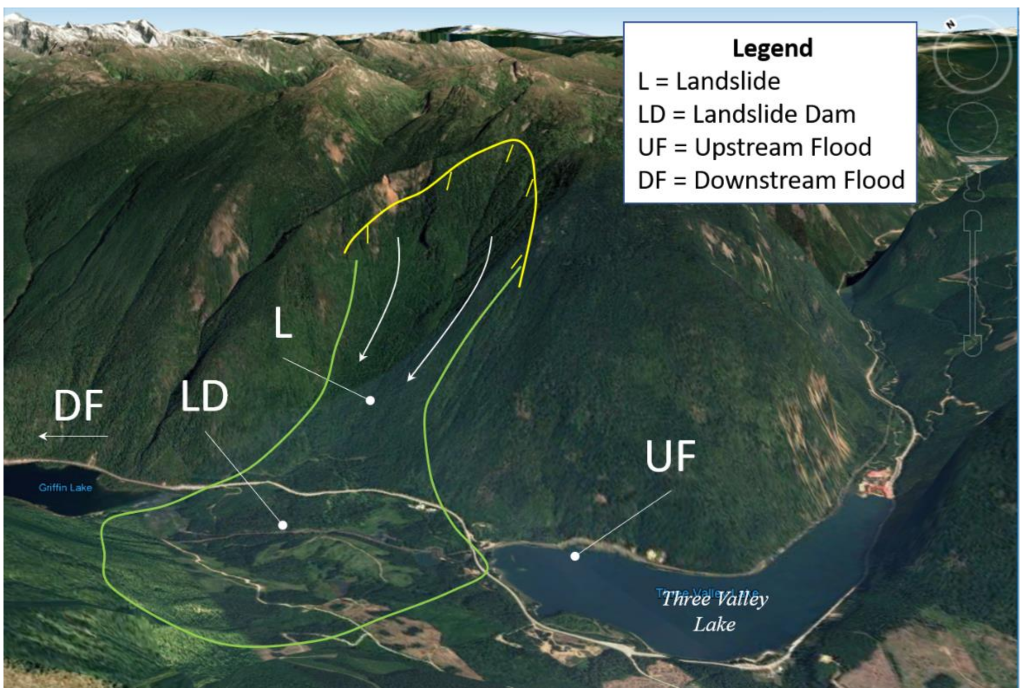


Figure D-1. Major components of a landslide-dam floods. Oblique image from Google Earth showing Three Valley Lake, a landslide dam lake on the Eagle River, BC (See Section D.1.3 and Figure D-2). Yellow shows the prehistoric landslide source areas and green lines show the approximate extent of landslide deposit.

Many landslide dam flood risks have been assessed; however, nearly all are studies of existing dams (e.g., Chen et al., 2017; Shi et al., 2017; Shrestha & Nakagawa, 2016; Zhu et al., 2015; Korup, 2005a; Yang et al., 2013; Dong et al., 2010; and Ermini et al., 2006). These methodologies are not easily applied to this analysis, which is a basin-wide risk analysis of potential flooding from potential landslide dam events. Korup (2005b) discusses risk-based framework for areas without pre-existing dams, and Hungr (2011) discussed methods for estimating landslide dam volumes, but both methods require detailed numerical modeling, which is beyond the scope of this study.

D.1.3. History of Landslide Dams in the Thompson River Watershed

Since 1880 least nineteen[1] landslide-dam formation and flooding events have been documented within the Canadian Cordillera (Clague & Evans, 1994). Three of those events occurred in the TRW between 1880 and 1921 on the Thompson River south of Ashcroft, BC (Figure D-2, Figure D-3, and Table D-1) along a 10 km stretch of river. These are the only documented historical accounts of landslide-dam flooding within the TRW; however, geomorphic evidence suggests similar events have occurred prehistorically within the TRW on other rivers.

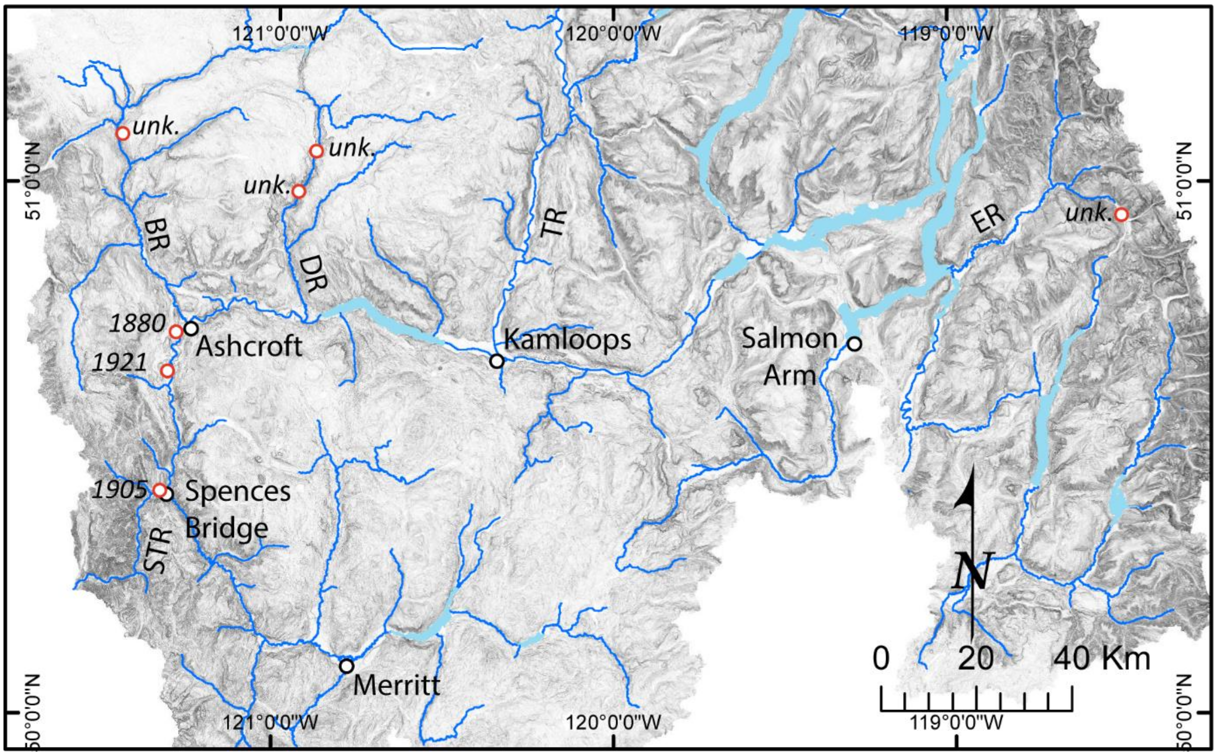


Figure D-2. Locations of historic landslide dam locations and other landslide dam locations of unknown age in the TRW. Landslide dam locations are shown as white circles with red outlines and labeled with event year in italics. Older events labeled as unknown ("*unk.*") age. Relevant rivers are labeled: STR = South Thompson River; BR = Bonaparte River; DR = Deadman River; TR Thompson River, and ER = Eagle River.

[1] Total excludes known or possible mining-related events compiled by Clague and Evans (1994).

Figure D-3. Locations of historic landslide on the South Thompson River between Ashcroft and Spences Bridge, BC. White dots labeled with numbers correlate to site numbers in Table D-1. Unlabeled black dots are other landslide sites in Tappenden (2017). Image from Google Earth.

Evans (1981) mapped landslides sourced from tertiary volcanics along the Deadman River and documented multiple landslide dams. Evidence for damming is also found on the Bonaparte River, about 45 km upstream from Ashcroft, but is not documented in literature. What might be the largest example of a landslide dam in the TRW is on the Eagle River, approximately 50 km upriver from Shuswap Lake. At this location, a large (>2x10^6 m^3) rock avalanche sourced on Mt. Griffin, fell into the valley, dammed the river and created Three Valley Lake (Evans et al., 2002). None of these landslides have been datedbut their morphology suggestsan age of hundreds to thousands of years. These sites are different from landslide dam sites along the South Thompson River because landslide deposits remain in the valley bottom and in some cases still impound water, probably because of more erosion-resistant or somewhat permeable landslide dam materials, and less energetic and erosive watercourses.

D.1.3.1. Historic Landslide-Dam Flood Events in the Thompson River Watershed

The following paragraphs describe the three historic landslide dam events along the Thompson River. Table D-1 summarizes these and other historic partial dam events in the same area.

Table D-1. Historical landslide dam and partial landslide dam events in the TRW.

No.	Location or Landslide Name	Date	Type	Current Activity	Effects
1	Spences Bridge Shawnikan Mtn	August 1, 1880	Rockslide(?)	NA	Partial dam, Thompson River
2	North	October 14, 1880	Complex earth slide-debris flow	Reactivated	**Thompson River dammed** for 44 hours
3	Goddard	October 19, 1886	Compound earth slide	Reactivated	Severed CPR rail line
4	CN 50.9	September 22, 1897	Compound earth slide	Inactive, stabilized	Constricted Thompson River
5	Spences Bridge	December 31, 1899	NA	NA	Partial dam, Thompson River
6	Spences Bridge	August 13, 1905	Complex earth slide	NA	**Thompson River dammed** for 5 hours and created a 3-4.5 m wave; 15 fatalities.
7	Red Hill / Hammond Ranch	August 13, 1921	Compound earth slide	Reactivated	**Thompson River dammed**
8	Goddard	September 24, 1982	Complex earth slide	Reactivated	Severed CPR rail line

Notes:

1. CPR = Canadian Pacific Railway.
2. NA = Data are not available.
3. Table after Tappenden (2017).
4. Site numbers in table (No.) correspond to site numbers shown in Figure D-3.

<u>1880 landslide-dam event</u>

On October 14, 1880 a landslide in Quaternary sediments with an estimated volume of 15 x 10^6 m^3 and a length of approximately 900 m dammed the Thompson River 7 km downstream from Ashcroft. This site of the landslide is known as the north slide. The lake which formed behind the dam had an estimated maximum pool depth of approximately 18 m and extended 14 km upstream, which flooded the town of Ashcroft with at least 40 cm of water. On October 16, 1880, workers excavated an emergency spillway and drained the lake as a precaution against outburst flooding (Clague & Evans, 1994; Tappenden, 2017).

1905 landslide-dam event

On August 13, 1905 a landslide in Quaternary sediments occurred at the First Nations village of Spences Bridge. The landslide completely blocked the flow of the Thompson River and formed a lake with a maximum depth of approximately 4.5 m. Within four to five hours workers excavated an emergency spillway to drain the lake as a precaution against outburst flooding. At least 18 lives were lost in this event (Septer, 2007; Tappenden, 2017; Walkern, 2015).

1921 landslide-dam event

On August 13, 1921 a landslide occurred in Quaternary sediments 9 km downstream from Ashcroft at the Red Hill/Hammond Ranch landslide. It completely blocked the flow of the Thompson River and it formed a lake with a depth of about 4 m. The dam lasted for several hours before it was naturally destroyed (Clague & Evans, 1994; Septer, 2007; Tappenden, 2017).

D.1.4. Data Sources

Data compiled to support the primary tasks of the landslide-dam flood hazard assessment include the following:

Elevation data

- 20-meter digital elevation models (DEM) downloaded from Canada Digital Elevation Model[2] (CDEM).

Digital stream network

- The digital stream network was downloaded from BGC Engineering Inc.'s (BGC) proprietary River Network Tools (RNT™) (see Appendix B, Section B.2). Strahler[3] order ≥6 watercourses were then selected as a subset because of their spatial overlap with the in-scope extent of the study (Thompson River and the main tributaries). They were then merged into 40 separate watercourses based on geographic names (Figure D-4).

Imagery

- Google Earth™, which was used for analysis of aerial imagery.

[2] CDEM data downloaded from URL: https://open.canada.ca/data/en/dataset/7f245e4d-76c2-4caa-951a-45d1d2051333.
[3] Strahler stream order is a classification of watercourse segments by its branching complexity within a drainage system and is an indication of the significance in size and water conveying capacity at points along a river (Strahler, 1957).

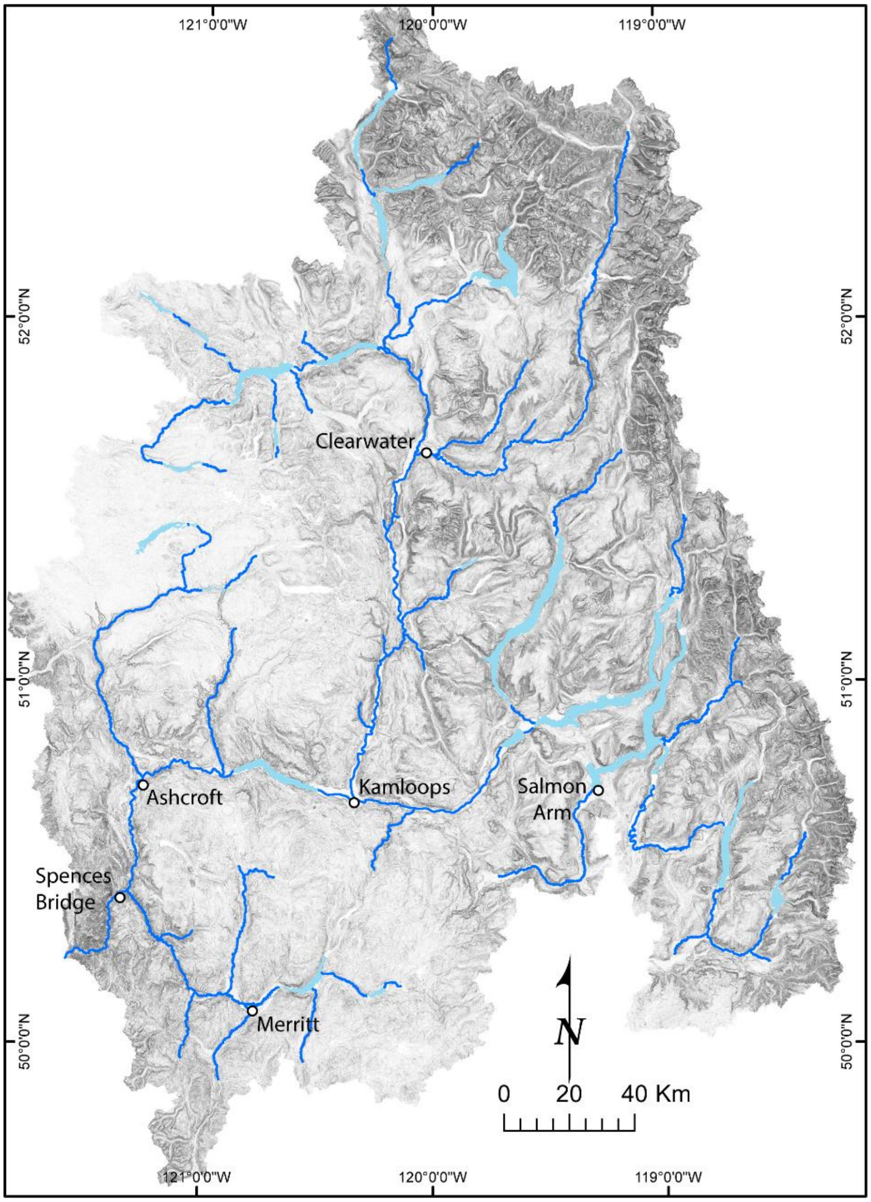


Figure D-4. Watercourses of Strahler order ≥6 and major lakes of the TRW. Town locations shown for geographical reference. Grayscale basemap is the 20-m DEM slope map clipped to the TRW boundary.

Interferometric synthetic aperture radar (InSAR)

- BGC compiled InSAR data for the extent of the TRW. These data were collected between 2007 and 2011 by the L-band PALSAR (PS1) sensor with a typical revisit time of 46 days. The approximate grid cell resolution is 15 m, and each scene measures about 70 km x 100 km on the ground. The InSAR data were used in this study with the intent of identifying areas of slope movement as a method for identifying potential landslide dam sources. However, visual inspection of the data found that the quality and resolution of the data to be limited which made widespread use of the data across the TRW not possible. For areas where data quality is suitable for use, BGC used the InSAR as an additional method for locating potential large landslide sources. The InSAR work is fully described under separate cover (3v, 2018).

Landslide locations

- The inventory of potential landslide dams includes 91 landslide locations (points) compiled from published reports, literature and maps, an internal BGC landslide location database, and locations interpreted by BGC from 20-m DEM and InSAR data. It includes landslide locations across the TRW, with an emphasis on areas around Strahler order ≥6 watercourses. The inventory is not exhaustive but does form an important input into characterising landslide and landslide dam likelihood along the different watercourse included in this study.

D.2. ASSESSMENT WORKFLOW

Section 5 of the main document describes the risk prioritization framework, which is consistent across the clear-water flood, steep creek, and landslide-dam flood geohazard types considered in this study. In all cases, the assessment involves determining geohazard and consequence ratings for a given area (section of river), which combine to form a priority rating.

The assessment workflow is built around several questions:

1. Geohazard identification:
   - Where are landslides capable of blocking watercourses?
   - Given these landslide scenarios, how can streams be separated into by stream reaches with different likelihoods of landslide-dams occurring and flooding developed areas?
2. Geohazard rating:
   - For a given a watercourse segment, what is the likelihood that a landslide could occur and form a dam somewhere in that segment?
   - Given that a landslide dam forms, what is a reasonable upstream and downstream limit to potentially flooded areas, for the purpose of prioritization, and what is the chance that any given location within this extent could be flooded?
3. Consequence rating:
   - Given landslide-dam flooding, what elements at risk are potentially exposed to hazard? What would be the anticipated intensity (destructive potential) of the flooding?
4. Priority rating:
   - What is the combined, relative probability that landslide-dam floods occur and reach developed areas (geohazard rating), and impact elements at risk with some intensity?

Section D.3 describes methods related to geohazard identification, defining river sections to be prioritized. Once these are defined, Figure D-5 describes the work flow to address the remaining questions and assign geohazard and consequence ratings. Inputs informing how the ratings were determined are shown around the perimeter of the figure.

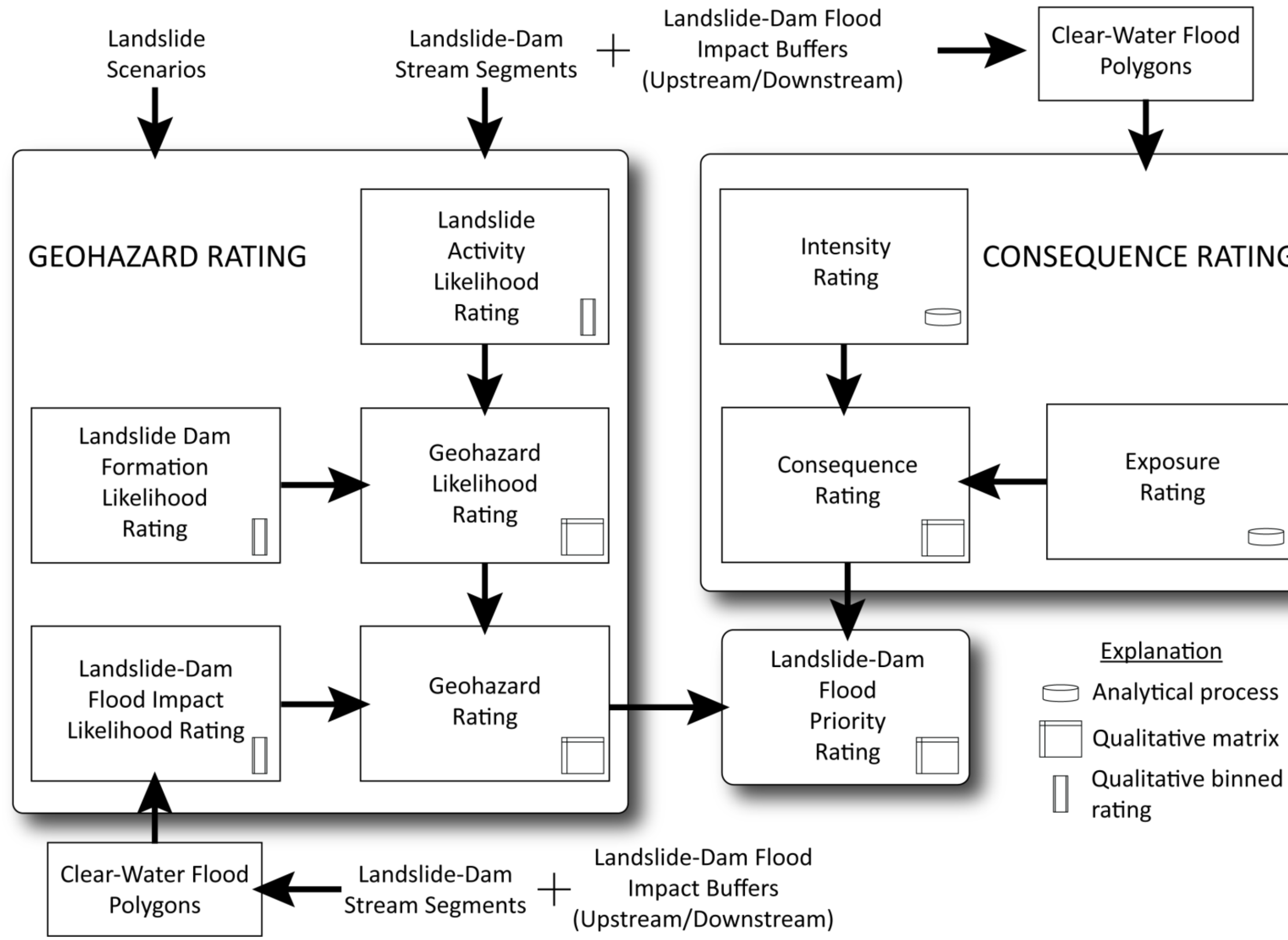


Figure D-5. Landslide-dam flood hazard analysis workflow. Geohazard rating elements are described in Appendix D (this text). Consequence rating elements are described in other sections (Appendix B and C, and Section 5.0 of the Main Report).

The following sections describe each step of Figure D-5 in more detail. Section 5.0 of the main report describes how geohazard and consequence ratings are combined to provide priority ratings.

D.3. GEOHAZARD IDENTIFICATION

This section describes how watercourses were divided into segments to be prioritized from the perspective of landslide-dam flood risk. It is these watercourse segments that are shown on the web application to display results and supporting information.

Two questions are addressed to define watercourse segments:

1. What landslide scenarios could result in landslide dams? (Section D.3.1)
2. Given these landslide scenarios, how can streams be separated into by stream reaches with different likelihoods of landslide-dams occurring and flooding developed areas? (Section D.3.2)

D.3.1. Landslide Scenarios

Most types and styles of landslide are possible in the TRW. In this study not all types are considered; instead, BGC focused on those with the potential to form dams with guidance from Clague & Evans (1994). We consider rapid to extremely rapid (Varnes, 1978) landslides, which were chosen because slower landslides are more likely to be eroded by the higher order watercourses included in this study.

BGC also considered landslides having volumes of $5x10^5$ m^3 or larger, and which occur from failures in bedrock slopes, dissected Quaternary valley fills, and relatively thin Quaternary sedimentary mantling rock slopes as most likely to form landslide dams. The minimum credible landslide volume ($5x10^5$ m^3) is based on the detectable resolution of landslide morphology of the 20-m DEM and within the size range for small landslides events compiled by Clague and Evans (1994). Geological and topographical conditions make landslides more-or-less likely for any given location within the study area. We did not evaluate the potential for each landslide explicitly, nor did we define site-specific governing scenario(s), instead we use these criteria to capture a range of capable landslide-dam sources.

D.3.2. Landslide Dam Watercourse Segments

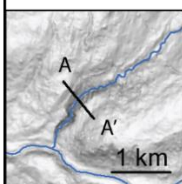
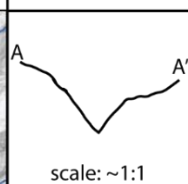
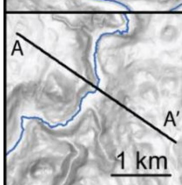
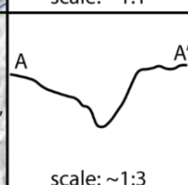
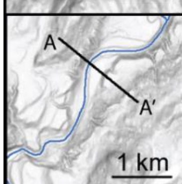
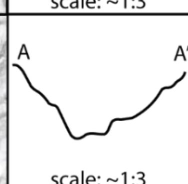
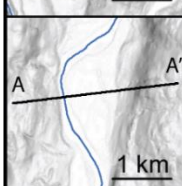
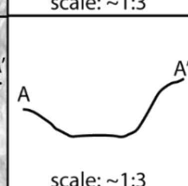
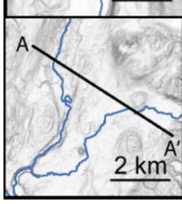
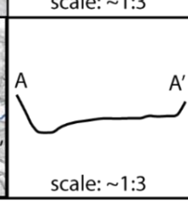
The TRW encompasses a very large region characterized by highly variable geologic and topographic conditions (see Section 2.3 and 2.4). For risk prioritization, watercourses must be divided into segments that can be characterized and prioritized in terms of landslide-dam flood risk. All information gathered and assessed is assigned to each water course segment, for reporting and display on maps.

To identify unique segments at a scale appropriate for this study, the 40 Strahler order ≥6 watercourses (Figure D-4) were split into shorter segments of relatively uniform morphology, then classified by landslide dam formation likelihood. The segmentation process was guided by the valley morphology and geological conditions, and segment boundaries were placed at major changes in valley and stream morphology.

After the segmentation process, the individual segments were classified into one of five landslide-dam formation likelihood types. This classification is based on valley type descriptions by Rosgen (1996), who classifies valley morphology based on 12 valley types descriptions; Using some of the aspects of the Rosgen (1996) classification, such as terminology and groupings of their valley types, the classification system developed for this study includes the assumption that deeper, narrower valleys are more susceptible to landslide damming than those which are broader and less constrained.

Each watercourse segment was classified based on the descriptions shown in Table D-2, listed from highest to lowest likelihood of dam formation (given a landslide):

Table D-2. Watercourse classification scheme with representative images and profiles.

Example Image	Schematic Profile	Description
		**Very High**: River segment is deeply entrenched and confined within a steep and narrow V-notch valley.
		**High**: River segment is entrenched and confined within a narrow valley and may have constrictions. If flood plain is present it does not have significant area to attenuate landslide debris and may become blocked.
		**Moderate**: The river valley is moderately steep and confined, may include glacial troughs and incised alluvial valleys.
		**Low**: River valley is broad with low angle to flat valley floors; includes broad U-shaped valleys and the confluence of some tributaries where blockage is possible but not certain.
		**Very Low:** River valley is very broad and flat, and confining relief is at a distance that would require very rare long landslide runout lengths and volumes. Includes confluence of major tributaries, broad U-shaped valleys in glaciated uplands, and alluvial fans in broad valleys.

Notes:

1. Example Image and Schematic Profiles shows representative valley shapes for each valley type.
2. Basemaps for Example Image are 20 m DEM slope map data.
3. Schematic profile scale = horizontal : vertical.

This process resulted in 146 segments classified by landslide dam formation likelihood, which range in length from < 1 km to 70 km and have an average length of 14 km. Each segment was analysed (Figure D-5) and individually attributed with likelihood ratings. These segments are displayed in Cambio Communities to present landslide-dam flood hazard likelihoods and ratings.

D.4. GEOHAZARD RATING

Table D-3 displays the matrix used to assign geohazard ratings to landslide-dam flood watercourse segments based on the following two factors:

1. Geohazard likelihood: What is the likelihood of landslide-dam flood event large enough to potentially impact elements at risk through upstream and downstream flooding (Section D.3.1).
2. Impact Likelihood: Given a geohazard event occurs, how susceptible is the hazard area to uncontrolled flooding that could impact elements at risk (Section D.3.2).

Table D-3. Geohazard rating for landslide-generated flooding potential.

Geohazard Likelihood	Geohazard Rating				
Very High	M	H	H	VH	VH
High	L	M	H	H	VH
Moderate	L	L	M	H	H
Low	VL	L	L	M	H
Very Low	VL	VL	L	L	M
Impact Likelihood	Very Low	Low	Moderate	High	Very High

Geohazard ratings are displayed for each Strahler order ≥6 watercourse segment (n = 146) in Cambio Communities and are also provided at an overview level of detail in Figure D-6. Section D.4.1 describes how geohazard likelihood ratings were estimated. Section D.4.2 describes how BGC defined the upstream and downstream limit of impact from landslide dams in a given watercourse segment, and 0 describes how BGC assigned impact likelihood ratings for these areas.

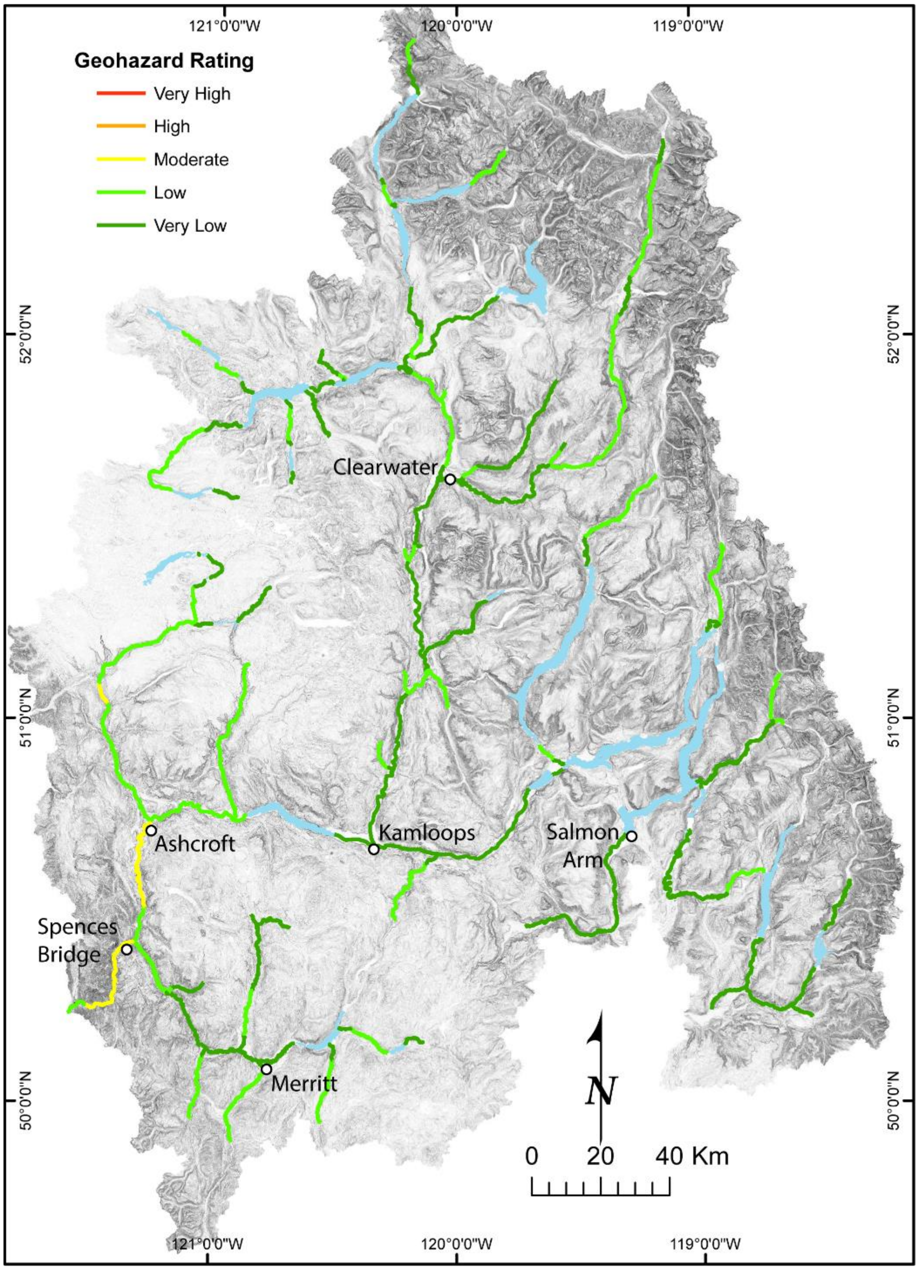


Figure D-6. Landslide dam watercourse segments (n=146) symbolized by Geohazard Rating. Grayscale basemap

D.4.1. Likelihood Rating

This section defines the process used to assign ratings to each watercourse segment described in Section D.3, for the estimated likelihood that landslides occur and result in landslide dams somewhere in the watercourse segment. Two questions are addressed:

1. Within a given watercourse segment, how likely is it that a potentially dam-forming landslide occurs?
2. Given that such a landslide occurs, what is the likelihood that it forms a dam?

These questions are addressed by assigning ratings for the likelihood that a landslide will happen (Landslide Activity Likelihood Rating) and – if it happens – form a dam capable of causing upstream and downstream flooding (Landslide-Dam Formation Likelihood rating). The ratings are combined in a matrix with values ranging from Very Low to Very High (Table D-4).

Sections D.4.1.1 and D.4.1.2 provide more detailed description of how these ratings are estimated. A map showing the Geohazard Likelihood for all 146 landslide dam watercourse segments is shown in Figure D-7.

Table D-4. Likelihood rating.

Landslide Activity Likelihood	**Likelihood Rating**				
Very High	M	H	H	VH	VH
High	L	M	H	H	VH
Moderate	L	L	M	H	H
Low	VL	L	L	M	H
Very Low	VL	VL	L	L	M
Landslide-Dam Formation Likelihood	Very Low	Low	Moderate	High	Very High

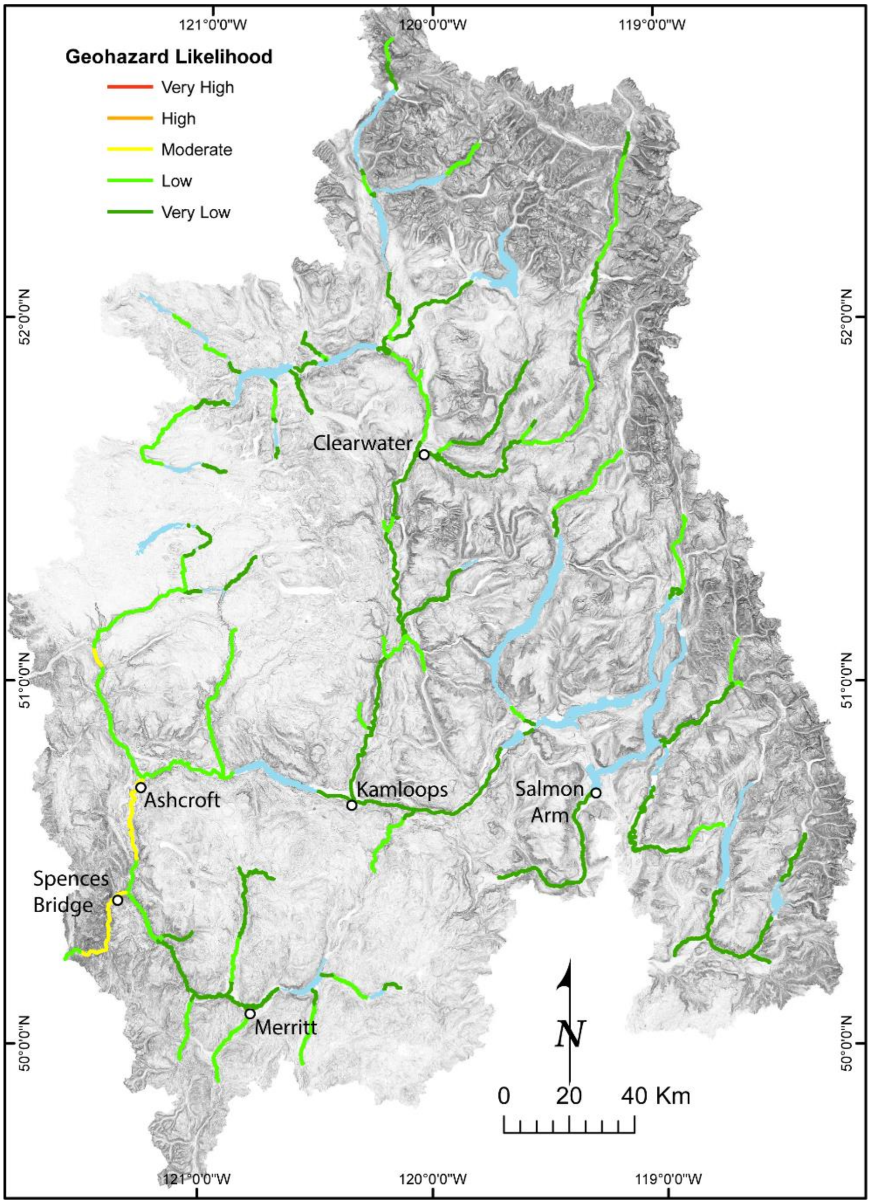


Figure D-7. Landslide dam watercourse segments (n=146) symbolized by Landslide Damming Likelihood. Grayscale basemap is the 20-m DEM slope map clipped to the TRW boundary.

D.4.1.1. Landslide Activity Likelihood

Landslide activity likelihood corresponds to the historic frequency and average annual probability of landsliding at a scale large enough to form a dam. Each landslide dam watercourse segment was evaluated based on historical accounts, literature review, visual inspection of DEM, InSAR, aerial imagery, and the landslide inventory (see Section D.1.3) to predict rates of landslide activity. Although this methodology may omit individual landslides smaller than $5x10^5$ m^3, it is expected to capture most large events and also shows areas of high rates of landslide activity. Each landslide dam watercourse segment is assigned a rating from very low to very high based on the criteria shown in Table D-5.

Return periods are estimated based on available event ages for historical events or estimated based on the visual inspection of available data. The frequency scale applied for this rating is calibrated for higher frequency hazards, such as clear-water floods and debris flows. It is not calibrated to the annual frequency of occurrence for large landslide which in many regions occurs on timescales of hundreds to thousands of years (Clague & Evans, 1994). However, the purpose of this analysis is to prioritize areas in the TRW where landslide return periods are occurring at relatively high rates, without precisely resolving the likelihoods of less frequent landslides. Based on the criteria shown in Table D-4, this analysis characterized sites with very low to high landslide activity likelihood. No sites were characterized as a very high landslide activity likelihood.

Where the average annual return period for large landslides is 30 to 100 years, historic events have almost surely occurred and are likely documented in available records. The landslides should have a relatively fresh appearance on the landscape, meaning that their extents are well defined, and vegetation is likely disturbed. Events with an average annual return period of 100 to 300 years, might be within the historic record depending on settlement and occupation dates[4]. In appearance, they are likely more weathered, but still have well defined boundaries, and revegetation may be moderate. Events with an average annual return period of >300 years will be more weathered and have a more subdued expression on the landscape than shorter-return period events. The landslide scars may be difficult to detect, and the debris and scars could be heavily vegetated. BGC expects expect that the lowest frequency events in this category could have return periods in the thousands of years; however, that wide range is acceptable for this study because the objective is to prioritize, and identify the highest likelihoods, rather than precisely define the lowest.

The legacy of a landslide and landslide dam on the landscape varies, although none are expected to extend past the most recent glacial period. Nearly all central British Columbia was covered by the Cordilleran Ice Sheet at the time of the last glacial maximum (LGM), about 18,000 years ago (Clague, 2017). By 11,000, most of the ice had retreated, and the landscape experienced high rates of mass wasting and reworking of unstable sediments as the landscape adjusted to a relatively ice-free postglacial setting (i.e., paraglacial sedimentation) (Church & Ryder, 1972). Very large landslides from this time period that were composed of blocks of resistant rock and not scoured away by rivers or buried in sediment may still be preserved in the landscape today. Alternatively, smaller landslides and dams composed of erodible material may be essentially undetectable after several hundred years.

[4] Early settlement in the TRW happened in the early 1800’s. Populations increased in the 1860’s during the gold rush and arrival of the Canadian Pacific Railway in 1883.

Table D-5. Landslide activity likelihood rating criteria.

Landslide Likelihood	Characteristic for the respective watercourse segment
Very High	Abundant and relatively fresh landslide morphology and deposits within the valley and along the valley margins of the watercourse segment. Displaced slope material is abundant and constricts the river valley. Return period for events in stream reach is less than 10 years.
High	Numerous landslide deposits and morphology within the valley and along the valley margins is common Landslide scarps may be weathered and scars are deposits are revegetating but are clearly defined. Return period for any landslide damming event in stream reach is estimated to 10 to 30 years.
Moderate	Landslide source areas are well defined and visible on the landscape, but scars and deposits be moderately weathered and revegetated. Return period for any landslide damming event in stream reach is estimated to 30 to 100 years.
Low	Landslide source areas are poorly defined and there is an absence of fresh landslide deposits and morphology within the valley and along the margins. Return period for any landslide damming event in stream reach is estimated to 100 to 300 years.
Very Low	Landslide source areas may be very difficult to detect. Landslide scars and deposits are weathered, possibly subtle, and revegetated with mature trees. Return period of any landslide damming event any landslide damming is estimated to greater than 300 years.

The resulting landslide activity likelihood for all assessed watercourse segments is provided in Figure D-8.

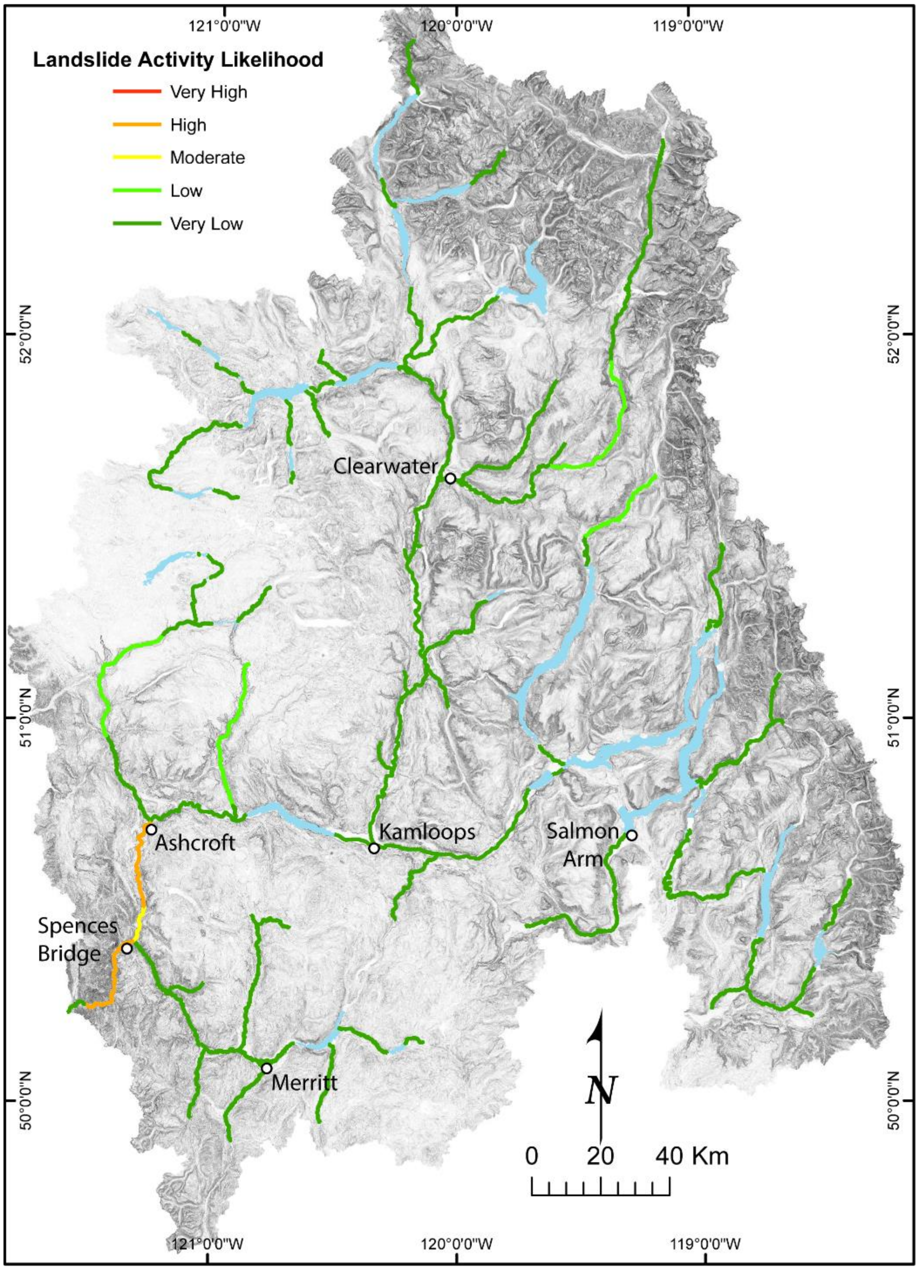


Figure D-8. Landslide dam watercourse segments (n=146) symbolized by Landslide Activity Likelihood. Grayscale basemap is the 20-m DEM slope map clipped to the TRW boundary.

D.4.1.2. Landslide-Dam Formation Likelihood

This evaluation considers the likelihood that a landslide dam will form, and flooding will occur. Landslide dam formation is a complex and highly uncertain process which relies on the integration of multiple factors that may or may not result in landslide-dam related flooding. To simplify the highly uncertain aspects of landslide dam formation, this criterion assumes that a given landslide dam will result in both upstream and downstream flooding.

BGC assigned a landslide dam formation likelihood to each watercourse segment based on the shape of the valley, as described in Section D.3.2. The 20-m DEM slope and hillshade maps and Google Earth were used to evaluate each watercourse segment, and then each watercourse segment was rated on a scale from Very Low to Very High, corresponding to the approximate chance that a dam will form, given landslide occurrence. Uncertainties in this evaluation are related to the ability of landslides to block the flow of water and create a dam. The criteria for these rankings are shown in Table D-6, while the assessed rating for each watercourse segment is shown in Figure D-9.

Table D-6. Landslide-dam formation likelihood rating criteria.

Landslide-Dam Formation Likelihood	Characteristic
Very High	Watercourse segment is deeply entrenched and confined within a steep and narrow V-notch valley. Nearly all (9 in 10) landslides will create a dam.
High	Watercourse segment is entrenched and confined within a narrow valley. If flood plain is present it is narrow. Most (2 in 3) landslides will create a dam.
Moderate	The river valley is moderately steep and confined; may include glacial troughs and incised alluvial valleys. Approximately half of all landslides may form a dam.
Low	River valley is broad with low angle to flat valley floors; includes broad U-shaped valleys and the confluence of major tributaries where blockage is possible but not certain, 1 in 3 events may create a dam.
Very Low	River valley is very broad and flat, confining relief is at a distance that would require long landslide runout lengths. Includes confluences of major watercourses, very broad U-shaped valleys in glaciated uplands and alluvial fans in major river valleys. Fewer than 1 in 10 landslides will form a dam.

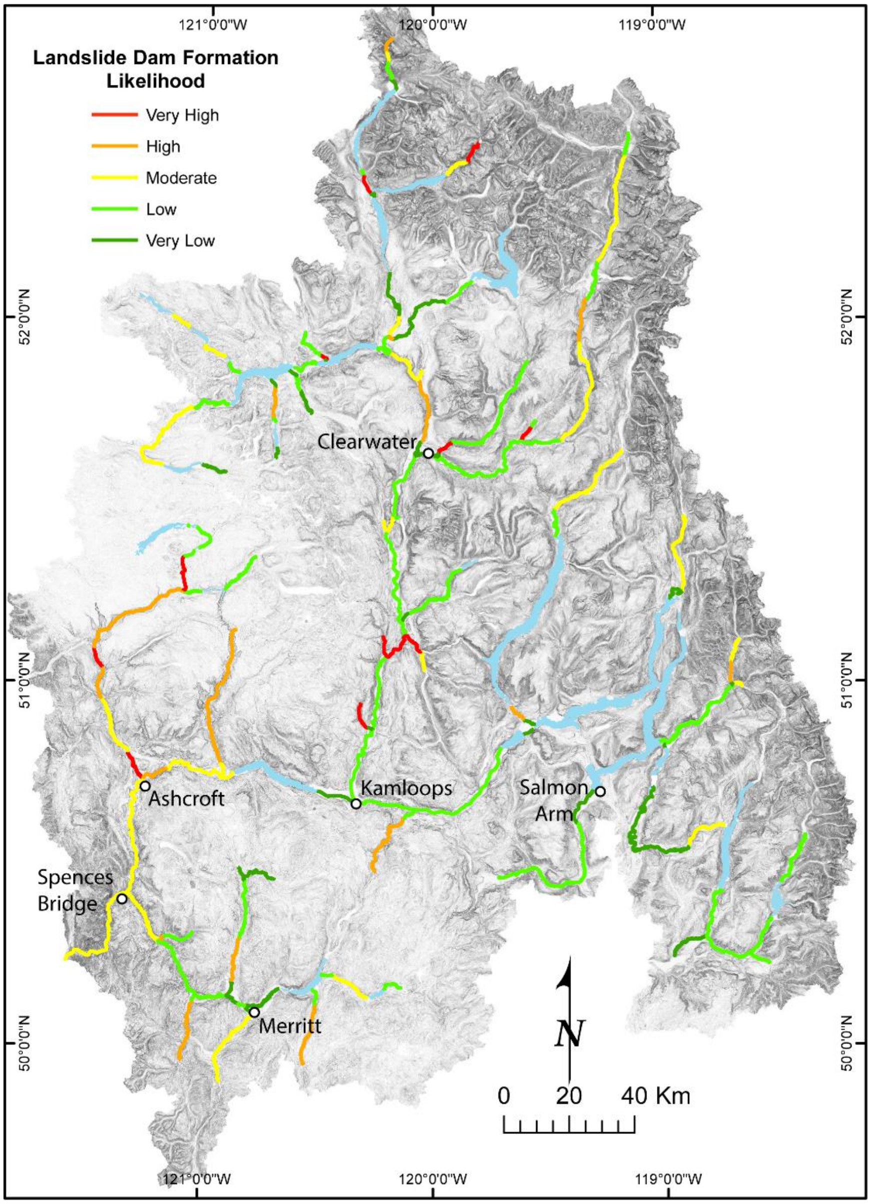


Figure D-9. Landslide dam watercourse segments (n=146) symbolized by Landslide-Dam Formation Likelihood. Grayscale basemap is the 20-m DEM slope map clipped to the TRW boundary.

D.4.2. Landslide-Dam Flood Impact Areas

The upstream and downstream extent of landslide-dam floods can be many kilometres from the dam location. For a given landslide-dam watercourse segment, a landslide-dam flood could impact areas not only along the segment, which assumes relatively consistent likelihood of landslide dam formation, but also beyond its upstream and downstream limits.

BGC applied a standardized approach to define potential landslide-dam flood impact areas associated with each landslide-dam watercourse segment. The approach addressed the following two questions:

1. Watercourse length: What is a reasonable upstream and downstream limit to the length of watercourse that could be affected by a landslide-dam flood, including the landslide-dam watercourse segment plus some distance beyond its upstream and downstream limit?
2. Impact area: For the length of watercourse affected, what is the floodplain area that could be impacted?

Watercourse Length

For a given dam height, the maximum upstream impoundment from a landslide-dam flood is likely to be caused by a landslide dam near the upstream limit of the watercourse segment. Conversely, a dam near the downstream limit is likely to result in outburst floods furthest downstream.

For downstream outburst flooding, BGC assigned a standard distance of 10 km beyond the downstream limit of a watercourse segment. While the downstream limit of flood propagation is highly uncertain, this distance captured elements at risk for standardized comparison of hazard exposure.

For upstream flooding, BGC assigned a standard distance beyond the upstream limit of a watercourse segment. The distance was based on an assumed watercourse gradient and dam height. For example, a higher dam and gentler river gradient would impound water further upstream.

BGC calculated the average river gradient for every watercourse in the TRW and assigned an average gradient to each watercourse segment based on their Strahler order. Then, BGC assumed a landslide dam height of 10 m at the upstream end of the segment. Table D-8 lists the resulting upstream flood distance calculated for each watercourse segment.

The 10 m dam height was chosen following review of recorded landslide dam events (Table D-7) and is based on the reported estimates of landslide-dam lake depths; thus, they may represent minimum heights. While historic landslide dams have exceeded 10 m, note that the 10m height is measured at the upstream limit of the water course. A higher dam would be required further downstream, to achieve the same limit of upstream flood impoundment.

Table D-7. Estimated historic landslide-dam heights.

Event Year	Event Name	Estimated Dam Height[5] (m)	Affected Upstream Reach (km)	Source
1880	North Landslide	18	14	Clague & Evans, 1994
1905	Spences Bridge	4.5	3.3[6]	Septer, 2007
1921	Red Hill/Hammond Ranch	4	5.5[7]	Septer, 2007

Table D-8. Estimated upstream landslide-dam flood distances by average gradient.

Strahler Order	Assumed Dam Height (m)	Average Gradient (%)	Estimated Upstream Flood Distance (km)
6	10	0.52	2.0
7	10	0.21	4.5
8 & 9	10	0.05	20.0

Impact Area

Given the screening level of study and size of study area, BGC used the same floodplain extents to define potential inundation areas for both clear-water floods and landslide-dam floods. Appendix B describes methods to define clear-water flood extents. For a given watercourse segment, BGC used floodplain extents along the watercourse and for the defined distances beyond its upstream and downstream limits.

BGC feels that this simplified approach is reasonable to prioritize areas, but it does not replace detailed landslide-dam flood modelling, which was outside the scope of work. With the information available, it is not possible to rule out the potential for landslide-dam flood impact areas to extend beyond the limits defined in this study.

D.4.3. Landslide-Dam Flood Impact Likelihood

Table D-9 shows the landslide-dam flood impact likelihood rating used in this study to describe for each landslide-dam watercourse segment (plus upstream and downstream distances) the proportion of the flood polygon expected to be impacted. The rating levels correspond approximately to those used for steep creek geohazards (Appendix C).

Given the screening level of study and the poor constraints on assigning this factor for landslide-dam floods, BGC assigned a uniform Low rating to each segment considered. This rating reflects the logic used to assign upstream and downstream limits of flooding. Specifically, Section D.4.2

[5] Landslide dam heights are estimated from reported landslide-lake depths.
[6] Upstream reach estimated from reported flood depths.

described how flood limits were conservatively based on landslide dams occurring near the upstream or downstream ends of a segment. A landslide-dam near the upstream end of a segment would likely cause flooding furthest upstream, and a landslide-dam near the downstream end of a segment would likely cause the furthest flooding downstream. As such, the total *possible* flood extent is large, but a specific location within this extent is not certain to be inundated. Because the location of landslide damming within a given segment is not known, the rating thus estimates a low chance of impact to a given location within a large area.

This estimate should be revisited following more detailed study. More detailed study would constrain the potential limit of flood extent (Section D.4.2) and increase confidence in estimates of spatial probability of landslide-dam flood impact within this area.

Table D-9. Landslide-dam flood impact likelihood rating. Low (shaded green) was applied to all areas.

Landslide-Dam Flood Impact Likelihood	Typical scenario (% of potential flood area impacted)
Very High	~>60%
High	30-60%
Moderate	15-30%
Low	<15%
Very Low	<5%

D.5. CONSEQUENCE RATING

BGC assigned Consequence Rating based on the following two factors:

1. Hazard Exposure Rating: Exposure of elements at risk to geohazards.
2. Hazard Intensity Rating: Destructive potential of uncontrolled flows that could impact elements at risk.

D.5.1. Hazard Exposure Rating

Elements at risk are things of value that could be exposed to damage or loss due to geohazard impact (geohazard exposure). This study assessed areas that contained elements at risk and were subject to geohazards. As such, identification of elements at risk was required to define the areas to be assessed and to assign consequence ratings as part of risk prioritization. Section 3.0 of the main study report provides a complete list of elements at risk that were assessed in the study and the relative weightings applied to elements for prioritization.

The hazard exposure rating considers the entire possible impact area, to reflect the range of elements at risk within the area. However, a single landslide-dam flood scenario is considered unlikely to flood the entire area (see Section 0). BGC considered this in risk prioritization by applying a low Impact Likelihood Rating. More detailed study would constrain the hazard exposure rating.

D.5.2. Hazard Intensity Rating

Estimating the intensity (destructive potential) of landslide-dam floods is highly uncertain in the absence of detailed modelling of upstream impoundment and downstream flood propagation, which were outside the scope of work. In the absence of detailed modelling, BGC applied the same relative hazard intensity rating to landslide-dam flood areas as clear-water flood areas covering the same extent. While flood intensity will differ in practice between these process types, this results in higher relative ratings being applied to watercourses with greater flood discharge, weighting prioritization more heavily towards the largest rivers prone to landslide-dam floods. This approach is not satisfactory for detailed geohazard mapping but is considered reasonable for relative risk prioritization at the scale of study. Appendix B describes methods used to assign hazard intensity ratings to clear-water flood hazard areas.

D.6. LANDSLIDE-DAM FLOOD PRIORITY RATING

Section 5.0 of the main report describes how geohazard and consequence ratings were combined to arrive at a priority rating for each geohazard area, or watercourse segment in the case of landslide-dam flood geohazards. The results are displayed on Cambio Communities and summarized in Section 6.0 of the main report.

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APPENDIX E
EXPOSURE ASSESSMENT

E.1. INTRODUCTION

This study assessed areas that both contained elements at risk and that were subject to geohazards. This appendix describes how elements at risk data were organized across the study area. Section 3.0 of the main report describes how weightings were assigned to these data as part of risk prioritization.

This appendix uses the following terms:

- **Asset** is anything of value, including both anthropogenic and natural assets.
- **Elements at risk** are assets exposed to potential consequences of geohazard events.
- **Exposure model** is a type of data model describing the location and characteristics of elements at risk.

Table E-1 lists the elements at risk considered in this study. These data were organized in an ArcGIS SDE Geodatabase stored in Microsoft SQL Server. Software developed by BGC was used to automate queries to characterize elements at risk within hazard areas. This will allow updates to be efficiently performed in future. Sections E.2 to E.8 describe methods used to characterize elements at risk and lists gaps and uncertainties. Appendix B lists data sources.

The elements at risk listed in Table E-1 was compiled from public sources, local and district government input, and data available from the Integrated Cadastral Information Society ((ICI Society, 2018)[1]. It should not be considered exhaustive. The prioritized geohazard areas typically include buildings improvements and adjacent development (i.e., transportation infrastructure, utilities, and agriculture). Elements where loss can be intangible, such as objects of cultural value, were not included in the inventory. Hazards were not mapped or prioritized in areas that were undeveloped except for lifelines or minor dwellings (i.e. backcountry cabins).

[1] Metadata stored with these data clarifies data sources and is available on request.

Table E-1. Elements at risk.

Element at Risk Type	Description	Category
People	Total population	<10
		10 – 100
		100 – 1,000
		1,000 – 10,000
		>10,000
Buildings Improvements	Total Improvement Value	<$100k
		$100k - $1M
		$1M - $10M
		$10M - $50M
		$50M - $100M
Critical Facilities	Presence of critical Facilities	Emergency Response Services
		Emergency Response Resources
		Utilities
		Communication
		Medical Facilities
		Transportation (excluding roads)
		Environmental
		Community
Businesses	Total annual revenue, or number of businesses where revenue data was not available.	<$100k annual revenue, or <2 businesses
		$100k - $1M annual revenue, or 2-4 businesses
		$1M - $10M annual revenue, or 5-10 businesses
		$10M - $50M annual revenue, or 11-50 businesses
		$50M - $100M annual revenue, or >50 businesses
		>$100M annual revenue, or >100 businesses
Lifelines	Road	Presence of any type
	Highway	0-10 vehicles/day (Class 7), or no data

Element at Risk Type	Description	Category
		10-100 vehicles/day (Class 6)
		100-500 vehicles/day (Class)
		500-1000 vehicles/day (Class 4)
		> 1000 vehicles/day (Class <4)
	Highway	Presence of any type
	Railway	
	Petroleum Infrastructure	
	Electrical Infrastructure	
	Communication Infrastructure	
	Water Infrastructure	
	Sanitary Infrastucture	
	Drainage Infrastructure	
Environmental Values	Active Agricultural Area	Presence of any type
	Fisheries	
	Species and Ecosystems at risk	

E.2. BUILDINGS (IMPROVEMENTS)

BGC characterized buildings (improvements) at a parcel level of detail based on cadastral data, which define the location and extent of title and crown land parcels, and municipal assessment data, which describe the usage and value of parcels for taxation.

Titled and Crown land parcels in British Columbia were defined using Parcel Map BC (ICI Society, 2018) and joined to 2018 BC Assessment (BCA) data to obtain data on building improvements and land use. BGC applied the following steps to join these data and address one-to-many and many-to-one relationships within the data:

1. BGC obtained the “Parcel code” (PID) from the Parcel Map BC table. If no Parcel code was available on this table, BGC joined from it to the “SHARED_GEOMETRY” table using the “Plan ID”, and from this obtained the PID.
2. PID was then used to join to the “JUROL_PID_X_REFERENCE” table, to obtain the “Jurol code”.
3. Jurol code was then joined to BCA data

BCA data was then used to identify the predominant actual use code (parcel use) and calculate the total assessed value of land and improvement. Where more than one property existed on a parcel, improvement values were summed. Table E-2 lists uncertainties associated with the use of BCA and cadastral data to assess the exposure of buildings development to geohazards.

Table E-2. Uncertainties related to building improvements and cadastral data.

Data Element	Uncertainty	Implication
Building Value	Improvement value was used as a proxy for the 'importance' of buildings within a geohazard area. While assessed value is the only value that is regularly updated province-wide using consistent methodology, it does not necessarily reflect market or replacement value and does not include contents.	Underestimation of the value of building improvements potentially exposed to hazard.
Cadastral Data Gaps	Areas outside provincial tax jurisdiction (i.e. First Nations Reserves) do not have BCA data are subject to higher uncertainty when characterizing the value of the built environment.	Incomplete information about the types and value of building improvements.
Unpermitted development	Buildings can exist on parcels that are not included in the assessment data, such as unpermitted development.	Missed or under-estimated valuation of development.
Actual Use Code	BGC classified parcels based on the predominant Actual Use Code in the assessment data. Multiple use buildings or parcels may have usages – and corresponding building, content, or commercial value – not reflected in the code.	Possible missed identification of critical facilities if the facility is not the predominant use of the building.
Parcel boundary	Parcels partially intersecting geohazard areas were conservatively assumed to be subject to those geohazards.	Possible over-estimation of hazard exposure

E.3. POPULATION

Population data was obtained from the 2016 Canada Census (2016) at a dissemination block[2] level of detail. BGC estimated population exposure within hazard areas based on population counts for each census block. Where census blocks partially intersected a hazard area,

[2] A dissemination block (DB) is defined as a geographic area bounded on all sides by roads and/or boundaries of standard geographic area. The dissemination block is the smallest geographic area for which population and dwelling counts are determined. (Statistics Canada, 2016).

population counts were estimated by proportion. For example, if half the census block intersected the hazard area, half the population count was assigned to the hazard area.

While Census data is a reasonable starting point for prioritizing hazard area, it contains uncertainties in both the original data and in population distribution within a census block. It also does not provide information about other populations potentially exposed to hazard, such as workers, and does not account for daily or seasonal variability. Because Census populations do not include the total possible number of people that could be in a geohazard area, they should be treated as a minimum estimate.

E.4. CRITICAL FACILITIES

Critical facilities were defined as facilities that:

- Provide vital services in saving and avoiding loss of human life
- Accommodate and support activities important to rescue and treatment operations
- Are required for the maintenance of public order
- House substantial populations
- Confine activities or products that, if disturbed or damaged, could be hazardous to the region
- Contain irreplaceable artifacts and historical documents.

BGC distinguished between "critical facilities" and "lifelines", where the latter includes linear transportation networks and utility systems. While both may be important in an emergency, linear infrastructure can extend through multiple geohazard areas and were inventoried separately.

BGC compiled critical facilities data provided as point shapefiles by District governments. Facility locations are shown on the web map, classified according to the categories shown in Table E-3.

Table E-3. Critical facility descriptions.

Category	Example facilities in this category, based on Actual Use Value descriptions[1]
Emergency Response Services	Emergency Operations Center, Government Buildings (Offices, Fire Stations, Ambulance Stations, Police Stations).
Emergency Response Resources	Asphalt Plants, Concrete Mixing, Oil & Gas Pumping & Compressor Station, Oil & Gas Transportation Pipelines, Petroleum Bulk Plants, Works Yards.
Utilities	Electrical Power Systems, Gas Distribution Systems, Water Distribution Systems, Hydrocarbon Storage.
Communication	Telecommunications.
Medical Facilities	Hospitals, Group Home, Seniors Independent & Assisted Living, Seniors Licenses Care.
Transportation	Airports, Heliports, Marine & Navigational Facilities, Marine Facilities (Marina), Service Station.
Environmental[2]	Garbage Dumps, Sanitary Fills, Sewer Lagoons, Liquid Gas Storage Plants, Pulp & Paper Mills.
Community	Government Buildings, Hall (Community, Lodge, Club, Etc.), Recreational & Cultural Buildings, Schools & Universities, College or Technical Schools.

Notes:

1. From BC Assessment Data classification.
2. Includes facilities with potential environmental hazards.

E.5. LIFELINES

Lifelines considered in this assessment are shown on the web map and include roads; railways; and electrical, sanitary, drainage, petroleum, communication, and water infrastructure. Table E-4 provides a more detailed breakdown of the utility classes shown in Table E-1 (ICI Society, 2018). BGC also obtained traffic frequency data from BC Ministry of Transportation and Infrastructure (MoTI), which were used to assign relative weights to different road networks as part of the prioritization scheme.

Table E-4. Utility systems data obtained from ICI Society (2018).

Id	Classified Type (BGC)	Description (ICI Society, 2018)	Position
1	Electrical Infrastructure	Electrical Duct Bank	Surface
2	Electrical Infrastructure	Electrical Junction	Surface
3	Electrical Infrastructure	Electrical Main	Surface
4	Electrical Infrastructure	Electrical Manhole	Surface
5	Electrical Infrastructure	Electrical Overhead Primary	Surface
6	Electrical Infrastructure	Electrical Overhead Secondary	Surface
7	Electrical Infrastructure	Electrical Overhead Transmission Line	Surface

Id	Classified Type (BGC)	Description (ICI Society, 2018)	Position
8	Electrical Infrastructure	Electrical Pole	Surface
9	Electrical Infrastructure	Electrical Pull Box	Surface
10	Electrical Infrastructure	Electrical Service Box	Surface
11	Electrical Infrastructure	Electrical Street Light	Surface
12	Electrical Infrastructure	Electrical Switching Kiosk	Surface
13	Electrical Infrastructure	Electrical Transmission Circuit	Surface
14	Electrical Infrastructure	Electrical Transmission Low Tension Substation	Surface
15	Electrical Infrastructure	Electrical Transmission Structure	Surface
16	Electrical Infrastructure	Electrical Underground Primary	Subsurface
17	Electrical Infrastructure	Electrical Underground Secondary	Subsurface
18	Electrical Infrastructure	Electrical Underground Structure	Subsurface
19	Electrical Infrastructure	Electrical Underground Transformer	Subsurface
20	Electrical Infrastructure	Electrical Vault	Subsurface
39	Sanitary Infrastructure	Municipal Combined Sewer and Stormwater	Subsurface
40	Sanitary Infrastructure	Municipal Sanitary Sewer Main	Subsurface
41	Drainage Infrastructure	Municipal Stormwater Main	Subsurface
21	Petroleum Infrastructure	Petroleum Distribution Pipe	Subsurface
22	Petroleum Infrastructure	Petroleum Distribution Station	Subsurface
23	Petroleum Infrastructure	Petroleum Distribution Valve	Subsurface
24	Petroleum Infrastructure	Petroleum Facility Site	Surface
25	Petroleum Infrastructure	Petroleum Kilometer Post	Surface
26	Petroleum Infrastructure	Petroleum Methane Main	Subsurface
27	Petroleum Infrastructure	Petroleum Pipeline	Subsurface
28	Petroleum Infrastructure	Petroleum Transmission Pipe	Subsurface
29	Petroleum Infrastructure	Petroleum Transmission Pipeline Facility	Subsurface
30	Petroleum Infrastructure	Petroleum Transmission Valve	Subsurface
31	Communication Infrastructure	Telcom Cable Line	Surface
32	Communication Infrastructure	Telcom Facility	Surface
34	Communication Infrastructure	Telcom Main	Surface
33	Communication Infrastructure	Telcom Manhole	Surface
35	Communication Infrastructure	Telcom Pole	Surface
36	Communication Infrastructure	Telcom Structure	Surface
37	Communication Infrastructure	Telcom Underground Line	Subsurface
38	Water Infrastructure	Water Distribution	Subsurface

E.6. BUSINESS ACTIVITY

Business point locations were obtained in GIS format (point shapefile) and used to identify the location and annual revenue of businesses within hazard areas (InfoCanada Business File, 2018). Total annual revenue and number of businesses were used as proxies to compare the relative level of business activity in hazard areas.

Table E-5 summarizes uncertainties associated with the data. In addition to the uncertainties listed in Table E-5, business activity estimates do not include individuals working at home for businesses located elsewhere, or businesses that are located elsewhere but that depend on lifelines within the study area. Business activity in hazard areas is likely underestimated due to the uncertainties in these data.

Table E-5. Business data uncertainties.

Type	Description	Implication
Revenue data	Revenue information was not available for all businesses.	Under-estimation of business impacts
Data quality	BGC has not reviewed the accuracy of business data obtained for this assessment.	Possible data gaps
Source of revenue	Whether a business' source of revenue is geographically tied to its physical location (e.g., a retail store with inventory, versus an office space with revenue generated elsewhere) is not known.	Over- or under-estimation of business impacts.

E.7. AGRICULTURE

BGC identified parcels used for agricultural purposes where the BCA attribute "Property_Type" corresponded to "Farm". Given the regional scale of study, no distinction was made between agricultural use types.

E.8. ENVIRONMENTAL VALUES

BGC included stream networks classed as fish bearing and areas classed as sensitive habitat in the risk prioritization.

In the case of fish, the BC Ministry of Environment (MOE) maintains a spatial database of historical fish distribution in streams based on the Fisheries Information Summary System (FISS) (MOE, 2018a). The data includes point locations and zones (river segments) where fish species have been observed, the extent of their upstream migration, and where activities such as spawning, rearing and holding are known to occur. As a preliminary step and because fisheries values are of regulatory concern for structural flood mitigation works, FISS data was used to identify fan and flood hazard areas that intersect known fish habitat. Hazard areas were conservatively identified as intersecting fish habitat irrespective of the proportion intersected (e.g., entire hazard areas were flagged as potentially fish bearing where one or more fish habitat points or river segments were identified within the hazard zone), so these results should be interpreted as potential only.

For endangered species and ecosystems, the BC Conservation Data Centre (BC CDC) maintains a spatial data set of locations of endangered species and ecosystems, including a version available for public viewing and download (MOE, 2018b).

BGC emphasizes that the information used to identify areas containing environmental values is highly incomplete, and estimation of vulnerability is highly complex. More detailed identification of habitat values in areas subject to flood geohazards starts with an Environmental Scoping Study (ESS), typically based on a review of existing information, preliminary field investigations, and consultation with local stakeholders and environmental agencies.

BGC also notes that environmental values are distinct from the other elements at risk considered in this section in that flood mitigation, not necessarily flooding itself, has the potential to result in the greatest level of negative impact. For example, flood management activities, particularly structural protection measures (e.g., dikes), have the potential to cause profound changes to the ecology of floodplain areas. The construction of dikes and dams eliminates flooding as an agent of disturbance and driver of ecosystem health, potentially leading to substantial changes to species composition and overall floodplain ecosystem function.

Within rivers, fish access to diverse habitats necessary to sustain various life stages has the potential to be reduced due to floodplain reclamation for agricultural use and wildlife management, restricting fisheries values to the mainstem of the river. Riparian shoreline vegetation also provides important wildlife habitat, and itself may include plants of cultural significance to First Nations peoples. On the floodplains, reduction in wetland habitat may impact waterfowl, other waterbirds, migratory waterbirds, and associated wetland species such as amphibians.

The ecological impacts of dike repair and maintenance activities can also be severe. Dike repairs often result in the removal of riparian vegetation compromising critical fisheries and wildlife habitat values. The removal of undercut banks and overstream (bank) vegetation results in a lack of cover for fish and interrupts long term large woody debris (LWD) recruitment processes and riparian function. Alternative flood mitigation approaches could include setback dikes from the river, providing a narrow floodplain riparian area on the river side of the dike, and vegetating the dikes with non-woody plants so that inspections may be performed and the dike integrity is not compromised. Such approaches may prevent conflicting interests between the *Fisheries Act* and *Dike Maintenance Act*.

Lastly, BGC notes that increased impact to fish habitat may result where land use changes (e.g., logging, forest fires) have increased debris flow activity and the delivery of fine sediments to fish bearing streams.

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Ministry of Environment (MOE), 2018b. Endangered Species and Ecosystems – Masked Occurrences Data. Web location: https://catalogue.data.gov.bc.ca/dataset?type=Application

APPENDIX F
CLIMATE CHANGE

F.1. INTRODUCTION

Climate change is expected to impact flood hazards both directly and indirectly through complex feedback mechanisms. This challenges the ability to reliably estimate future flood hazards for the entire spectrum of flood processes across the range of spatial and temporal scales. At this time, climate change science for the Thompson River watershed (TRW) can provide general trends on average values at regional scales, and limited information (with higher uncertainty) on the extremes[1] that are of interest for flood hazards on specific watercourses.

For this study, BGC developed simplified evaluation methodologies based on readily available data at the regional scale to differentiate relative, rather than absolute, climate change sensitivity between hazard sites within the TRW. Given that hydrological and mass movement processes are higher order effects of air temperature increases, their prediction is highly complex and often site-specific. For this reason, the results of the climate change sensitivity analysis were not incorporated into the prioritization. However, they do provide some additional insight for planning purposes into how these hazards could change in the future. The evaluation provided in this screening-level study also supports more detailed assessment of changes to clear-water flood and steep creek geohazards in the TRW, as part of future studies.

F.2. BACKGROUND

A number of temperature, precipitation, and hydrologic climate change impact studies have been completed for the TRW region, including studies conducted by the Pacific Climate Impacts Consortium (PCIC) that have looked at wide-scale changes in the Fraser River basin (e.g., Shrestha et al., 2012; Islam et al., 2017), of which the Thompson Rivers are tributaries.

Observed changes in central BC include an earlier onset of the spring freshet with faster melt of the snowpack and prolonged periods of minimum low flows (e.g., Whitfield & Cannon, 2000), and in some watersheds, a shift away from a glacier or nival (snow-dominated) regime towards a more hybrid or pluvial (rain-dominated) regime. Historical data from the region shows that average annual temperatures and total annual precipitation have increased 1.0^{o}C and 17%, respectively between the period of 1900 to 2013 (MOE, 2016). Trends suggest that the interior region of BC is getting warmer and wetter due to increased temperatures and number of frost-free days.

Projected changes in average climate variables across the TRW are presented in Table F-1 based on PCIC (2012) and show that there is likely to be:

- A net increase in precipitation (i.e., rain and/or snow), including a decrease in summer precipitation and an increase in winter precipitation.

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[1] "Extremes" can refer to both extreme highs and extreme lows. Flooding inherently refers to high flows. Climate change also has the potential to impact low flows/base flows/drought conditions, and sensitivity analyses could also be conducted for these conditions; however, these were not the hazards of interest for this study.

- A net decrease in snowfall, including a smaller decrease in winter and a larger decrease in spring snowfall (due to a projected increase in temperature).
- On average, there is likely to be a reduction in snowpack depth, an increase in winter rainfall, and higher freezing levels.

Average annual maximum hourly precipitation intensity (i.e., 2-year return period 1-hour rainfall or snowfall peak intensity) for both winter over December/January/February (DJF) and summer over June/July/August (JJA) periods are generally projected to increase in the TRW relative to the period 2001 to 2013 (Prein et al., 2017). This study also found that the frequency of extreme precipitation events is projected to increase around 50% for the JJA period and around 300% for the DJF period. There are large uncertainties with these projections as frequency changes are sensitive to changes in weather patterns, which were assumed to be constant in the study's simulations.

Table F-1. Plan2Adapt. Projected changes in average climate variables in the Thompson-Nicola region (2050s, A2 and B1 scenarios, PCIC 2012).

Variable	Unit	Season	Projected Change from 1961 – 1990 Baseline(1)	
			Median	Range (10th to 90th Percentile)
Temperature	ºC	Annual	+1.8 ºC	+1.1 ºC to +2.7 ºC
Precipitation(2)	%	Annual	+6 %	-1 % to +11 %
		Summer	-9 %	-19 % to +1 %
		Winter	+7 %	-4 % to +15 %
Snowfall	%	Winter	-11 %	-20 % to 0 %
		Spring	-55 %	-75 % to -12 %

Notes:

1. Values provided reflect results from 30 Global Climate Model (GCM) projections from 15 different models each with a high (A2) and a low (B1) greenhouse gas emission scenario. The range of values represents the median, 10th and 90th percentiles of these results. The range in model output values reflects uncertainties in projections of future greenhouse gas levels (in this case represented by the A2 and the B1 scenarios) as well as uncertainties due to simplifications of complex natural process in the models themselves. For more information on how these numbers were obtained, the reader is directed to www.plan2adapt.ca/tools/planners.
2. Precipitation includes both rain and snow.

F.3. RELATIVE CLIMATE CHANGE SENSITIVITY - REGIONAL EVALUATION

The following sections describe how relative climate change sensitivity was assessed across the TRW. Climate change sensitivity was defined and evaluated differently for clear-water and steep creek flood hazards.

F.3.1. Clear-Water Flood Hazards

For clear-water flood hazards, the typical parameters of interest are flood magnitude, duration and frequency of occurrence. Research has not progressed sufficiently to differentiate relative or absolute changes in these parameters due to projected climate change across the study area at the scale of individual watersheds.

However, the TRW can be sub-divided into seven (7) hydrologic regions, each with a relatively different, typical snowpack depth. Additionally, many of the streams in the region have a peak flow that is influenced by snowmelt (freshet). As a screening-level indicator of climate change sensitivity, it was assumed that that:

- Multiple factors contribute to changes in clear-water flood hazards when examining the impacts of climate change, but snowmelt strongly influences streamflow. Therefore, climate-induced changes to snowmelt are likely to drive the biggest changes in clear-water flood hazards.
- The influence of snowmelt (or lack of snow) affects the shape of the annual streamflow hydrograph. In BC, five typical flow regimes can be differentiated. Each regime has a varying relative sensitivity to snowmelt, and the generic shape of each regime describes differences in the number, magnitude and timing of peak floods. As of the date of this report, no systematic regime classification has been undertaken by BGC or others for watercourse segments in the TRW.
- Multiple factors contribute to changes in snowmelt as it relates to flood hazards. The quantity of snow available for melt can be used as a proxy to characterize the influence of snowmelt on the hydrograph and rate the relative sensitivity of flood hazard areas to changes in the timing of freshet floods as a result of region-wide declines in snowpack depth due to climate change.
- The largest changes in the timing of peak floods would be expected for those areas with a flow regime that shifts away from being freshet-dominant to rainfall dominant/driven. Therefore, those watersheds with the thinnest snowpacks would be the most sensitive.
- Those areas with an existing streamflow regime without a pronounced freshet would experience little change in their freshet timing and magnitude and are, therefore, the least sensitive.

Therefore, for clear-water flood hazard areas:

- Climate change sensitivity was defined as: the relative sensitivity of flood hazard areas with similar watershed characteristics to changes in the timing of freshet floods as a result of region-wide declines in snowpack depth due to climate change.
- Sensitivity was characterized using regional differences in existing snowpack, as well as a regional approximation methodology for identifying existing watersheds that do not have a freshet.

The following subsections provide additional details on regional variations in snowpack, streamflow regimes and the influence of snowmelt, results and uncertainties.

F.3.1.1. Regional Variations in Snowpack

The TRW can be sub-divided into three major watershed sub-basins, including the North Thompson, South Thompson and Thompson–Nicola basins, each with relatively distinct physiographic settings, precipitation and runoff characteristics (Table F-2); suggesting that the future responses for the three regions could vary considerably due to climate change. The three watershed sub-basins of the TRW intersect seven of the hydrological regions defined by MOE (2011) at a provincial scale with some overlap between basins (Figure F-1).

BGC reviewed hydro-climatic data from select Environment and Climate Change Canada (ECCC) climate stations and Water Survey of Canada (WSC) hydrometric gauges to classify the three sub-basins based on available metrics (Table F-2). General hydro-climatic characteristics of the basins include:

- The Thompson-Nicola sub-basin experiences the lowest annual precipitation and runoff of the three sub-basins but includes the greatest variation of hydrological regions. The sub-basin also receives contributions in terms of flows from the South and North Thompson sub-basins and is therefore sensitive to hydro-climatic changes that occur in the upper watershed.
- The South and North Thompson sub-basins are generally similar in terms of annual precipitation and runoff as both sub-basins are located within the North Columbia Mountains hydrological region. Flows within both sub-basins include a small glacial-melt component that contribute to summer low flows with glacier coverage slightly greater (approximately 2.7%)[2] in the North Thompson sub-basin.
- The majority (45 to 55%) of precipitation falls between the period of October to March within the three sub-basins and is assumed to be snowfall. Of the three sub-basins, the North Thompson sub-basin experiences the great variation in annual precipitation with a range of 477 to 1,204 mm/yr between the period of 1981 to 2010 based on climate normal in the region and also the highest in terms of annual runoff.

[2] Glacier coverage based on Déry et al. (2012) and does not reflect current conditions within the sub-basins. Given the rate of glacier change within the region due to climate change, this number is assumed to be lower.

Table F-2. Hydrological regions by major watershed sub-basins of the TRW and select physiographic, hydro-climatic characteristics.

Sub-basin	Hydrologic Regions[1]	Basin Area (km^2)	Glacier (%)[2]	Mean Elev. (m)[3]	Average Climate Normals (1981 – 2010)[4]				Runoff (mm/yr)[5]
					Precip. (mm)	Precip. Range (mm)	Precip. Oct – March (mm)	Snowfall (cm)	
North Thompson	North Columbia Mountains Southern Quesnel Highland	19,600	2.7	2,684	585	477 - 1,024	265	180	680
South Thompson	North Columbia Mountains Okanagan Highland	16,200	0.6	1,228	580	359 - 739	315	160	595
Thompson-Nicola	Northern Thompson Plateau Southern Thompson Plateau Eastern South Coast Mountains Fraser Plateau	20,200	0.0	1,747	425	264 - 557	193	127	440

Notes:

1. Hydrologic zone boundaries of British Columbia (MOE, 2011).
2. Déry et al. (2012).
3. Vertical datum is NAVD 88.
4. Mean annuals based on 1981 to 2010 climate normals from Environment and Climate Change Canada (ECCC) climate stations located within each sub-basin.
5. Runoff values based on gauge data from the Water Survey of Canada (WSC) North Thompson River at McLure (08LB064), South Thompson River at Chase (08LE031) and Thompson River near Spences Bridge (08LF022) as reported in Shrestha et al. (2012) normalized for the period of 1981 to 2010.

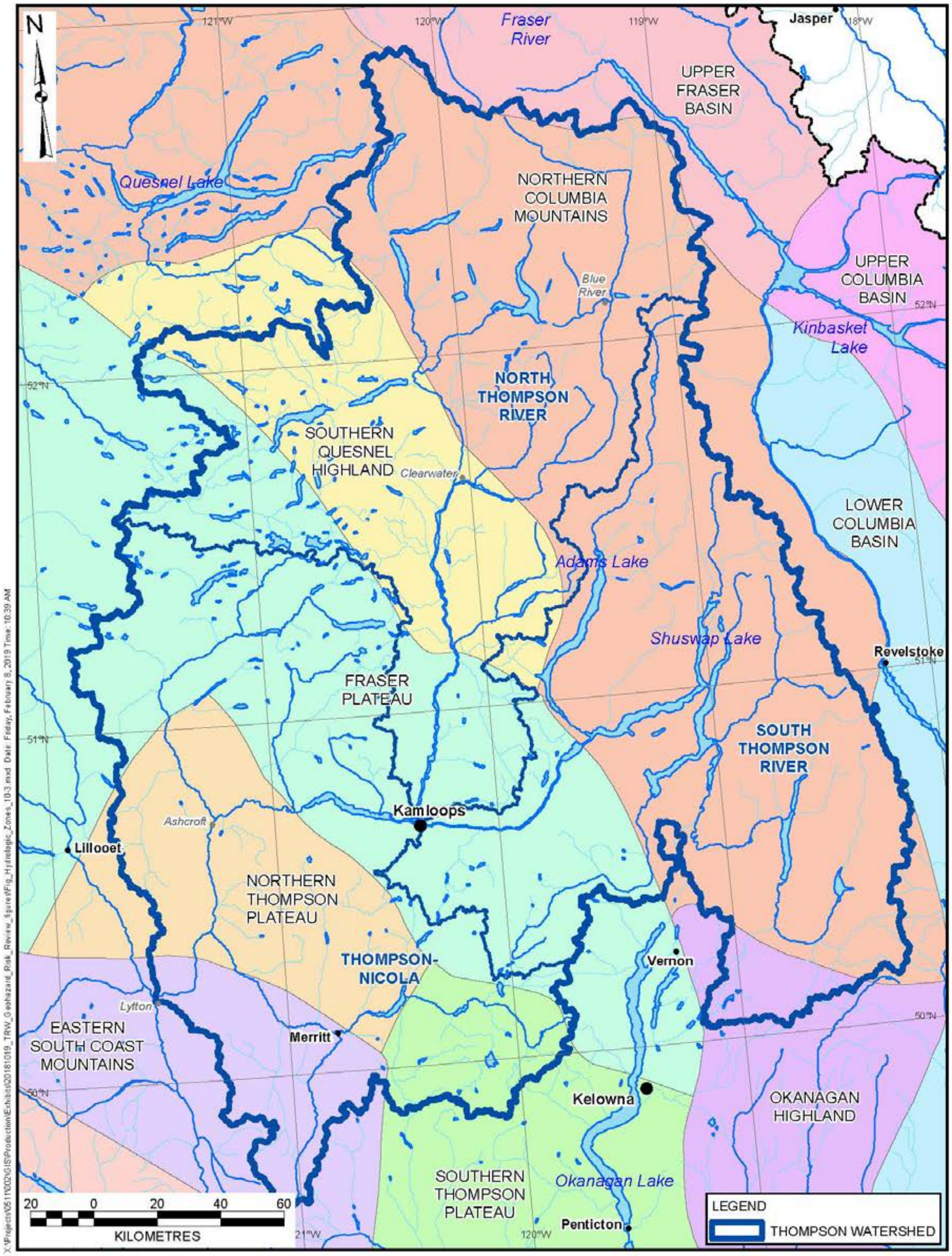

Figure F-1. Provincially-delineated hydrologic region boundaries in the vicinity of the study area (MOE, 2011). The TRW intersects seven regions. Also shown are the three major watershed sub-basins of the TRW.

F.3.1.2. Streamflow Regimes

Annual streamflow hydrographs in BC can be classified into one of five streamflow regimes (Ministry of Forests and Range, 2010):

- Pluvial (rain driven)
- Pluvial-dominant hybrid (rain dominant)
- Nival-dominant hybrid (snowmelt driven)
- Nival (snowmelt dominant)
- Glacial-supported nival (snowmelt driven in spring and glacial melt driven in summer).

Conceptual hydrographs for glacial, nival and pluvial regimes are shown in Figure F-2. Nival (snowmelt dominant) regimes have their maximum annual flow occur with the spring freshet. While, in a nival-dominant hybrid regime, a secondary, smaller peak flow typically occurs in the autumn and is often associated with a snowfall event(s), typically with low freezing elevations, followed by rising freezing levels and rain-on-snow. In these watercourses, a shallower winter snowpack would likely result in a decrease in freshet magnitude. If, under climate change conditions, the reduction in an already shallow winter snowpack effectively resulted in a loss of the winter snowpack entirely, then the freshet event would disappear from the hydrograph and the timing of the annual peak could shift to a different season[3] such as in a pluvial regime (Figure F-2c). Pluvial-dominant hybrid regimes have multiple high flow events that typically coincide with large rainfall events and rain-on-snow events. Watercourses with pluvial regimes do not typically experience sufficient snow accumulation to affect the hydrograph.

The **magnitude of the freshet** depends on the snowpack depth as well as spring temperature and rainfall patterns. The **timing of the freshet** can be exemplified as follows:

- A shallower snowpack takes less time to melt, potentially resulting in an earlier freshet.
- Higher spring temperatures typically result in snowmelt beginning earlier in the season and therefore an earlier freshet.
- Changes to spring rainfall patterns would change the timing of the freshet to be earlier or later depending on what the existing typical spring rainfall pattern is, and how it changes.
- Watershed relief and elevation range. High relief will have a longer freshet due to sequential snowmelt starting with lower elevations and working up-gradient.

However, the quantity of snow available for melt (as expressed by snowpack depth) dominates timing sensitivity. Where climate change is projected to result in a reduced snowpack, streamflow

[3] It should be noted that there are large uncertainties as to the timing of annual peak flows for pluvial systems in the future. It is plausible that the annual peak will shift to winter – currently it is the wettest season for much of southwestern BC – however, this assumes no substantial change to existing patterns of rainfall extremes. Although total rainfall is projected to decline in summer, this will not be the case for summer rainfall extremes that are predicted to increase in both frequency and magnitude (Prein et al. 2016).

regimes would be expected to shift (Figure F-3) so that there is a reduced dominance of the freshet (spring) and an increased dominance of rainfall (following the timing and magnitude of the changes in rainfall patterns).

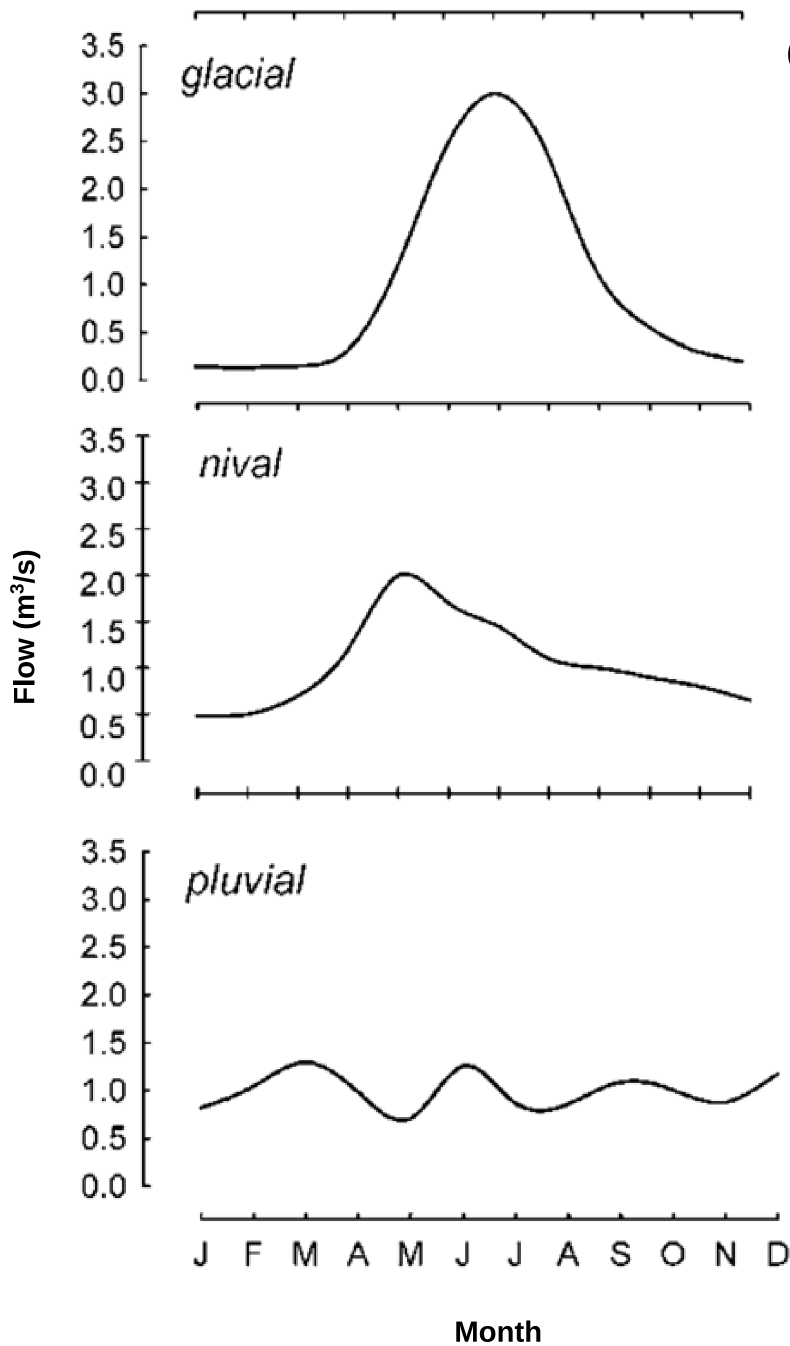

Figure F-2. Conceptual hydrographs for (a) glacial, (b) nival (snow-dominated) and (c) pluvial (rain-dominated) regimes. Adapted from Zeiringer et al., (2018). Climate change is expected to shift streamflow regimes from a snow-dominated to a rainfall dominated regime in the region.

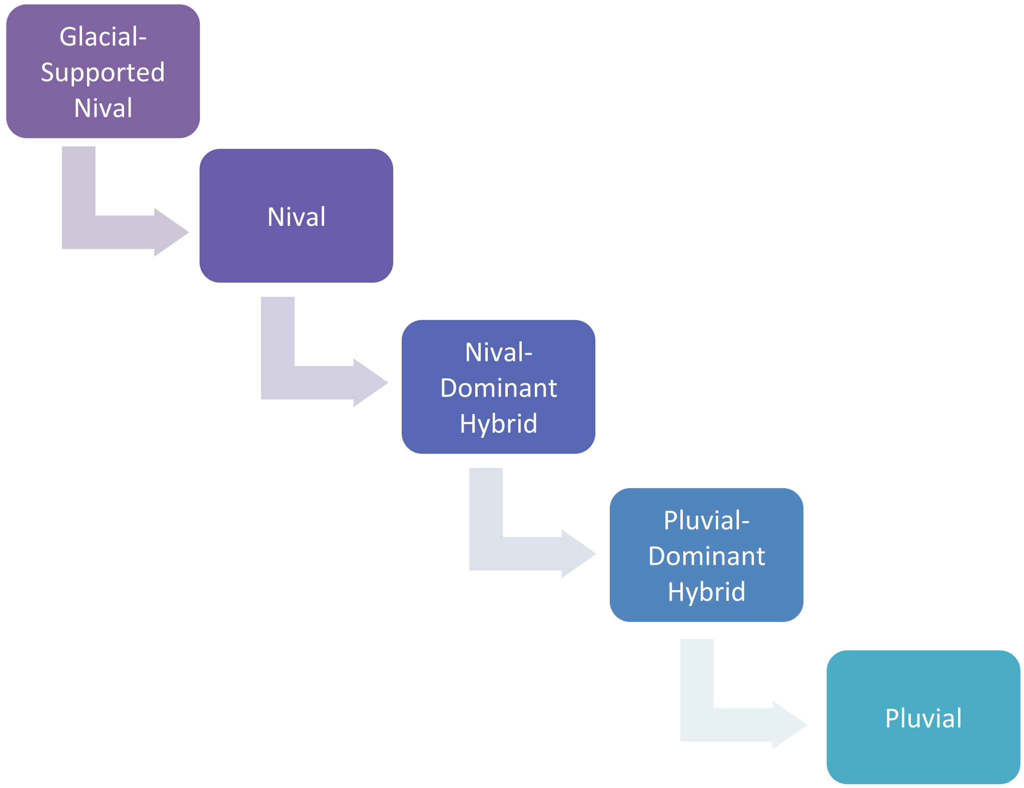

Figure F-3. Climate change is anticipated to shift streamflow regimes, reducing the influence of glacial/snow-melt.

Example annual hydrographs are shown in Figure F-4 for the three major watershed sub-basins in the TRW. All three watershed sub-basins have a hydrograph characteristic of a snow-dominated regime with the maximum annual flow occurring during the spring freshet; however flows within the North Thompson sub-basin (and to a limited extent within the South Thompson sub-basin) also have a glacial-melt component that may provide additional flow during the summer low-flow period (Table F-2). Although, glaciers provide streamflow contributions to rivers and headwater streams through glacial melt (Stahl and Moore 2006), the number of glaciers in BC are in significant decline due to climate change. Across the province, glaciers are expected to continue to retreat in the interior and smaller glaciers are likely to disappear (MOE 2016). As a result, sub-basins such as the North Thompson could shift from a glacial-supported nival regime to a nival (snow-dominate) regime with climate change.

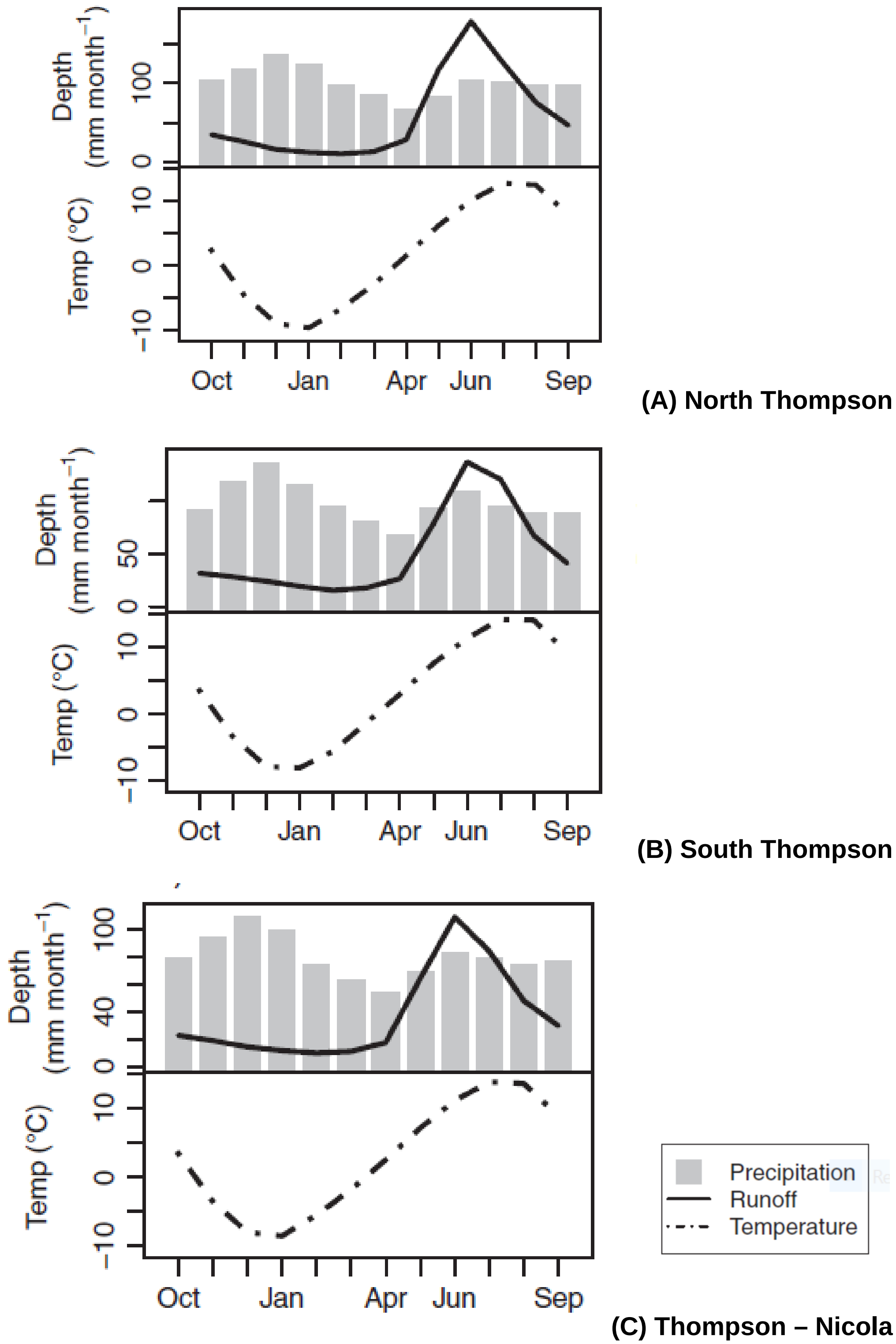

Figure F-4. **Monthly mean precipitation, temperature and runoff for the three main sub-basins of the TRW for the period of 1961 to 1990. From Shrestha et al. (2012).**

F.3.1.3. Projected Streamflow and Precipitation by Sub-basin

Previous studies have looked at basin-scale changes in the Thompson Rivers in terms of future scenarios of precipitation and streamflow (e.g., Shrestha et al., 2012; Islam et al., 2017). For example, Shrestha et al. (2012) simulated 30-year baseline (1970s) and future (2050s) hydrologic regimes based on climate forcings derived from eight global climate models (GCMs) runs under three emissions scenarios (B1, A1B and A2) for each of the sub-basins contained within the 230,000 km^2 Fraser River basin.

For the TRW, the most significant projected future hydrologic trends included:

- Shifting from snow-dominant to either a hybrid or a rain-dominant regime which has a potential impact on the occurrence and timing of the freshet
- Earlier onsets of snowmelt-driven peak discharge due to higher temperatures
- Shifting in the hydrograph with greater portions of the runoff volume occurring in winter and spring and decreasing portions occurring in summer
- Increasing total annual discharge volume (mainly due to increased temperatures and greater precipitation as rainfall), but with a decreasing in the maximum annual discharge (specifically, the 30-year mean of the future peak annual discharge).
- Declining April 1st snowpack depths and SWE
- Shorten the length of and delay the start of lake ice cover (MFR 2010).

Table F-3 summarizes projected changes in SWE and flow volume averaged for each of the three scenarios by major watershed sub-basin. In terms of SWE, the Thompson-Nicola is expected to have the greatest change in snowpack; while the North Thompson is expected to have the greatest increase in flow volume; potentially due to the contribution from glacial melt to runoff.

Table F-3. GCM ensemble medians of April 1st SWE volume and annual discharge (runoff) changes (2050s versus 1970s) for the sub-basins of the TRW based on Shrestha et al. (2012).

Variable[1]	Sub-basin		
	North Thompson	South Thompson	Thompson-Nicola[2]
SWE change (%)[2]			
Average	-20	-27	-33
Flow volume change (%)			
Average	9	6	2

Notes:

1. The snow water equivalent (SWE) and annual runoff change for the regions are for sub-basin grid cell average values. Annual discharge change for the sub-basins is for routed values at the sub-basin outlets.
2. Values represent the projected changes at approximately the outlet to the TRW watershed.

F.3.1.4. Results

All three watershed sub-basins are characteristic of a glacial-nival to nival (snow-dominated) regime with the maximum annual flow occurring during the spring. Ranking of the relative sensitivity to climate change of the **timing and intensity of the freshet** (for comparable watersheds) placed those hazard areas located in regions of typically deeper snowpacks as being relatively insensitive, while those in regions with typically the shallowest snowpacks are the most sensitive. The ranking is summarized in Table F-4 along with potential implications for flood hazards within the TRW due to a shift in streamflow regimes within each sub-basin under future climatic conditions. Climate change sensitivity for an individual hazard area can be inferred from the sub-basin and to a lesser extent on the hydrologic region based on Figure F-1. Clear-water flood hazard areas and hydrologic regions are shown on the web-map as two separate layers.

Table F-4. Summary of climate change sensitivity by major watershed sub-basins of the TRW and potential implications for flood hazards.

Rank	Sub-basin	Current Regime	Regime shift under climate change	Sensitivity and Potential Implication for Flood Hazards
1	Thompson – Nicola	Nival	Nival dominant hybrid	Relatively low snowpack, most sensitive due to a decreasing snow component and increasing rain component resulting in a “flashier” (steeper hydrograph) response to rain events (decreased snow storage) and the development of secondary peak/autumn flow events. Potential for extended spring flood hazard season. Sub-basin is also impacted by streamflow regime changes that occur in the upper watershed.
2	South Thompson	Nival	Nival dominant hybrid	Relatively deep snowpack, glacier melt component assumed to be minimal, moderate sensitivity due to a decreasing snow component and increasing rain component. Potential for extended flood hazard season (later autumn floods and earlier spring floods); increased secondary peak/autumn flow events; increase in number of high flow events through increased frequency of rain-on-snow events (a driving factor).
3	North Thompson	Glacial-Nival	Nival	Relatively deep snowpack for the region, low sensitivity to climate change in the short-term, but longer term there is a decrease in summer low flows due to shrinking glaciers and increasing likelihood of spring flood hazards with greater inter-annual variability.

Ranking of the relative sensitivity to climate change of the timing of the freshet (for comparable watersheds) placed those hazard areas located in regions of typically deeper snowpacks such as hazards occurring within the North Columbia Mountains hydrological region as being relatively insensitive in the medium term (i.e. the next few decades), while those in regions with typically the shallowest snowpacks are the most sensitive in the short and medium term. Over the long term (century time scale), sensitivity to the timing of spring freshets will be affected even for deep snowpack watersheds as they transition to shallower snow packs.

F.3.1.5. Uncertainties

The ranking methodology described above examines only one variable (relative snowpack depth), is based on generalizations about regional hydro-climatology and anticipated streamflow regimes and is relative to comparable watercourses within the TRW only. Most hazard areas are located in valley bottoms and receive contributing flow from watersheds with a wide elevation range. Hazard areas located at high elevations will have different sensitivities than low elevation hazard areas.

There are considerable uncertainties with the evaluation described above. Uncertainties exist in the current understanding of hydrology and climatology, particularly in the complex, mountainous terrain of the TRW, as well as in the projections of first order climate change effects (“direct” impacts, those that result directly from changes to precipitation and temperature) with respect to timing, magnitude and frequency.

Additional uncertainties exist in second (and 3^{rd}, 4^{th},...n^{th}) order effects (“indirect” impacts) which can alter a part of the environment that in turn leads to changes in flood hazard (e.g.. changes in wildfire frequency or tree mortality due to widespread beetle infestations followed in some cases by salvage logging, leading to changes in the hydrologic regime). Human factors, not necessarily related to climate change, also impact flood hazards and are dynamic in time and space (e.g., watershed development (road construction, land use, forest management) and river management (diking, dredging)). The above processes themselves influence each other through complex feedback mechanisms, challenging reliable future flood hazard estimates for the entire spectrum of flood processes, and spatial and temporal scales. However, understanding potential changes to the timing of flood hazards is helpful for emergency management planning, among other functions of the regional district.

F.3.2. Steep Creek Hazards

Steep creek basins can be generally categorized as being either:

- Supply-limited: meaning that debris available for transport is a limiting factor on the magnitude and frequency of steep creek events. In other words, once debris in the source zone and transport zone has been depleted by a debris flow or debris flood, another event even with the same hydro-climatic trigger will be of lesser magnitude[4]; or,
- Supply-unlimited: meaning that debris available for transport is not a limiting factor on the magnitude and frequency of steep creek events, and another factor (such as precipitation frequency/magnitude) is the limiting factor. In other words, there is always an abundance of debris along a channel and in source areas so that whenever a critical hydro-climatic threshold is exceeded, an event will occur. The more severe the hydro-climatic event, the higher the resulting magnitude of the debris flow or debris flood.

Regional climate change projections indicate that there will be an increase in winter rainfall (PCIC 2012) and an increase in the hourly intensity of extreme rainfall and increase in frequency of events (Prein et al., 2017). Changes to short duration (one hour and less) rainfall intensities are particularly relevant for post-fire situations in debris flow generating watersheds. Within the year to a few years after a wildfire affecting large portions of a given watershed, short duration and high intensity rainfall events are much more likely to trigger debris flows or debris floods, than prior to a wildfire event.

The sensitivity of these two types of basins to increases in rainfall (assuming intensity and frequency increase) are different (Figure F-5):

- Supply-limited basins would likely see a decrease in individual geohazard event magnitude, but an increase in their frequency as smaller amounts of debris that remains in the channel are easily mobilized (i.e., more, but smaller events)
- Supply-unlimited basins would likely see an increase in hazard magnitude and a greater increase in frequency (i.e. significantly more, and larger events)

All fans in the district were characterized as being either supply limited or supply-unlimited, and reported on the web-map, within the geohazard information for a specific steep creek geohazard area. From this information the reader can infer the corresponding hazard sensitivity to climate change.

It should be noted that supply limited basins can transition into supply unlimited in the event of a wildfire or large landslide event in the watershed generates a long-lasting sediment supply. Similarly, a mining operation with poor waste rock management could lead to a change in sediment supply conditions. The impact of a wildfire on debris supply is greatest immediately after the wildfire, with its impact diminishing over time as vegetation regrows. Wildfires are known to

[4] In this context, magnitude is defined as both the total debris and water volume as well as the peak discharge associated with the event.

both increase the sediment supply and lower the precipitation threshold for steep creek events to occur.

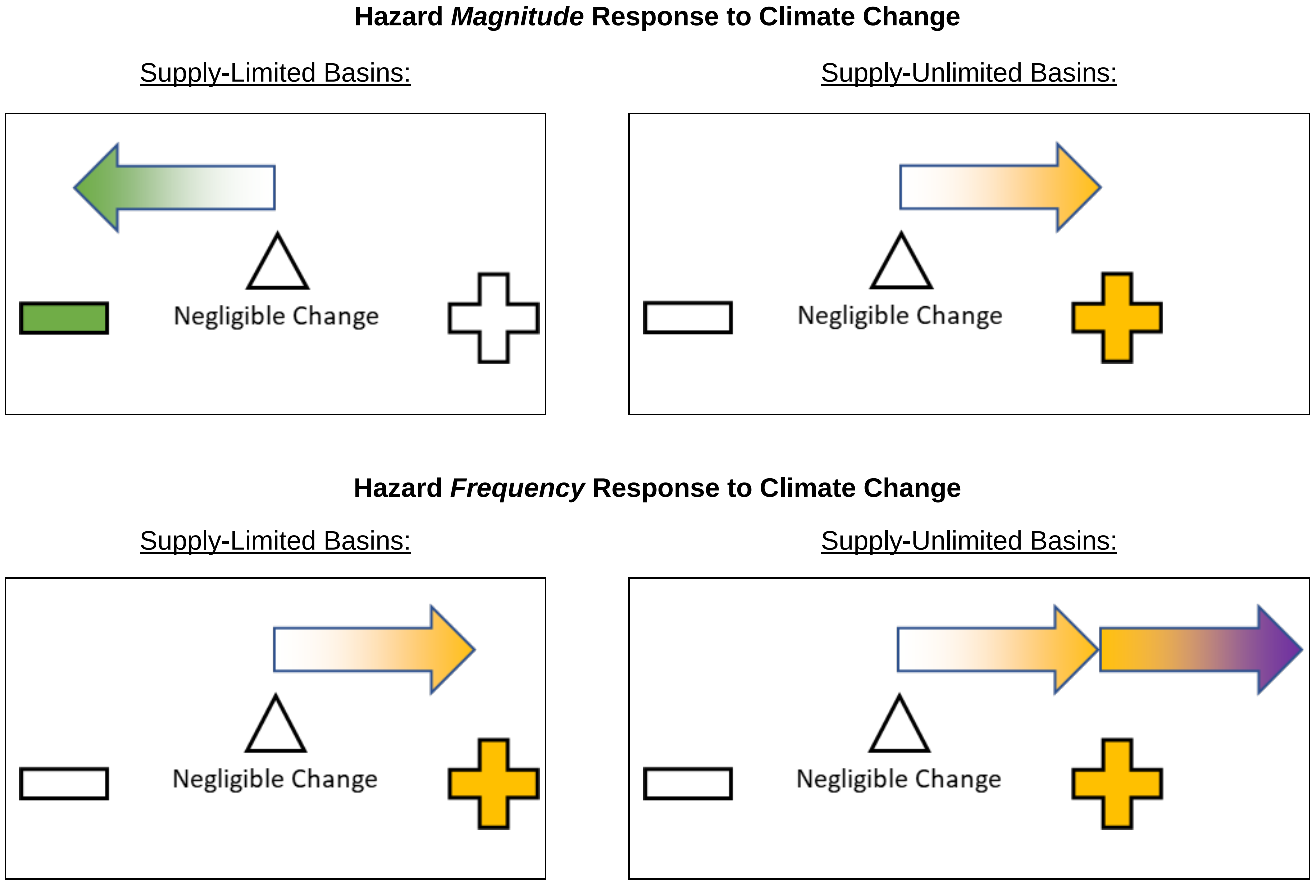

Figure F-5. Steep creek hazard sensitivity to climate change – supply-limited and supply unlimited basins.

F.4. FUTURE POTENTIAL INITIATIVES

At a regional scale, reducing the methodological uncertainty outlined in Section F.3 could be achieved by:

- Developing reliable methodologies to systematically assign streamflow regimes to all watercourse segments based on regionally available metrics.
- Using remote sensing to evaluate existing snowpack depths and freezing level variations across the region and evaluate specific climate change scenarios on these variables.
- Using coupled climate change rainfall-runoff models to numerically model changes in runoff magnitude and timing given various climate change forcings for the full spectrum of streamflow regime types.

- Use downscaled climate change projections of precipitation variables to better characterize steep creek hazard sensitivity. Recently, Jakob, Schnorbus and Owen (2018) attempted to quantify changes in sediment volumes in debris floods associated with climate change.
- Integrate climate-impacted forest fire susceptibility modeling into the steep creek sensitivity evaluation.

For site-specific assessments, various different approaches could be pursued. Downscaled climate data could be used as inputs to flood models and compared with existing steep creek shear stress-based bedload mobilization thresholds. Historical datasets could be evaluated for trends, and the trends quantified, extrapolated and applied to individual sites.

A detailed climate change screening tool could be developed and implemented. Figure F-6 shows an example of a climate change screening tool developed by BGC for pipelines. The example is similar to the Engineers Canada Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol (https://pievc.ca/protocol), which aims to project the nature, severity and probability of future climate changes and events.

BGC

Climate Change Flood Screening Tool

Risk Evaluation and Response

VH	Very High	Risk is imminent and could happen at any time irrespective of particular triggers; short-term risk reduction required; long-term risk reduction plan must be developed and implemented
H	High	Risk is unacceptable; long-term risk reduction plan must be developed and implemented in a reasonable time frame.
M	Moderate	Risk may be tolerable; more detailed review and monitoring required; reduce risk to As Low As Reasonably Practicable
L	Low	Risk is tolerable; continue to monitor and reduce risk to As Low As Reasonably Practicable
VL	Very Low	Risk is broadly acceptable; no further review or risk reduction required

Climate Change Input to Flood Processes Acting in Study Area					
Climate Change has potential to lead to major (> 30%) changes in peak flows by 2100	**4**	M	H	VH	VH
Climate change is likely to cause substantial change (10 to 30%) change in peak flows	**3**	L	M	H	VH
Climate change is likely to casue some measureable change (5 to 10%) in peak flows	**2**	VL	L	M	H
Climate change is unlikely to result in changes in peak flows above natural variability (< 5%)	**1**	VL	VL	L	M
		1	**2**	**3**	**4**
Consequence (in terms of design flood freeboard exceedances)		Return Period of flooding will be reduced so that existing dike freeboard is unlikely to be exceeded for design flood	Return Period of flooding will be reduced so that existing dike freeboard may be exceeded for design flood	Return Period of flooding will be reduced so that existing dike freeboard will likely be exceeded for design flood	Return Period of flooding will be reduced so that existing dike freeboard will very likely be exceeded for design flood

Figure F-6. Example of a climate change risk assessment matrix developed for river flooding. Source: BGC Engineering (DRAFT).

The effects of climate change are likely to be profound and potentially without precedent in the documented history of the study area. Especially the projected substantial changes in the frequency and magnitude of hydroclimatic extremes will undoubtedly lead to severe losses. Given that climate change science and understanding of its effects on flood hazards are continually improving, a key factor in climate change evaluations and policy integrations is that climate change impacts are revisited and refined over the long term.

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APPENDIX G
EVENT HISTORY

Year	Month	Type of hazard	Location	Source	Report (if applicable)	Description of Event
1866	May/June	Flood	Ashcroft, Bonaparte River	Septer (2007)		The waters of the Bonaparte River rose to unusual heights, causing considerable property damage.
1873	June 1	Debris flow	Clinton, Mill Creek	Septer (2007)		On June 1, heavy rain caused a debris flow in Clinton. About 100 m of street was buried by up to 3 m of debris. Several buildings were damaged causing $51,000 damage. The debris flow was released by the breach of a dam or log jam on Mill Creek.
1875	April 22	Flood	Cache Creek, Bonaparte River	Septer (2007)		The Bonaparte River was the highest in recent memory. Every bridge across the Bonaparte River was carried away, including the one at Cache Creek House. The stage stable at Cache Creek was swept away and all ranches in the river valley were flooded.
1880	August 1	Landslide dam	Spences Bridge, Ashcroft, Thompson River	Septer (2007)	Evans (1984); Clague & Evans (1994)	A landslide took place at Cook's Ferry near Spences Bridge. A huge mass of Shawnikan Mountain was observed to be moving. Thousands of tons of earth and rock went into the channel of Thompson River. The course of the river was impeded and a large portion of the flat on the opposite side was covered by the slide. The source material was Quaternary sediments. The upstream lake formed by the landslide dam flooded the present site of Ashcroft. A house floated away near the mouth of the Bonaparte River. Homes downstream were temporarily evacuated as a precaution against a possible outburst flood.
	October 14	Landslide dam	Ashcroft, Black Canyon	Septer (2007)	Evans (1992)	A landslide occurred 10 km below Cache Creek, just south of Ashcroft in Thompson River valley. The slide consisted of fine gravel and loam and took place about 32 km above Spences Bridge. Approximately 15 million m^3 of Pleistocene-aged glacial lake sediments on the east wall of the valley suddenly failed and flowed across Thompson River, stemming its flow. The Black Canyon landslide blocked the Thompson River completely and stopped the flow of water for approximately 44 hours. The lake formed upstream of the blockage and attained a maximum depth of 18 m and a length of 14 km before it began to empty through a channel cut by workmen. The dam left the river dry below the dam, and at Lytton the Fraser River fell 2 m. Catastrophic breaching of the dam did not take place, since the escaping waters gradually enlarged the spillway until the lake was empty two days later.
1881	October	Landslide dam	Ashcroft, Thompson River	Septer (2007)	Stanton (1897); Drysdale (1914)	Near Ashcroft, an irrigation water reservoir broke its dam, further flooding an already well-soaked upper terrace/bench. A few miles below Ashcroft on the east side of the valley, about 150 ac. (60 ha) of benchland, probably weighing about 100 million tons, collapsed. It suddenly sank vertically in one movement to a depth at the back edge of over 120 m. The lower portion of the slide, about 600 m wide, was forced entirely across the Thompson River, a distance of 240-300 m. Abutting against the steep bluff on the opposite side, it filled the whole inner gorge of the valley and formed a dam 48 m high. For several days the flow of the river completely stopped, enabling people to walk dry-shod across the riverbed below the dam. The dam formed a lake 19 km in length, roughly estimated to have contained some 198 million m^3 of water. As soon as the water rose and formed an outlet, it swept away the slide material, causing a terrific flood in the valley below.
1886	October 19	Landslide dam	Ashcroft, Thompson River	Septer (2007)		A landslide came down along the left bank of the Thompson River Valley, 4 km south of Ashcroft. The site of the first documented derailment by a landslide became known as the Goddard Slide. A steam engine, tender, and baggage car of a westbound CPR passenger express train were derailed. The landslide was 575 m long and took place minutes after a trackman had passed the spot. The failure surface is seated in glaciolacustrine silts.
1894	May 24	Washout	Spatsum	Septer (2007)		Washouts reported at Spatsum.
		Flood	Kamloops	Septer (2007)		The Kamloops airport at Fulton Field was flooded.
	May 29	Flood	Salmon Arm	Septer (2007)		Around May 29, after two weeks of warm weather, flooding was reported in Salmon Arm. Almost the entire valley was flooded and several of the settlers had had to leave their homes the previous week. James D. Gordon's bridge washed away and the government bridge on the road to Shaw's Ranch was expected to go shortly. The roads were flooded and the bridges and culverts were afloat.
	May 31	Flood	Salmon Arm, Salmon River	Septer (2007)		The gravel road at Salmon River was flooded with 1.2 m of water for about 2 km and nearly impassable. The Salmon River bridge opposite Mackie's was afloat.

Year	Month	Type of hazard	Location	Source	Report (if applicable)	Description of Event
	June 1-3	Flood	Salmon Arm, North Thompson River	Septer (2007)		Between June 1-3, the North Thompson River dropped about 0.75 m but the heavy rains on the afternoon of June 3 sent it up again. After a rapid rise it appeared to peak on June 6. The North Thompson River surpassed the high-water level of 1876. At the mouth of the North Thompson River, the water rose higher than ever known before.
		Flood	Kamloops to Spences Bridge	Septer (2007)		On the morning of June 2, the steel bridge at Ashcroft on the Cariboo road went out, and on June 3 the Savona bridge was washed away. In 1894, floodwaters took out five bridges on the Thompson River: Kamloops, Savona, Ashcroft, Spences Bridge and Lytton.
		Flood	Lytton	Septer (2007)		At the mouth of the Thompson River in Lytton, the bridge was endangered. Despite efforts to save the bridge, it weakened by driftwood tearing out braces and truss rods. On June 1 at 1 a.m., it went out with a terrific crash and settled down on the Lytton side. The pier turned over and was gone.
		Flood	Quilchena	Septer (2007)		The road to Kamloops under 0.5 m of water at Quilchena, Merritt was practically isolated.
		Flood	Nicola River, Ruby Creek	Septer (2007)		The bridges over the Nicola River and Ruby Creek washed away. The bridge across the Nicola River was damaged. It was reported swaying as a train passed over it and half an hour later floodwaters carried part of it away.
	June 30	Flood	Eagle River	Septer (2007)		Water levels in Eagle River, which the railroad crosses five times, were almost level with the track. Some of the smaller bridges washed away and pilings were displaced. In some places the track was under 0.2-0.25 m of water.
		Debris flow	Clanwilliam	Septer (2007)		A mudslide buried about 180 m of railroad track to a depth of 2 m or more. Immediately on completion of a temporary track laid over this slide, a second slide came down. It buried this false track 2 m deep to a length of 90 m.
1897	September 19-22	Landslide dam	Ashcroft, Thompson River	Septer (2007)		On September 19 at about 2 p.m., an enormous mass of earth sunk down many feet. The area involved seemed to be 150 ac. (60 ha) or more. The land formed domes and pyramids resembling the ones seen in the Dakota Bad Lands. For a couple of days, the slide appeared to be stationary and there seemed little danger of the entire mass suddenly sliding down into the river bed and temporarily damming the water. The slide gradually pushed its way into the Thompson River, being washed away by the current. Acting as a wedge, it evidently had pushed the entire riverbank for nearly 800 m into the stream. On September 22 at 1 a.m. the “big gravel mountain” started to move. A large portion of landslide broke off and started with a “rumble like thunder” towards the Thompson River. The section first in motion was about 1.3 km^2 and some 120-150 m high. The motion was slow at first but increased as the immense strip of land advanced towards the river. Within two hours the Thompson River was said to have risen 0.2 m.
1899	December 31	Landslide dam	Spences Bridge, Thompson River	Septer (2007)	Stanton (1898); Evans (1984); Evans (1986); Clague & Evans (1994)	A landslide occurred near Spences Bridge, damming the Thompson River with Quaternary sediments.
1900	June 24-26	Flood	Ashcroft, Lytton, Thompson River	Septer (2007)		On June 24, sudden warm weather and recent rain melting snow caused the Thompson to rise rapidly. On June 26, the Fraser River at the Thompson River junction at Lytton was higher than it had been in a number of years. At the junction it reached a point 13 m above the low water mark and passed the highest point reached in 1899.
1903	June 16	Flood	Ashcroft, Thompson River	Septer (2007)		The Thompson River rose 12.5 cm at Ashcroft in 24 hours.
1905	August 13	Landslide dam	Spences Bridge, Thompson River	Septer (2007)	Evans (1992)	A landslide occurred about 2 km south of Spences Bridge a short distance below the town on the west side of the valley. A large mass consisting mainly of Pleistocene glaciolacustrine silt suddenly broke away from the valley wall at the base of Arthur’s Seat Mountain and descended at great velocity to Thompson River, filling the valley bottom from bank to bank. The slide material formed a dam and caused a large wave 3-4.5 m high to sweep up the river against the current. The slide, which came down on the opposite side of the river from Spences Bridge, and subsequent wave wiped out a First Nations village on the Thompson River. The wave swept up the river more than 3 km. The river was converted into a lake, widening

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						from 400-1,600 m. The water rose between 21-24 m. After the first wave it came up almost 30 cm a minute. At one time it was 1.5 m over the railway tracks at the opposite side of the river. The river was completely dammed for four or five hours. Various reports put the death toll at 18 in the slide and subsequent flooding.
1920	July 13	Debris flow or debris flood	Cache Creek	Septer (2007)		A cloudburst over Cache Creek washed away a home, filled several buildings with debris, washed away a road camp and damaged roads. The flood did not last more than 15 minutes.
1921	August 13	Landslide dam	Ashcroft, Thompson River	Septer (2007)	Clague & Evans (1994)	A landslide dam occurred 10 km south of Ashcroft. The slide was about 800 m wide and came down in stages, completely changing the landscape. The dam, formed by quaternary sediments, blocked the Thompson River for several hours. Several miles upstream, the river rose about 4 m before it broke through the dam.
1922	May 18	Flood	Nicola, Nicola River, Clapperton/Mill Creek	Septer (2007)		Nicola River rose an estimated 9 m in less than 20 minutes after an irrigation dam holding back water for a Nicola Lake stock farm broke. Warm weather during the previous few days caused the water levels in the lakes to rise rapidly. Efforts to open the sluices in the dam failed due to the great pressure. The dam's spillway gates got out of control when workmen were trying to close them. It caused a wall of water many feet high to sweep through the small town of Nicola. In addition to the bridge in town, 6 km of government road were also taken out. Total damage was estimated at $20,000. This amount included the dam, three houses in town that were carried out, and the losses of the farmers in the valley.
1927	Unknown Date	Debris flood	Sicamous Creek	Dobson Engineering Ltd. (December 1998)		A landslide in the mid 1920's (1925 to 1927) caused high bedload transport rates onto the fan.
1928	May 22	Flood	Louis Creek	Septer (2007)		Louis Creek suddenly rose far above its usual height at the lower end just before where it joins the North Thompson River.
	May 24	Flood	Clearwater River	Septer (2007)		The Clearwater River went on a rampage. 90 m of the government road flooded up to 0.6 m deep. The relatively new road was "apparently not built above the high water mark". Due to the highwater, the Blackpool ferry was not running. Floodwaters also threatened the Clearwater bridge.
	May 28	Flood	Kamloops	Septer (2007)		Heavy rain caused floodwaters in Kamloops to almost reach the baseball grandstand while Riverside Park was submerged.
1935	July 1	Debris flood	Kamloops, Tranquille Creek	Septer (2007)		Near the headwaters of Tranquille Creek, two dams burst, turning the stream into a torrent. One life was believed lost in the raging stream, which also swept away the 45 m bridge on Tranquille, 29 km east of Kamloops. The dams burst under pressure of water resulting from days of continuous rain.
		Flood	Chase Creek	Septer (2007)	Dobson Engineering Ltd. (March 31, 2005)	Chase Creek went on a rampage, and seven bridges on the CNR line were swept away. The buildings were reported to have piled up causing floodwaters to spread across open land.
	Unknown date	Debris flood	Sicamous Creek	Dobson Engineering Ltd. (December 1998)		Sicamous Creek avulsed during a flood and abandoned its northern channel, reactivating an older channel and flowing into the south bay.
	June 29-30	Flood	Cooke Creek	Thurber Engineering Ltd. (November 1990)		The bridge washed out at Cooke Creek and water spread out over approximately 200 ft wide area.
	June 29-30	Debris flow/Debris flood	Fall Creek, Brash Creek, Ashton Creek	Thurber Engineering Ltd. (November 1990)		At Fall Creek, a debris flow carried a house and garage away. The debris flow also washed out the bridge. The stream avulsed its channel in several locations. Events also occurred on Brash and Ashton Creeks during this same storm event. Approximately 66.5 mm of rain fall from June 28 to July 1, with 35.8 mm falling on June 30.
1936	June 1	Flood	Kamloops, Thompson River	Septer (2007)		Low-lying areas flooded as the Thompson River rose another 0.3 m overnight. It reached to within less than 0.9 m of its record high level of 6 m., established in 1928. The river rose nearly 0.6 m in the previous two days to 5 m.

Year	Month	Type of hazard	Location	Source	Report (if applicable)	Description of Event
1946	June 1	Flood	Spences Bridge, Thompson River	Septer (2007)		On June 1, the Thompson River at Spences Bridge recorded a maximum daily discharge of 3,200 m^3/s. On June 1-2, the Thompson River at Kamloops dropped nearly 0.6 m.
1947	September 27	Landslide	Ashcroft	Septer (2007)		A 59-car westbound CNR freight train struck a slide in the Thompson gorge at Anglesey, about 19 km east of Ashcroft. Five people were killed instantly. One engine and 11 boxcars were wrecked. The engine was half buried in the ground on the inside track under a perpendicular clay bank about 30 m in height.
1948	May 23	Washout	Westwold	Septer (2007)		Around May 23, a washout between Westwold-Monte Lake caused a disruption on the Kamloops to Kelowna rail line.
	May 25	Debris flow or debris flood	Heffley Creek	Septer (2007)		A dam on Devick Lake burst, sending a 9 m wall of water down Heffley Creek, a tributary of the North Thompson River. The flow killed one person, brought debris down into the valley and damaged the bridge across Edwards Creek.
		Flood	Sorrento	Septer (2007)		At Sorrento, Shuswap Lake rose 0.2 m daily until May 31, when the rate dropped to 0.1 m. Some of the beach homes at Sorrento were flooded.
		Flood	Barriere, Chinook Cove, Barriere River	Septer (2007)		Flooding threatened the residents of the Barriere and Chinook Cove districts. The Barriere River threatened to change its course when it broke through a low spot in the road in the central part of the community. Only quick action of sandbagging and later lining the break with rocks and putting in a foot bridge kept the road open. Fields were flooded, and some houses were surrounded by water. Some 90 m of the large irrigation ditch of the Barriere Irrigation District was washed out.
	May 27	Flood	Peterson Creek, Allan Lake	Septer (2007)		Peterson Creek had high flows. It was feared that the dam some miles up the creek at Allan Lake might fail. Four families living along the creek were forced to evacuate and move their stock for a number of days. The dam was saved by employees of the BC Power Commission.
	May 28	Flood	Kamloops, North and South Thompson River	Septer (2007)		The Oak Hills area experienced fairly heavy flooding throughout the lower business area. Flooding of North Kamloops was only prevented after a number of dykes were hastily put up. The Thompson River at Kamloops started flooding in the McKenzie Road area, affecting about 100 residents. Despite the erection of an emergency dyke, some homes were inundated. In an effort to save the area between the two rivers, similar dykes were built on the other side of the North Kamloops promontory.
	May 29	Flood	McLure, North Thompson River	Septer (2007)		A bus driver reported 2.4 m of water on the road at McLure.
		Flood	Chase, Chase Creek	Septer (2007)	Dobson Engineering Ltd. (March 31, 2005)	Chase was left without power and water after floodwaters of Chase Creek washed out the system's intake.
	May 31	Flood	Little Fort, Louis Creek, Lemieux Creek, North Thompson River	Septer (2007)		13 km north of Little Fort, the rising North Thompson River forced the evacuation of residents of Roundup near Little Fort. By May 26, Little Fort itself was surrounded by water. Fields stretching for 800 m south of Little Fort, formed a lake. Lemieux Creek overflowed its banks, cutting channels through fields, damaging bridges and cutting off traffic. A log jam upstream had to be blasted to save main bridges on the creek and a barn that was threatened from being washed away. At Louis Creek, roads were impassable.
		Flood	Walachin	Septer (2007)		The Thompson River took out the middle span of the massive concrete CNR bridge 3 km east of Walachin.
		Flood	Kamloops	Septer (2007)		12 families evacuated in the low westerly Brocklehurst district. North and east of the Brocklehurst school, a temporary dyke erected prevented flooding here. Floodwaters cut off the Happy Vale area, forcing some families to leave their homes. Some sections of Tranquille Road were under water. At the other side of the North Kamloops peninsula, four smaller dykes were erected to stop flooding by the North Thompson River.
	June 1	Flood	Savona	Septer (2007)		Kamloops Lake rose to a level higher than had been ever seen before. Savona's water supply, supplied by the CPR, was cut off because the pumphouse was under water and the equipment had to be moved to higher ground. A large number of homes were flooded, forcing residents to evacuate.

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	June 3	Flood	Spences Bridge, Thompson River	Septer (2007)		The Thompson River at Spences Bridge set an all-time record with a daily discharge of 4,130 m^3/s.
	June 12	Flood	Blind Bay	Septer (2007)		The high level of Shuswap Lake divided the community of Blind Bay in two. In places the water was 0.9 m deep on the road. Several cabins were flooded and the Scotch Creek to Sorrento ferry was using the dock at Catherwoods, instead of the Sorrento wharf.
	Unknown date	Flood or debris flood	Ross Creek	M.J. Milne & Associates Ltd. and Grainger & Associates Consulting Ltd. (June 2002)		A high flow event occurred on Ross Creek in 1948.
	Unknown date	Debris flood	Fall Creek, Kingfisher Creek	Thurber Engineering Ltd. (November 1990)		Floods, which included mud, rocks, and debris, took out bridges at Fall and Kingfisher Creeks.
1949	November 26	Debris flow	Gladwin	Septer (2007)		A mudslide blocked the Trans-Canada Highway at Gladwin, 4.8 km east of Lytton.
	December 3	Landslide	Spences Bridge, Lytton, Boston Bar, Hope, Thompson River			CN railway reported nine slides between Spences Bridge and Lytton, and five slides between Boston Bar and Hope.
1950	Unknown date	Debris flow	Kenyon Creek	Thurber Engineering Ltd. (November 1990)		A large debris avalanche occurred, with an approximate volume of 8,000 m^3.
1954	May 13	Flood	Chase, Revelstoke	Septer (2007)		Floodwaters cut across the Trans-Canada Highway near Chase and Revelstoke.
	May 20	Flood	Nicola	Septer (2007)		In the Nicola Valley, 60 m of CP railway track washed out during spring runoffs.
		Flood	Merritt	Septer (2007)		Floodwaters were creeping at the outskirts of Merritt during spring runoffs. One family had to be evacuated while others were threatened.
1950s	Unknown date	Debris flood	Sicamous Creek	Dobson Engineering Ltd. (December 1998)		A debris flood at an unknown date in the 1950s caused highway damaged and washed out the bridge over Sicamous Creek. The event occurred during snowmelt season, with an intense June rainfall event.
1958	December 1	Debris flow	Spences Bridge	Septer (2007)		A mudslide on the CN railway tracks near Spences Bridge delayed a passenger train for an hour and disrupted telegraph services.
1963	February 4	Debris flow	Lytton, Thompson River	Septer (2007)		A mud and rockslide, 60 m and 4.5 m deep, cut through the highway 8 km east of Lytton. The slide kept oozing down a steep slope all night. Five cars were abandoned between the washouts and a sixth was swept into the Thompson River moments after the occupants jumped out.
1967	June 2	Washout	Clanwilliam, Griffin Lake, Victor Lake, Big Griffin Creek	Septer (2007)	Thurber Consultants Ltd. (December 1987)	Major highway washouts occurred at Griffin Lake, Victor Lake and Clanwilliam. In addition, smaller problems at the same general area closed the highway for about seven hours. At Big Griffin Creek, the channel deposited approximately 10,000 to 15,000 cubic yards of sediment. The debris blocked the highway culvert, crossed the highway, and flowed across the fan. At Clanwilliam Creek, debris blocked the culvert and flowed across the highway.

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		Flood	Malakwa, Eagle River	Septer (2007)		Eagle River, swollen by torrential rain, topped its banks and flooded Malakwa and low-lying farms downriver. Five head of cattle were reported drowned on farms between Malakwa and Sicamous. These were the first victims claimed by the spring runoff from a record snowpack. The flooding also caused a number of washouts and left a bridge at Craigellachie dangling. On June 4, the river had dropped about 0.6 m. Malakwa was dry again and water was receding from the farms.
		Debris flow	Eagle River	Septer (2007)		At 11 p.m., a mudslide 19.2 km west of Revelstoke (east of Malakwa) derailed a CP railway freight train. Three diesel units and 28 boxcars left the tracks at a point where Eagle River separates the railway and highway. On June 5 railway traffic was restored.
	June 6	Flood	Shuswap Lake, Sicamous	Septer (2007)		Shuswap Lake level was high. To reduce wake damage in Sicamous Channel, a 5 km/h speed limit was imposed on boats.
1968	June 5	Debris flow	Camp Creek	Septer (2007)	Department of Highways (June 7, 1968)	Heavy rain caused a debris flow at Camp Creek, west of Revelstoke. It covered the Trans-Canada Highway, killing four occupants of a car travelling on the highway. Later that same evening, two more slides came down. The first slide was over 900 m long, up to 180 m wide and about 6 m deep. The bridge over the creek was completely carried away into nearby Griffin Lake, the west-end of which was full of floating debris emptied into it by the slide. The Camp Creek debris torrent involved 76,000 m^3 of debris. By June 8, the highway was open for one-lane traffic and was reopened for two-lane traffic on June 10.
1971	Unknown date	Debris flood	Camp Creek	Thurber Consultants Ltd. (December 1987)		In 1971 or 1972, boulders blocked the highway bridge and water flowed over the highway.
1972	May 25	Debris flow	Thuya Creek, Little Fort	Septer (2007)		A landslide on Thuya Creek near Little Fort removed much of the roadway of a highway.
	June 1	Flood	Clearwater, Barriere, North Thompson River	Septer (2007)		Water levels on the North Thompson River at Clearwater and Barriere increased to close to the 1967 high water mark.
		Flood	Little Fort, North Thompson River	Septer (2007)		Due to high water, ferry service at Little Fort was suspended for about a week. According to a ferry operator conditions on the river, which peaked at Little Fort around June 1-2, were the worst since 1948.
	June 2	Flood	Kamloops, North Thompson River	Septer (2007)		Several subdivisions in Kamloops flooded. In one area, 150 houses and 52 mobile homes flooded due to dike failure. The new Oak Hills subdivision at Westsyde flooded with 1.5 m of water when the earthfill dyke developed a 45 m break. Within minutes, the rushing water covered approximately 20 ha, upsetting trailers and damaging homes. Damage estimates ranged from $2-5 million. Some 65 trailers valued at between $10,000-15,000 each sustained most of the damage.
	June 3	Flood	Kamoops, South Thompson River	Septer (2007)		On June 3-4, minor flooding occurred down the South Thompson in the Dallas area. As the river continued to rise, it threatened some homes along River Street in Kamloops. Up the North Thompson, water levels started to recede.
		Flood	Savona, Kamloops Lake	Septer (2007)		At least 10 houses and more mobile homes were flooded. Some residents were forced to evacuate as some homes had up to 1 m of water in their basements. Kamloops Lake continued to rise. Between June 2 at 2:30 p.m.-June 3 at 8 a.m., it rose 0.2 cm. The area from the Savona Hotel to the bridge at the entrance of Thompson River was flooded.
	June 6	Flood	Chase, Salmon Arm, Shuswap Lake	Septer (2007)	Dobson Engineering Ltd. (March 31, 2005)	Flooding was reported in Chase from Chase Creek. Minor flooding occurred at some summer homes along the lakeshore.
		Flood	Barriere, Barrier River, North Thompson River	Septer (2007)		High water on the North Thompson and Barriere rivers forced the evacuation of several people or relocation of several people or relocation of trailers.

Year	Month	Type of hazard	Location	Source	Report (if applicable)	Description of Event
	June 10	Flood	Sicamous, Shuswap Lake, Mara Lake, Shuswap River	Septer (2007)		Residents of Sicamous fled to higher ground as Shuswap and Mara lakes flooded the entire downtown area and some sections of the Oak Hills subdivision with up to 0.2 m of water. Many backroads to farms were reported washed out. The area about 2.4 km along Riverside Road flooded forcing some 25 families to evacuate overnight. On June 10, the area was still flooded by seepage from Shuswap River. Overnight June 11-12, Shuswap Lake rose 0.1 m, worsening the flood situation in Sicamous. A few Sicamous residents were evacuated after parts of the community flooded with water up to 0.9 m. Evacuation continued on June 12 with over 40 homes vacated to that date. Shuswap and Mara lakes rose to at least 1.2 m above normal high water. According to unofficial figures from the highways department, lakes and rivers in the Sicamous area came to within 0.2 m of the 1948 flood level.
	June 12	Flood	Salmon Arm, Shuswap Lake	Septer (2007)		At Salmon Arm, Shuswap Lake flooded its banks in several places.
		Flood	Clearwater, North Thompson River	Septer (2007)		Birch Island north of Clearwater was flooded up to 0.9 m of water in places. On June 12-13, residents were evacuated.
	June 14	Washout	Clearwater, North Thompson River	Septer (2007)		A 1 m deep washout 14.4 km south of Clearwater closed Highway 5 to traffic.
		Flood	Little Fort, North Thompson	Septer (2007)		The Rivermount Hotel, above Little Fort, adjacent to the highway was completely surrounded by water.
	June 15	Flood	Spences Bridge, Kamloops, Blackpool, Barriere, Thompson River, Shuswap Lake	Septer (2007)		The Thompson River near Spences Bridge recorded a maximum instantaneous and maximum daily discharge of 4,130 m^3/s, reaching an all-time high for the period of record. At the Rayleigh Correctional Camp, 16 km north of Kamloops, the entire lower half of the camp flooded. The river completely covered fence posts and debris piled up against buildings. Though water levels at Blackpool dropped 0.4 m and 0.3 m at Barriere and Shuswap Lake only rose by 2 cm, seepage through dikes and sandbags remained a real problem.
1973	January 15	Flood	Kamloops, North Thompson River	Septer (2007)		Around 5 a.m., flooding occurred in the low-lying spots of Georgean Road and Greenacres Road areas in Westsyde, Kamloops.
	June 23	Debris flow	Camp Creek	Septer (2007)		A debris flow event cut the highway.
	Unknown Date	Debris flood or debris flow	Fall Creek, Cooke Creek	Thurber Engineering Ltd. (November 1990)		In 1973 or 1974, flooding cut the road near the culvert at Fall Creek. The culvert at Cooke Creek was also damaged in the same storm.
1974	January 16	Flood	Kamloops, Merritt, Spences Bridge	Septer (2007)		As snow turned to rain, a block-long section of the Trans-Canada Highway was flooded up to 0.9 m deep. East of Kamloops, another section was closed due to flooding. In Kamloops, the temperature went up to 13° C and basements flooded from the abrupt snow melt. Rain added to a three-day accumulation of melting snow and flooding was also reported from Merritt and Spences Bridge. The Merritt sawmill was closed after it flooded with 0.6 m of water in the mill yard.
	June 17	Flood	Sicamous, Shuswap Lake	Septer (2007)		Flood conditions started to develop on Shuswap Lakes with water levels 0.2 m below flood level at Sicamous. The rising water levels in Shuswap Lake caused some flooding in Sicamous. About two dozen homes and five businesses were affected in Sicamous.
1975	Unknown date	Flood	Chase Creek	Dobson Engineering Ltd. (March 31, 2005)		Significant flooding event in 1975 at Chase Creek.
1980	December 27	Washout	Shouz River	Septer (2007)		High water flows caused erosion of highway banks and bridge abutments in vicinity of Shouz Creek and Kingvale
		Flood	Merritt, Coldwater River			Near Merritt, the Coldwater River overflowed its bank. The Spring Island Trailer Court was flooded. For the second time in nine days, its residents had to be evacuated. When the floodwaters receded on December 28, two trailers were left uninhabitable and the possessions stored in some shed were lost. City crews cut the new dyke, downstream of the trailer court to allow the release of increasing floodwaters trapped behind the dyke. The flooding washed out a portion of railway

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						track, 1.6 km from Merritt in the direction of Brookmere. The Coldwater River washed out Coldwater Road in half a dozen places. Worst damage occurred at the Patchett Creek bridge near the mouth of Midday Creek. On Patchett Creek Road about 32 km from Merritt, Patchett Creek washed out a bridge approach. The gaping hole was blocked with a huge logjam. According to the manager of the Merritt Highways district, the creek had to be rechannelled before the approach could be reconstructed. There was 15-23 m of right bank erosion upstream and downstream of the bridge for 50-100 m and approximately 6-9 m of bank erosion on the left bank at the bend upstream of the bridge. About 21 m of the right bank approach road from the abutment toward the bank was washed out completely. About 30 m of the road leading down to the bridge washed out as well. Floating debris damaged the timber nose of the center pier and part of the bridge railing. There was also negligible damage to the right abutment. The left bank approach road washed out at the eroded bend upstream.
1981	January 1	Washout	Coldwater River	Septer (2007)		The logging road on the left bank of the Coldwater River just east of Fig Lake washed out at a steep cut bank on the lower loop of the switchback climbing out of the valley. Damage to Coldwater Valley roads was estimated at $250,000.
1982	March/April	Flood	Sicamous, Gillis Brook	Septer (2007)		At the end of March to the middle of April, residents in the area to the south of Maclean and MacPherson Road, behind the D Dutchmen Dairy, experienced flooding problems from Gillis Brook. Particularly along Green Road basements flooded, and sewage systems were disrupted. The heavy snowfall and the fact that Gillis Brook, which provides much of the drainage for the area, no longer provided adequate drainage caused the flooding. In the past few years, it had silted up considerably and bank cave-ins and debris had plugged it up. According to a long-time area resident, about 7-8 years earlier homeowners got together and paid about $50-60 each to have a section of creek dug out. Though it helped some, the creek had only been excavated to a depth of about 0.9 m while the resident thought it should have been to 2-2.5 m. The area most affected by flooding was bounded by Kappel Street to the south, Larch Avenue to the east and Highway 97A to the west. Local residents affected by the flooding got together and agreed to construct a network of interconnecting ditches and waterlines to drain to Mara Lake. Over 100 basements flooded in the Hedberg subdivision on the southeastern outskirts of Sicamous during the same time.
	June 21	Flood	Salmon Arm, Shuswap Lake	Septer (2007)		Low-lying lakefront property was flooded up to 1 m in some areas.
	September 25	Landslide dam	Ashcroft	Septer (2007)		Following three days of heavy rain, a 500-m wide slide came down the Thompson River Valley about 5 km downstream of Ashcroft. (Similar location to the slide in October 1880) Material was pushed 30 m into a 120-m section of the river. It caused the riverbed to come up about 2.5 m because pressure resulting from the slide caused a downward pressure pushing it up.
	Unknown date	Debris flow	Wickenberg Creek	Thurber Engineering Ltd. (November 1990)		A small debris flow occurred in 1981 or 1982.
	Unknown date	Flood	Chase Creek	Dobson Engineering Ltd. (March 31, 2005)		Significant flooding occurred at Chase Creek in 1982.
1983	February	Flood	Sicamous	Septer (2007)		The basements of more than 100 houses in the Hedberg subdivision on the southeastern outskirts of Sicamous flooded when ditches overflowed and covered the streets. Residents claimed that the re-constructed Highway 97B was acting like a dam and impeding water flow towards Mara Lake. A study done for the Columbia-Shuswap regional district found that the highway was built without proper culverts and drainage systems from the subdivision to the lake. The highways department finally built a temporary culvert under the highway and promised a permanent culvert soon.
	Unknown date	Flood	Chase Creek	Dobson Engineering Ltd. (March 31, 2005)		Significant flooding occurred on Chase Creek in 1983.
1984	January 4	Flood	Nicola, Nicola River	Septer (2007)		Heavy rain in the headwaters, warm temperatures and heavy ice blocks formed a 450 m ice flow that forced the Nicola River to take a new course and caused extensive flooding throughout the Nicola Valley and surrounding area. Joe's

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						Bridge, 22 km east of Spences Bridge and the only access to Highway 8 for five families living on the south side of the Nicola River, was destroyed.
1986	Unknown date	Debris flow	Wickenberg Creek	Thurber Engineering Ltd. (November 1990)		A small debris flow occurred in 1986 or 1987. The debris flow damaged a water intake and formed small debris jams in the channel.
1990	June	Flood	Deadman Creek, Bonaparte River	Septer (2007)		The June 1990 flooding caused $47,000 of damage on Deadman Creek and $99,000 of damage along the Bonaparte River.
	June 10	Debris flow	Sicamous	Septer (2007)		A mudslide on Highway 97A blocked all traffic between Grindrod and Sicamous.
	June 11	Debris flow	Vavenby	Septer (2007)		Two people were killed at Vavenby, 20 km north of Clearwater, while trying to clear a blocked culvert when a mudslide hit them. The slide blocked Highway 5, which remained closed on June 13.
		Debris flows and debris floods	Enderby, Stone Creek, Fall Creek, Mabel Lake	Septer (2007)	Thurber Engineering Ltd. (November 1990)	Unprecedented rainfall in the Enderby area led to many debris flows and debris avalanches along a 4-km stretch of the southern end of Hunter's Range, 20 km east of Enderby. Debris flows partially or fully destroyed four BC Hydro transmission towers, temporarily disrupting power transmission from the Revelstoke Dam. During the same storm event, 61 debris avalanches and debris flows occurred near Enderby. Twelve of the tracks reached the highway. Homes were damaged, and a hydro line severed. A Stone Creek house tipped over into the river and floated away. Four houses were hit and destroyed by a mudslide in the Fall Creek area, about 40 km north of Vernon. Mudslides also washed out about 8 km of the 40-km Enderby to Mabel Lake road. The mud was up to 1.5 m deep across the road. A helicopter rescued more than 30 residents stranded by the slide.
	Unknown date	Flood	Chase Creek	Dobson Engineering Ltd. (March 31, 2005)		Significant floods occurred on Chase Creek in 1990.
1991	February 4	Flood	Merritt, Nicola River	Septer (2007)		Iceflows jammed between Merritt and Colletville, impeding Nicola River's flow and causing flooding at Merrit, Canford, Kingvale, and the 14-Mile Reserve area. Some 100 residents were flooded out and 10 dwellings were damaged or dislodged, causing up to $1 million damage. The huge ice floes caused heavy damage in Merritt. Several meters of riprapping were wiped out, leaving Merritt and Sunshine Valley vulnerable to future flooding. Roads were washed out, minor bridges damaged and gas lines shifted. The ice pushed a hole in one house, pushed mobile homes off their pads and turned others on their sides. City crews immediately began repairing dykes and managed to bulldoze ice that threatened to take out the wooden Main Street bridge.
		Flood	Nicola River	Septer (2007)		Unseasonably warm weather caused a rapid break-up of ice on the Nicola River. The chunks of ice swept down the Nicola River and piled up 20 km west at Sunshine Valley.
	May 5	Flood	Merritt, Mill Creek, Guichon Creek, Stumble Creek, Nicola River	Septer (2007)		Flooding occurred near Merritt. Mill Creek Road washed out, impacting six families. The culvert that replaced the bridge a year earlier was unable to handle the volume of water and became plugged. Guichon Creek, Stumble Creek and Nicola River rose and overflowed its banks, flooding nearby residences.
1993	Unknown date	Flood	Chase Creek	Dobson Engineering Ltd. (March 31, 2005)		Significant flooding occurred at Chase Creek in 1993.
1994	Unknown date	Debris flow	Sunnybrae, Hart Creek	Westrek (September 27, 2017)		A debris flow occurred in Hart Creek just prior to 1994. It initiated in the upper channel and travelled down to the lake.
1995	May 25	Flood	Kamloops	Septer (2007)		The flooding in the Kamloops areas was largely due to rain falling on saturated soil and rain-on-snow. Little of the reported run-off could be attributed to the above average high-elevation snowmelt. May was much colder and wetter than usual. Between May 1-30, Kamloops recorded 49.2 mm of precipitation.

Year	Month	Type of hazard	Location	Source	Report (if applicable)	Description of Event
1996	June 1	Flood	Chase	Septer (2007)	Dobson Engineering Ltd. (March 31, 2005)	The Village of Chase experienced flooding from Chase Creek. The preliminary damage assessment and remedial cost estimates totalled $132,275.
	June 6	Landslide	Adams Lake	Tetratech Consulting Ltd. (March 26, 1999)	Tetratech Consulting Ltd. (March 26, 1999)	The “Rock Island Slide”, an approximately 500, 000 m^3 landslide, occurred on the east shore of Adams Lake, approximately 2 km south of Rock Island. The landslide was sourced in a thick sequence of glacial materials with different textural types. The slide travelled approximately 100 m and deposited into Adams Lake.
1997	January 17	Flood	100 Mile House, Bridge Creek			An ice jam on Bridge Creek near 100 Mile House created local flooding, potentially affecting one home.
	May 5	Flood	Enderby, Mabel Lake, Mara Lake, Grindrod	Septer (2007)		A high number of flood-related problems were identified on the Lower Shuswap between Mabel Lake and Mara Lake with 12 or more properties impacted, several of which might require evacuation. In Grindrod, homes flooded. At the south end of Mara Lake, problems were identified at Pat McBridge subdivision. Several farms flooded from Falls Creek to Enderby and Enderby to Mara Lake.
	May 5	Flood	Nicola River, Merritt, Guichon Creek	Septer (2007)		Nicola River overflowed its banks at an unspecified location. Guichon Creek suddenly rose and flooded a residence.
	May 7	Flood	Kamloops, North Thompson River	Septer (2007)		Flooding occurred on the North Thompson River which caused $50,000 worth of dyke repairs from Arab Run Road to Beachview Road-Rayleigh.
	May 15	Debris flow	Hudson Creek, Shuswap Lake, Gillespie Bay	Septer (2007)		A debris torrent occurred on Hudson Creek, which enters Gillespie Bay on Shuswap Lake. The debris together with knocked down trees destroyed the creek channel and debris flowed in several directions.
	May 16	Debris flood	Chase	Septer (2007)		Two mudslides damaged about a dozen homes near Chase. Flooding from a nearby creek led to the mudslide
	June 1	Flood	Barriere, Barriere River	Septer (2007)		The Barriere River caused erosion damage to its north side bank that continued to retrogress even during low flows.
	June 3	Flood	Nicola River	Septer (2007)		Warm weather with a high snowpack caused flooding in mid-May and saturated ground conditions resulted in slow flood level recession. When substantial rain fell in June, lakes and rivers responded very quickly and returned to, and in some cases exceeded, the levels reached earlier.
	June 5	Flood	Kamloops Lake	Septer (2007)		The water level on Kamloops Lake was 0.5 m up on the emergency dyke.
	July 11	Debris flow	Swansea Point, Hummingbird Creek, Mara Lake	Septer (2007)	Jakob, Anderson, Fuller, Hungr, & Ayotte (2000)	A debris flow occurred at Swansea Point, at the confluence of Hummingbird Creek and Mara Lake at Highway 97A. The debris flow resulted in damage to residences in the area and closure of the highway. Initial damages were placed at $1.8 million. The channel below Highway 97A filled with gravel between the highway and Mara Lake, a distance of approximately 600 m.
		Debris flood	Sicamous Creek	Dobson Engineering Ltd. (December 1998)		A debris flood occurred at Sicamous Creek, along with other high flow events in the region. The highway bridge was damaged. The channel was rapidly infilled with sediment and dredging above the highway bridge was necessary during the flood. Private properties on the fan were affected by the event.
		Washout	North of Clearwater	Septer (2007)		A road washout at First Canyon, 15 km north of Clearwater, created a hole 50-60 m deep. The washout left approximately 260 people stranded, the majority of which in Wells Gray Provincial Park. Seventy-six people were flown out by helicopter. A temporary bridge 140 ft. (42 m) in length was placed across the canyon. By noon on July 17, the Clearwater Valley road access to Wells Gray Park reopened
		Debris flood	Ashton Creek	Septer (2007)		Heavy rainfall caused severe erosion of Ashton Creek and some flooding of adjacent properties. The damage extended from the apex of the alluvial fan located approximately 1.1 km above the highway to a bridge washout located approximately 700 m below the highway. Throughout the area, deposition of material in the channel and erosion of the

Year	Month	Type of hazard	Location	Source	Report (if applicable)	Description of Event
						banks was widespread. A large volume of debris from the upper catchment was transported and deposited within the existing channel through the village of Ashton. The reduction in channel conveyance capacity resulted in the channel overflowing its banks and eroding the adjacent soils. Estimated repair cost was $150,870. Two families were evacuated, and the mobile home park and store were flooded.
		Debris flow	Kingfisher, Kingfisher Creek	Septer (2007)		The streambed of Kingfisher Creek destabilized with an estimated repair cost of $30,000. The Enderby-Mabel Lake Road washed out, land was flooded, debris was on bridge, the bridge was washed out, and culverts were washed out.
		Flood, avulsion	Kingfisher, Falls Creek	Septer (2007)		Fall Creek jumped its channel for a distance of 300 m. As its new location posed a significant threat to the highway and three homes, it was returned to its old channel. The estimated repair cost was $15,000. Fall Creek overtopped the road, damaged properties, avulsed out of the channel, flooded a campground and damaged the highway crossing.
		Debris flow, washout	Kingfisher, Cooke Creek	Septer (2007)		A debris flow event on Cooke Creek washed out part of the Enderby-Mabel Lake Road.
		Flood, washout	Enderby, Almondberry Creek	Septer (2007)		A flood event on Almondberry Creek washed out a road.
		Flood	Avola	Septer (2007)		Flooding reported in area.
		Flood	Barriere	Septer (2007)		Several roads experienced flooding.
		Flood	Enderby, Brash Creek	Septer (2007)		Flooding on Brash Creek caused a dam in Enderby to collapse.
		Flood	Mara Lake, Blurton Creek	Septer (2007)		Flooding on Blurton Creek flooded a mobile home park.
		Flood	Cherry Creek	Septer (2007)		Flooding on the north fork of Cherry Creek caused flooding of adjacent houses and flooding and erosion of north fork road.
		Debris flow	Anglemont, Hudson Creek, Shuswap Lake	Septer (2007)		A debris flow event on Hudson Creek closed roads and overtopped the highway in three places.
		Debris flood	Albas, Seymour Arm, Humamilt Lake, Celista Creek	Septer (2007)		A slide on Humamilt Lake 3 km north of the east end leading into Celista Creek, caused a higher sediment load in Celista Creek.
		Flood	Malakwa, Loftus Creek	Septer (2007)		Loftus Creek at Cott Creek flooded two houses on Sommerville-Husted Road.
		Debris flow	Crazy Creek	Septer (2007)		Debris flow event on Crazy Creek.
		Flood	Mabel Lake, Noisy Creek	Septer (2007)		Flooding on Noisy Creek caused bank erosion and washed a road out that left campers stranded.
	July 15	Washout	Lytton, Gladwin	Septer (2007)		A washout at Gladwin on Trans-Canada Highway cost $3,000 to repair.
		Washout	Salmon Arm	Septer (2007)		Repairs related to runoff damage on Sunnybrae-Canoe Point Road cost $20,000.
	July 20	Washout	Sicamous Creek	Septer (2007)		Repairs related to runoff damage on Highway 97A, 5 km south of Sicamous cost $975,000.
	July 21	Flood	Kamloops	Septer (2007)		A violent storm passed through the interior. Rushing waters from rain and hail washed debris through Kamloops streets clogging catch basins for storm sewers. Hardest hit areas were Westsyde and Sahali on hillsides where most of the debris came from. The city received more than 100 storm-related calls. About a dozen places experienced some flooding.
	Unknown	Flood	Leonie Creek, near Barriere	Tetratech Consulting Ltd. (November 28, 1998)		A flood or debris flood occurred at an unknown date in 1997 on Leonie Creek in the area of the main road crossing south of Genier Lake.

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	Unknown	Debris flow	Leonard Creek, Salmon Arm	Golder Associates Ltd. (October 8, 1998)	Golder Associates Ltd. (October 8, 1998)	A debris flow deposited sand and gravel just south of 20th Avenue S.W. in Leonard Creek. Approximately 850 truck loads of gravel were removed from the site.
1999	April 2	Landslide dam	Revelstoke, Clanwilliam Lake, Eagle River	Septer (2007)		A landslide came down on Highway 1, 13 km west of Revelstoke on Clanwilliam Lake slide. Coming down on the north side of the valley, it dumped approximately 5,000-10,000 m^3 of rock, earth and trees into Clanwilliam Lake. Consequently, the lake backed up to over 1 m above normal low water levels. Debris from the slide landed in the outlet of the lake, which is the headwater of the Eagle River, causing the creation of a weir. Though the slide did not block the highway at the time of the incident, it did block the CPR mainline for 24 hours. Erosion problems were caused along the highway. On the lake there was a large moving log mass as well as a large volume of timber at the mouth of the lake. Total restoration cost was $150,000.
	May 25	Flood	Falkland, Bolean Creek, Salmon River	Septer (2007)		Flooding on Bolean Creek threatened a waterfront home and workshop near Falkland. During the previous week, the usually sedate creek rose nearly 2 m. Falkland is usually one of the first communities hit by rising spring waters as Bolean Creek and Salmon River meet in the center of town.
		Debris flow	Lytton, Gladwin	Septer (2007)		Spring runoff washed out a culvert under Highway 1 at Gladwin. The cost to replace the culvert, backfill and resurface the roadway was $1,500.
		Flood	Salmon Arm, Salmon River	Septer (2007)		The Salmon River spilled its banks in areas in the valley, Numerous fields started to look like lakes. Minor flooding reported in Salmon Arm.
		Flood	Lytton, Thompson River	Septer (2007)		Minor flooding was reported in Lytton.
	May 31	Flood	Barriere, Haggard Creek	Septer (2007)		Near Barriere, Haggard Creek jumped its banks threatening a home, a situation occurring every year.
	June 5	Debris flood	Enderby, Ashton Creek	Septer (2007)		Ashton Creek overflowed its banks, impacting one home.
	June 19	Debris flow, avulsion	Blue River, Allen Creek	Septer (2007)		A debris flow came down near Allen Creek, a tributary to Albreda River, 51 km north of Blue River. Allen Creek jumped its banks about 1 km upstream from Highway 5. The resulting torrent damaged approximately 600 m of main highway and a large parking lot. The maintenance contractor for the Ministry of Highways redirected the creek back into its original channel, allowing them to repair the road and parking lot. At Allen Creek, no homes were impacted.
	June 20	Flood	Barrier, North Thompson River	Septer (2007)		21 people were evacuated from Barriere. On June 21, 10 people were evacuated from the Barriere area. On June 23, the cresting of the North Thompson River forced the evacuation of 36 families in Clearwater and Barriere, affecting 89 people.
		Flood	Clearwater, North Thompson River	Septer (2007)		High water eroded 100 m of Auldgirth Road at Dunn Lake Road, 16 km south of Clearwater. Cost to haul and place 7,000 m^3 of road base and cap with gravel to re-establish the road profile was $176,500.
		Flood	Clearwater, Murtle River	Septer (2007)		High water wave action eroded the toe of a fill slope at Mushbowl Falls on Clearwater Valley Road, 41 km north of the Highway 5 intersection. Restoration cost was $32,000.
		Flood	McLure, North Thompson River	Septer (2007)		The North Thompson River at McLure reached 5.21 m, surpassing the 1972 peak of 5.15 m.
	June 21	Washout	Sunnybrae, Reinecker Creek	Septer (2007)		At Herald Park, 12 km east of the Trans-Canada Highway on Sunnybrae-Canoe Point Road, a portion of the Margaret Falls Trail washed out. Restoration cost was $5,000.
		Flood	Clearwater	Septer (2007)		41 residents were evacuated plus another unregistered 12.
	June 23	Flood	Kamloops, Thompson River	Septer (2007)		The Thompson River at the Overlander Bridge at Kamloops reached 9.24 m, 24 cm higher than the 1997 peak.
	June 25	Flood	Squilax, Shuswap Lake	Septer (2007)		Shuswap Lake flooded the 15-ha Cottonwood Campsite.

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	June 30	Flood, washout	Deka Lake	Septer (2007)		High water caused a road washout at the outlet of Deka Lake, km 0.3, Womack Road, Deka Subdivision. Cost to re-install the culvert, riprap and road surface was $160,000.
		Flood, washout	Canim Lake Reserve, Bridge Creek	Septer (2007)		High water flows caused the Biss Bridge on the Tsq'escen Road, Canim Lake, to float off its foundations, destabilising the structure. The approach fill washed out. The bridge acted as a dam, contributing to flooding adjacent areas. The cost to replace bridge, riprap and approach fills and washed out paved surface was $300,000. Cost to repair washed out road surface and severe road failure, reconstruct road base and repave was $91,000.
		Flood	93 Mile, Longbow Creek	Septer (2007)		Gustafson bridge on Buffalo Creek Road lost its banks, riprap and approaches. Restoration cost was $10,000.
		Flood	Forest Grove, Bridge Creek	Septer (2007)		The approaches on Bates Road were eroded away, causing $12,000 damage.
		Flood	Canim Lake, Bridge Creek	Septer (2007)		High water on Bridge Creek eroded the upstream bank adjacent to and under the Lily bridge on Canim Road. Cost to restore the bank and riprap was $12,500.
		Flood	100 Mile House, Bridge Creek	Septer (2007)		High water washed out the approaches to the bridge on Houseman Road over Bridge Creek and caused the loss of a wingwall. Restoration cost was $28,500.
		Flood	100 Mile House, Bridge Creek	Septer (2007)		High water washed out the road surface on Doman Road, inlet of Horse Lake, 100-Mile House. Cost to restore the road surface was $113,000.
		Flood	100 Mile House, Fawn Creek	Septer (2007)		High water washed the culvert inlet at Fawn Creek on Horse Lake Road and caused bank erosion. The cost to replace the failed culvert and riprap at inlet was $21,500.
	July	Flood	Canim Lake Reserve, Bridge Creek	Septer (2007)		At the end of June after running high for two months, the Bridge Creek rose up to the bridge levels and flooded, cutting off Canim Lake Reserve residents. On July 3-4, rains caused the river to continue to rise, completely flooding over the bridge as well as the road on either side with 0.3 m of water. In early June, some 45 people were evacuated from part of the Canim Lake Reserve. Bridge Creek overflowed its banks in several other spots. It reached to within about 50 m from the Eliza Archie School. About 17 families relied on the bridge for access to their community. The other two roads into the reserve were both impassable due to mud and water.
		Flood	Spences Bridge, Cache Creek, Thompson River	Septer (2007)		High water levels on the Thompson River caused damage to Goldpan Provincial Park campsites, 7 km south of Spences Bridge, and Juniper Beach Provincial Park campsites, 19 km east of Cache Creek both on Highway No. 1. Restoration cost were $5,900 and $1,750, respectively.
		Flood	Magna Bay, Ross Creek	Septer (2007)		Ross Creek flooding caused damage to the Squilax-Anglemont Road that cost $650,000 to repair.
	July 4	Flood	Bridge Lake	Septer (2007)		In the Two Creeks-Bridge Lake area east of 100 Mile House, a private bridge washed out and the septic fields of two cottages were impacted.
	July 6	Flood	Clearwater, Barriere, North Thompson River	Septer (2007)		Flooding was reported on the North Thompson River near Clearwater and Barriere, involving farmland and impacting one home.
		Debris flow	Avola	Septer (2007)		A debris torrent came down at an unnamed creek 1.6 km north of Avola on Messiter Station Road. It covered Messiter Station Road with mud, damaged a culvert and filled 600 m of ditch with mud and also affected three private properties. The slide was triggered by water runoff on the mountainside, which in turn destabilized the ground. It resulted in a large flow of mud, rocks and debris down the hill and jumped the existing creek channel in several locations. On August 9 during a localized rainstorm, another debris flow on a slightly different course upstream covered the road in the same place. Further occurrences have happened since.
	July 7	Flood	Cache Creek	Septer (2007)		On July 3 and 4, heavy rains followed by a torrential downpour on July 7 caused many small lakes in the Cache Creek area already swollen by the melting snowpack, to overflow.
	July 8	Flood, Debris flow	Clearwater, Spahats Creek			On July 8, after rains washed out the main road into Wells Gray Provincial Park about 150 campers were temporarily stranded. The road washed out at Spahats Creek, some 20 km north of Clearwater. About 20 m of the Clearwater Valley

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						Road had disappeared after a debris torrent blocked a culvert. The subsequent water build-up washed out the road that serves as main access to the park. High water caused damage on Clearwater Valley Road north of the Highway 5 intersection. Floodwaters and debris plugged the pipe arch culverts at Spahats Creek at 10.25 km. Water flowing over the road caused the downstream embankment to fail. Two 3.6 m wide by 30 m long multi-plate structures washed out. One washed over the falls and the other lodged downstream, both damaged beyond repair. Cost to construct a bridge and approaches was $665,000.
		Flood	Cache Creek	Septer (2007)		High water washed out riprap, road shoulder and bridge flares on Highway 97, 10 km north of Cache Creek. Restoration cost was $48,500.
	July 9	Debris flow	Seymour Arm	Septer (2007)		A debris flow at 2.3 km on the Seymour Arm Forest Service Road destroyed the dam and water intake for the community of Seymour Arm. Restoration cost was $25,000. A slide took out road access and the water supply system to two homes on Bughouse Bay Road. A fly-over determined some seasonal homes were destroyed. By the middle of July, a washout on Bughouse Bay Road covered approximately 200 m of roadway and destroyed the water supply to 120 users, homes and businesses.
	July 10	Flood	Cache Creek, Bonaparte River	Septer (2007)		The Bonaparte River reached flood stage, having risen 13 cm since the previous day. On July 11, creek and lake levels in the south Cariboo remained high and bridges were being monitored. In Cache Creek, sandbagging was underway at several trailer courts in low-lying areas of town. Municipal water supply and several bridges were also threatened.
		Flood	Loon Lake, Bonaparte River	Septer (2007)		The retaining wall at km 24 on Loon Lake Road washed out, causing $65,500 damage.
	July 11	Flood	Loon Lake, Bonaparte River	Septer (2007)		High water levels washed out fill behind the wingwall on Loon Lake Road with a restoration cost of $5,500. At 20 km on Loon Lake Road, the road washed out from saturated shoulders and heavy rain. Cost to replace the rock retaining wall was $39,000.
	July 12	Flood	100 Mile House	Septer (2007)		During the period July 5-12, several runoff-related events occurred on the Bonaparte-Egan Forest Service Road in the 100-Mile House district. A plugged 500-mm culvert at 2.2 km caused erosion of road surface. The restoration cost of the road, accessing residents and the Moose Lake Recreation Area was $1,500.
	July 13	Flood	Salmon Arm, Syphon Creek	Septer (2007)		Heavy rains and rapid snow melt in July. West of Salmon Arm on Shuswap Lake at Pierre's Point, flooding impacted three mobile homes.
		Flood	Clearwater, Candle Creek	Septer (2007)		At Candle Creek, at 4.36 km, the culvert was unable to handle the heavy runoff. Overbank flows caused the collapse of the upstream lock-block retaining walls. The east lane was undermined and collapsed, and 200 m of shoulder and fill were destroyed with the loss of a 1.8 m and 4 m section of pipe. Restoration cost was $420,000.
	July 15	Flood	Shuswap Lake	Septer (2007)		Four runoff-related events occurred in Shuswap Provincial Marine Park. High water on Shuswap Lake eroded campsites at Cinnemouson Narrows, Four-Mile Creek, Encounter Point and Anstey View. At Four-Mile Point Marine Park, bridge abutments and a trail washed away. Total restoration cost was $5,000.
		Flood	Squilax, Hiuihill Creek	Septer (2007)		Failure of a bridge at Hiuihill Creek in Roderick Haig-Brown Park on the Squilax-Anglemont highway and Holding Road. Cost of reconstruction of one bridge, including new footings and the reconstruction of several km of type 2 trail was $50,000.
		Flood	Clearwater, Clearwater River, Trout Creek, Grouse Creek, Hemp Creek	Septer (2007)		Floodwaters and spring high water caused erosion, a mudslide and washouts on the Clearwater River Road, on the west side of the Clearwater River, north of Clearwater. Trail facilities were flooded and destroyed. The cost of reconstruction of road surface, ditches and culverts, riprapping eroded streambanks and realignment of river direction and trail reconstruction was $115,000. Floodwaters washed away the Trout and Hemp creeks bridges on the Flat Iron Trail. Floodwaters washed away the Moul Fall viewing platform and trail located off the Clearwater Valley Road at 24 km. Floodwaters washed away and destroyed the Spahats hiking bridge on the Clearwater River Trail and parts of the trails. Floodwaters and spring runoff caused erosion damage to the road surface and undermined the bridge abutments on the Battle Mountain access road located at 30 km on the Clearwater Valley Road.

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	July 17	Flood	Sicamous	Septer (2007)		Near Sicamous, high water on Shuswap Lake breached sandbag dykes on Adams Lake Band land, impacting Sandy Point Resort. Flooding affected undetermined number of recreational campers and impacted six homes in Sicamous.
	August 3	Flood	Barriere, North Thompson River	Septer (2007)		A backflow in the Exlou area south of Barriere caused flood damage to several homes on the west side of the river. It resulted from a culvert allowing the North Thompson River water to pass under the highway and rail line into this area whenever the river levels rise significantly.
	August 9	Debris flow	Clearwater, Spahats Creek	Septer (2007)		During a localized rainstorm north of Clearwater in Wells Gray Provincial Park, another debris flow occurred on a slightly different course upstream, covering the road in the same place as the July 8 slide. Further occurrences have happened since.
2001	August	Flood	Candle Creek	Silvatech (May 2002)		A summer rainstorm caused floods along Clearwater Valley Road. The culvert at Candle Creek was washed out and closed the road for some time.
2002	June 4	Flood	Merritt, Nicola River	Septer (2007)		Melting snowpacks and recent rain caused Nicola Lake to rise. This forced Ministry of Water, Land and Air Protection officials to release water from the lake through Nicola Dam into the Nicola River. This caused the river that runs through Merritt to flood. Nearly 40 homeowners sustained flood damage. To prevent further flooding, some 16,000 sandbags were placed at strategic locations along the river.
2003	June	Debris flow/debris flood	Falkland	Jordan & Covert (2009)		Post-wildfire debris flows from the Cedar Hills fire complex. Erosion occurred in approximately 50 small gullies along a 2.5 km long slope. In one gully, eroded sediment bulked into a debris flood and flowed onto the fan. The debris flood flowed into two residential yards and blocked the highway. The debris flows were caused by intense rainstorms onto terrain with high soil burn severity.
2005	January 24	Flood	Birch Island, North Thompson River	Septer (2007)		Ice jams on the North Thompson River caused flooding at the community of Birch Island, population 225, about 12 km north of Clearwater on Highway 5. Overnight January 23-24, the river went up 2.5 m and was covered with solid ice. Some of the homes seriously damaged by flooding could be structurally unsafe. A total of 20 homes were evacuated. The ice took out support beams and damaged the 65-year-old wooden Birch Island bridge over the North Thompson River beyond repair. Residents were forced to take an hour-long detour to reach the other side of the river via a logging road. The span across the river was too long for a temporary crossing. It took more than a year to build a new $2.5 million bridge. A second ice jam several kilometers upriver also threatened to further damage the bridge and cause a second flood on Birch Island.
		Flood	Avola, Mad River	Septer (2007)		Floodwaters on Mad River closed Highway 5, 70 km north of junction with Highway 24. The next day the Mad River bridge south of Avola was still closed.
		Flood	Little Fort, Barrier, North Thompson River, Barriere River	Septer (2007)		Ice jams threatened the communities of Little Fort and Barriere. Some residents were on standby for evacuation. The ice jams on Barriere River broke apart on January 26 alleviating the flood levels by 2 m.
	December 27	Flood	Birch Island, North Thompson River	Septer (2007)		The North Thompson River jumped its banks after an ice jam formed on a bend in the river. One house downstream of Birch Island was flooded with about 0.5 m of water.
2007	March 13	Debris flow	Gladwin	Bichler, Yonin & Stelzer (2012)		Approximately 2,000 m^3 of debris was deposited on Highway 1. This was the largest of the three significant events occurring at the site over a period of six years.
2012	June	Debris flood	Ashton Creek	Castanet News (2012)		Flooding occurred at Ashton Creek that impacted Mabel Lake Road.
	June 23	Debris flood	Camp Creek	Orlando (2012)		A debris flood occurred on Camp Creek, west of Revelstoke. Highway 1 was blocked at Camp Creek for more than two days. A separate debris flow blocked Highway 1 approximately 15 km west of Revelstoke.
	June 23-24	Debris flood	Sicamous Creek	"Sicamous B.C." (2012)	Ministry of Forests, Lands, and Natural	A debris flood occurred at Sicamous Creek, in the Two Mile Subdivision of Sicamous. The Highway 97A bridge was blocked by debris. Sicamous Creek avulsed and inundated the Waterway Houseboat Vacations property and damaged

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					Resources (2013)	several houses on the alluvial fan. Highway 97A was closed until repairs were completed to repair the bridge and re-route Sicamous Creek.
	June 23-24	Debris flood	Hummingbird Creek	Ministry of Forests, Lands, and Natural Resources (2013); “BC flooding” (2012)	Ministry of Forests, Lands, and Natural Resources (2013)	Flooding and channel avulsions damaged houses and businesses on the Hummingbird Creek alluvial fan. Debris blocked the culvert on Highway 97A, causing the channel to avulse and flow into the Swansea Point community.
	June 23-30	Flooding	Mara Lake, Sicamous	“BC flooding” (2012)		Mara Lake rose to nearly historic water levels. The lake levels rose as much as 8 cm/hour as several streams experienced flash floods. Nearly 350 people were evacuated from homes as the lake inundated parts of Sicamous. The flooding occurred because of rapid snowmelt followed by a heavy rainfall. Do-not-use advisories were put in place for water in Sicamous.
2013	May	Debris flow	Gladwin	Ministry of Transportation and Infrastructure (2017)		A debris flow 9 km east of Lytton caused Highway 1 to be closed.
2014	April 23	Debris flow	Sunnybrae, McIntyre Creek	Westrek (January 2, 2015)	Westrek (January 2, 2015)	A debris flow event occurred on McIntyre Creek on April 23 in the 6000 block of Sunnybrae-Canoe Point Road in Electoral Area C. The debris flow blocked the Sunnybrae-Canoe Point Road and affected some residential properties on the fan. The volume of the debris flow was estimated to be approximately 2000 ± 400 m^3.
	July 24	Debris flow and flood	Kamloops	“Kamloops cleans” (July 24, 2014)		Flash flooding and small mudslides were triggered from intense rainfall in the Kamloops area.
	May 2	Debris flood	Enderby, Dale Lake, Cooke Creek	Forest Practices Board (October 2016)	Forest Practices Board (October 2016)	In May 2014, Dale Lake, near Enderby, overflowed and caused a debris flood down Cooke Creek. The debris flood washed out two sections of the Cooke Creek Forest Service Road and overtopped the Enderby-Mabel Lake Road. The road was damaged extensively and impassable for two days. The debris flood inundated the Kingfisher Salmon Hatchery and Interpretive Centre. 60,000 salmon in the fishery were killed.
2015	February 8	Landslide	Anglemont	Wickett (2015)		A seasonal home in Anglemont Estates was destroyed by a landslide.
	February 15	Landslide	Grindrod	“Mudslide closes” (2015)		Highway 97A was closed between Grindrod and Sicamous after a mudslide impacted a residence and the debris crossed the highway.
	May 24	Flood	Cache Creek	Azpiri & Sweeney (2015); SNT Geotechnical Ltd. (December 20, 2017)		An hour-long cloudburst caused flash flooding on Cache Creek. Debris carried downstream blocked culverts and other drainage infrastructure causing flooding and debris inundation of dozens of homes. The debris and flooding also closed Highway 1 and Highway 97. Mud blocked access to the fire hall until volunteers dug it out. Crews had to use heavy equipment to clear debris from all over the village. The culvert conveying Lopez Creek under Stage Road was blocked by sediment and resulted in flooding and erosion of Stage Road. Flooding and erosion in Back Valley impacted roads and road structures on Backvalley Road.
	June 30	Flood	Kamloops	“Flash flooding” (2015)		A sudden downpour over the Westsyde neighbourhood flooded roadways and brought mud down from adjacent slopes. The flooding caused evacuation of 60 homes.
2017	May	Flood or Debris Flood	Gladwin	Ministry of Transportation and Infrastructure (2017)		Flooding 8 km east of Lytton caused lane closures on Highway 1.

Year	Month	Type of hazard	Location	Source	Report (if applicable)	Description of Event
		Flood	Cache Creek	"Cache Creek" (2017)		High waters on Cache Creek blocked culverts and overtopped banks upstream of the Village of Cache Creek and within the Village. The community's Fire Chief was swept away by high flows while checking water levels at a bridge that was later washed out.
		Flood	Lower Nicola, Guichon Creek	Ybarra (May 7, 2017)		Guichon Creek breached its banks and both bridges connecting Lower Nicola to Merritt were washed out. Power was also cut off by flooding.
		Flood	Merritt, Nicola River	Ybarra (May 12, 2017)		Overnight rainfall caused an already high Nicola River to breach its banks. Flooding affected Garcia Street extending from the Nicola Meadows senior home to just north of the Nicola Valley Memorial Arena. Houses around Lions Memorial Park and Voght Street were also affected.
		Flood	Kamloops, Campbell Creek	Donnelly (2017)		Snow melt caused high water levels on Campbell Creek. Residents claimed it was the highest water level they had ever seen since they moved there 11 years ago. Sand bagging efforts by volunteers limited damage to property.
		Flood	Nicola Lake	FLNRO (May 9, 2017)		Nicola Lake was filling at a rate in excess of 100 m^3/s, which was 40% more than the previous historical maximum, and the lake was rising 24 cm per day on May 9.
	May 5	Debris flow	Sunnybrae, Robinson Creek	Westrek (September 27, 2017)	Westrek (September 27, 2017)	A debris flow event occurred on Robinson Creek on May 6 in the 5900 block of Sunnybrae-Canoe Point Road in Electoral Area C. The debris flow blocked the Sunnybrae-Canoe Point Road and impacted two residential properties, causing one fatality. The debris flow initated in a bedrock crevice and entrained material along its channel upstream of the fan.
		Flood	Logan Lake	Klassen (2018)		Flooding of Logan Lake caused a washout on Tunkwa Lake Road, closing the road.
		Flood	Cherry Creek	Ybarra (May 5, 2017)		Homes along Cherry Creek were submerged by floodwaters after an intense thunderstorm passed through the region.
	October 16-18	Debris flow	Loon Lake	BGC (December 4, 2017)	BGC (December 4, 2017)	A post-wildfire debris flow occurred at a property along the south shore of Loon Lake.
	Unknown date	Debris flow	Lower Bonaparte Valley	SNT Geotechnical Ltd. (December 20, 2017)		Small post-wildfire debris flows deposited sediment to Highway 97.
2018	April 28	Flood, washout	Agate	VSA Highway Maintenance Ltd. (2018)		High water levels and flows on an unknown creek washed out part of Highway 8 near Agate. The creek continued to bring debris down and a geotechnical assessment was required before crews could work at clearing the debris and repairing the highway.
		Flood	Cache Creek	Fry (2018), Potestio (2018), Roden (May 1, 2018)		High water and flow levels on Cache Creek caused flooding adjacent to the channel. The Village of Cache Creek had crews placing sandbags and equipment keeping the channel clear of sediment throughout the high water levels to reduce flooding and to keep flow going through a culvert under Quartz Road.
	May	Flood	Kamloops, Campbell Creek	Fry & Cronin (2018); Donnelly (2018)		Highwater levels on Campbell Creek posed a safety risk to users of Barnhartvale Road so sections of the road were closed by the City of Kamloops and water levels were monitored at bridges until water levels receded.
		Flood	Lower Nicola, Guichon Creek	TNRD (May 6, 2018), Lovgreen (May 8, 2018a)		Flooding on Guichon Creek impacted a mobile home park as well as adjacent homes. Some residents were evacuated by the regional district. The high water also closed Highway 8 in both directions for multiple days.
		Flood	Nicola, Clapperton Creek	TNRD (May 5, 2018)		Rising water on Clapperton Creek in the vicinity of Mill Creek Road caused TNRD to issue an evacuation alert to three properties in the area.
		Flood	Cherry Creek	Cronin (2018)		Levels on Cherry Creek rose 1.5 m on May 3, flooding adjacent properties. Creek flow was reported to be much faster than May 2017 runoff flooding.

Year	Month	Type of hazard	Location	Source	Report (if applicable)	Description of Event
		Flood	Cache Creek, Arrowstone Creek	MoTI (May 1, 2018)		Flooding on Arrowstone Creek washed out the bridge on Backvalley Road as well as caused washouts of the bridge abutments and on the road downslope of the creek.
		Flood	Stump Lake, Frisken Creek	VSA Highway Maintenance Ltd. (May 5, 2018)		Flooding on Frisken Creek washed out a bridge on Old Kamloops Road on the west side of Stump Lake. A temporary bridge was installed on May 5, 2018.
		Flood	Merritt, Nicola River	Q101.1 Merritt's Music Mix (2018), Hill (May 6, 2018), Sperling (May 12, 2018)		The City of Merritt declared a local state of emergency on Garcia Street near the entrance to Nicola Meadows assisted-living facility on May 6. Some localized flooding on Vogt Street and Garcia Street from high water levels. The Nicola River had yet to breach its banks at the time of the report (May 7). The current information from FLNRO led city officials to expect the current level of water flowing through Merritt to increase over the next few days. The Nicola River breached its banks on both Garcia and Voght streets on May 12, prompting the evacuation of Nicola Meadows. Other evacuation orders were issued May 11 for residents on 2nd Avenue and a home on Voght Street.
		Flood	Logan Lake	MoTI (May 8, 2018)		A bridge was washed out by high water flows on Highway 97D, approximately 10 km east of the junction with Highway 97C in Logan Lake. The road was reduced to single lane alternating traffic
		Flood	Sorrento, Shuswap Lake			High lake levels caused flooding of Dieppe Road.
		Flood	Kamloops, Jamieson Creek			Spring freshet events have caused multiple washouts and landslides that have closed Jamieson Creek Forest Service Road until further notice from 0 km to 20 km.
		Flood	Ashcroft	MoTI (May 9, 2018)		Barnes Lake Road was closed due to washouts caused by highwater levels on adjacent creeks. As water levels receded, crews worked to repair the road and re-gain road access to the area.
		Flood	Silver Creek	Wickett (2018)		A resident on Silver Creek was evacuated as a berm made to keep water in the creek failed flooding fields and made its way to the house. The water was about 0.5 m high at the house.
		Flood	Skimikin Lake			Skimikin Road, adjacent to Skimikin Lake, flooded between Tappen Valley Road and Turtle Valley Road.
		Flood	Falkland, Salmon River, Falkland Creek			High water levels on the Salmon River caused flooding of Dear Road. Falkland Road also flooded due to high water levels at Falkland Creek.
		Flood	Westwold	MoTI (May 10, 2018)		Flooding on Highway 97 at Westwold impacted both directions of traffic.
		Flood	Quilchena, Nicola Lake, Quilchena Creek	Lovgreen (May 8, 2018b)		Spring freshet caused flooding on the golf course in Quilchena.
		Flood	Little Fort, McLure, North Thompson River			High water on the North Thompson River caused the Little Fort and McLure ferries to be closed causing a considerable detour.
		Flood	Ashcroft, Barnes Lake			Road flooding closed access to the Barnes Lake Recreation Site.
		Flood	Nicola, Helmer Lake			Flooding of the recreation site and a washout on Swakum Mountain Forest Service Road closed the Helmer Lake Recreation Site.
	July 31-August 3	Debris flow	Bonaparte Valley, Cache Creek	Winkelman & Roden (2018); Winkelman (2018).		Multiple post-wildfire debris flows were triggered along Highway 97 between Cache Creek and Clinton and the Loon Lake Road by rainstorms over terrain affected by the Elephant Hill wildfire. At least one residence along Loon Lake Road was surrounded by debris.
	August 11	Debris flow	Bonaparte Valley, Cache Creek, Ashcroft, Clinton, Hat Creek	Roden (August 13, 2018; August 14, 2018; August 21, 2018)		At least 17 post-wildfire debris flows along a 10 km stretch of Highway 99 were triggered by intense rainstorms west of the Highway 97/Highway 99 intersection. One fatality resulted from a debris flow pushing a car over the highway embankment into Hat Creek. Highway 99 was closed for more than 36 hours as crews cleaned up the debris. Twenty four members of the Bonaparte Band were evacuated from homes, and one house had mud deposited into the first floor. In Cache Creek, several homes in a trailer park near the post office were impacted by water and gravel transported from a gully near the trailer park entrance.

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APPENDIX H
CAMBIO COMMUNITIES

H.1. INTRODUCTION

H.1.1. Purpose

Cambio Communities is a web application that supports regional scale, geohazard risk - informed decision making by government and stakeholders. It is intended to support community planning, bylaw enforcement, emergency response, risk management, and asset management. It also provides a way to maintain an organized, accessible knowledge base of information about geohazards and elements at risk.

The results of this study are also provided separately from Cambio Communities, in the form of this report and digital information (GIS data download and web service for prioritized geohazard areas). Cambio communities provides a platform to access the same results in a structure that supports decision making.

The application combines map-based information about geohazard areas and elements at risk with evaluation tools based on the principles of risk assessment. Cambio Communities can be used to address questions such as:

- Where are geohazards located and what are their characteristics?
- What community assets (elements at risk) are in these areas?
- What geohazard areas are ranked highest priority, from a geohazard risk perspective?
- Why is an area ranked as high (or low) priority, from a geohazard risk perspective?
- What watershed change (in terms of community assets on the fan or floodplain and/or watershed morphodynamic processes) would need to occur to substantially change the geohazard risk priority.

These questions are addressed by bringing together three major components of the application:

<u>Hazard information:</u>

- Type, spatial extent, and characteristics of geohazard areas, presented on a web map.
- Supporting information such as hydrologic information, geohazard mapping and imagery.

<u>Exposure information</u>:

- Type, location, and characteristics of community assets, including elements at risk and risk management infrastructure.

<u>Analysis tools:</u>

- Identification of assets in geohazard areas (elements at risk).
- Prioritization of geohazard areas based on ratings for geohazards and consequences.
- Access to data downloads and reports for geohazard areas.

This user guide describes how users can navigate map controls, view site features, and obtain additional information about geohazard areas. It should be read with the main report, which describes methodologies, limitations, and gaps in the data presented on the application.

H.1.2. Site Access

Cambio Communities can be viewed at www.cambiocommunities.ca. User name and password information is available on request. The application should be viewed using Chrome or Firefox web browsers and is not designed for Internet Explorer or Edge.

Two levels of access are provided:

- Local/Regional Government users: Access to a single study area of interest (e.g. administrative or watershed area of interest for the user).
- Provincial/Federal Government users: Access to multiple study areas[1].

The remainder of this guide is best read after the user has logged into Cambio Communities. Users should also read the main document to understand methods, limitations, uncertainties and gaps in the information presented.

This guide describes information displayed across multiple administrative areas within British Columbia. Footnotes indicate cases where information is specific to certain regions.

H.2. NAVIGATION

Figure H.2-1 provides a screen shot of Cambio Communities following user login and acceptance of terms and conditions. Section H.3 describes map controls and tools, including how to turn layers on and off for viewing. Section H.4 describes interactive features used to access and download information about geohazard areas.

On login, the map opens with all layers turned off. Click the layer list to choose which layers to view (See Section H.3).

[1] User access may be limited by client permissions. BGC does not expect this to be a barrier for provincially/federally funded studies currently being completed under the NDMP Program.

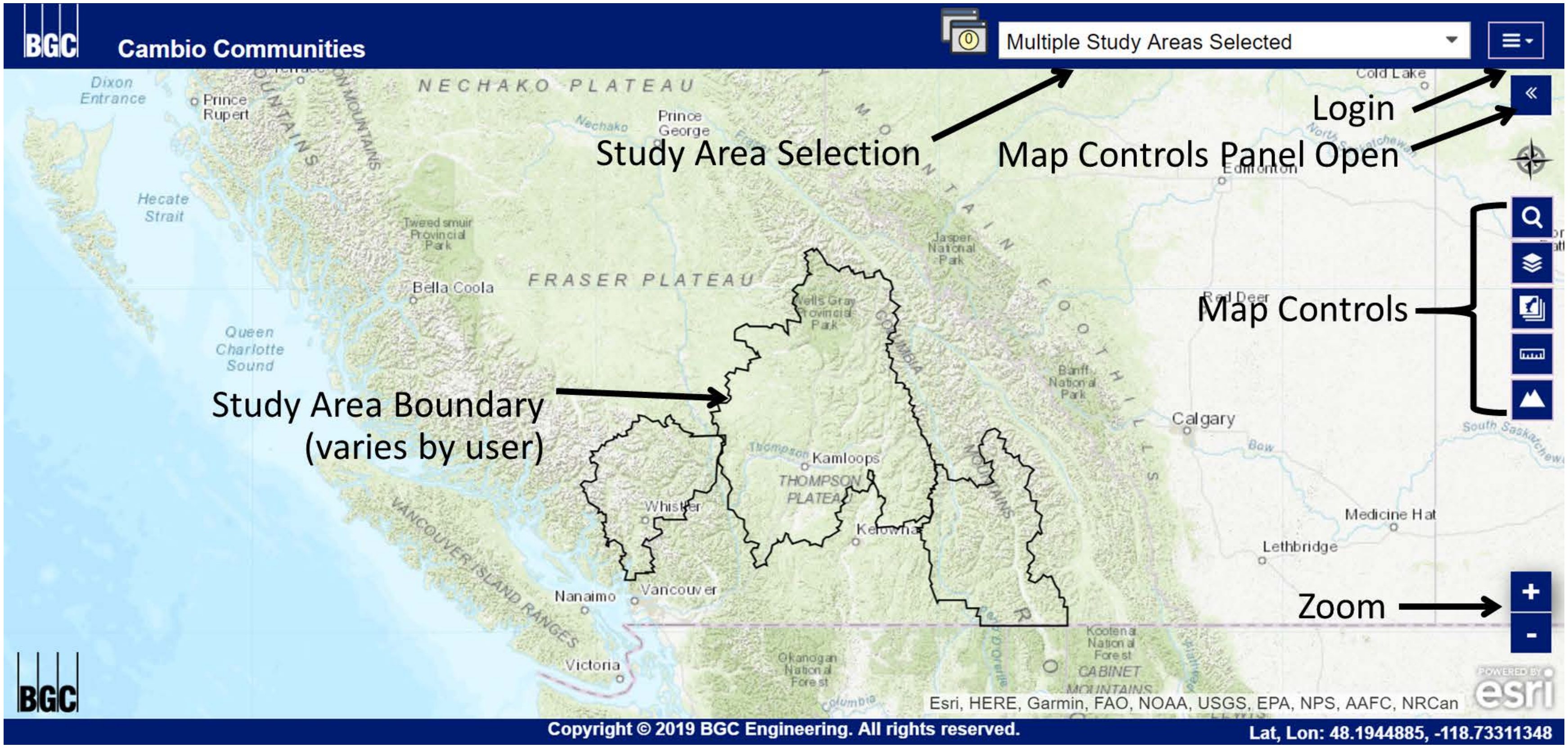

Figure H.2-1. Online map overview.

H.3. MAP CONTROLS

Figure H.2-1 showed the map controls icons on the top right side of the page. The map controls can be opened by clicking on each icon or click the arrow to reveal the controls in a sidebar for easier viewing (Figure H.3-1, Figure H.3-2). Sections H.3.1 to H.3.5 describe the tools in more detail.

Figure H.3-1. Map controls and tools.

Clicking on an icon displays a new window with the tool. The tool can be dragged to a convenient location on the page or popped out in a new browser window.

Figure H.3-2. Example of the top of the Layer List window, with the control icons defined.

H.3.1. Search

Search is currently available for geohazard area names and street addresses. To search:

a. Select the search type from the drop-down menu.
b. Scroll through the dropdown list to select the feature of interest or begin typing the feature's name.

H.3.2. Layer List

This control (Figure H.3-3) allows the user to select which data types and layers to display on the map. It will typically be the first map control accessed on login.

Note that not all layers are visible at all zoom levels, to avoid clutter and permit faster display. Labels change from grey to black font color when viewable, and if the layer cannot be turned on, use map zoom to view at a larger (more detailed) scale. Additionally, the user can adjust the transparency of individual basemap and map layers using the slider located below each layer in the layer list. Complex layers and information will take longer to display the first time they are turned on and cached in the browser.

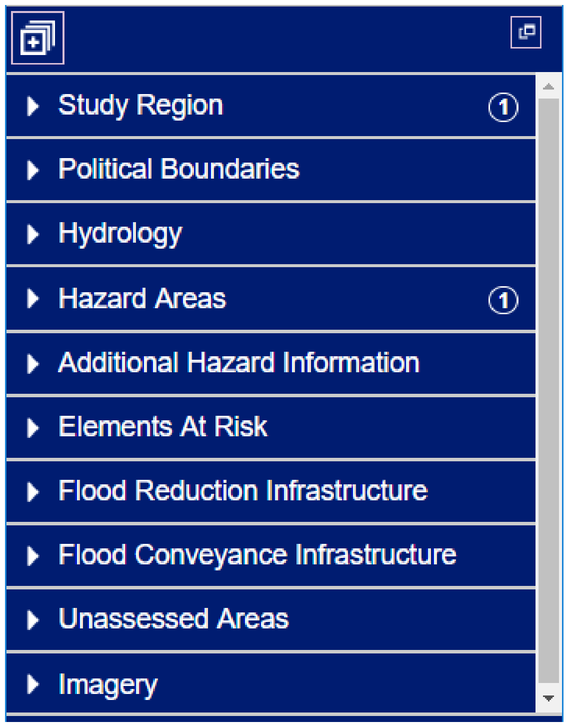

Figure H.3-3. Layers list.

H.3.3. Basemap Gallery

The basemap gallery allows the user to switch between eight different basemaps including street maps, a neutral canvas, and topographic hillshades. Map layers may display more clearly with some basemaps than others, depending on the color of the layer.

H.3.4. Measurements Tool

The measurements tool allows measurement of area and distance on the map, as well as location latitude and longitude. For example, a user may wish to describe the position of a development area in relation to a geohazard feature. To start a measurement, select the measurements tool icon from the options in the drop down.

H.3.5. Elevation Profile Tool

The elevation profile tool allows a profile to be displayed between any two points on the map. For example, a user may wish to determine the elevation of a development in relation to the floodplain. To start a profile, click “Draw a Profile Line”. Click the starting point, and double click the end-point to finish. Moving the mouse across the profile will display the respective location on the map. The “i” in the upper right corner of the profile viewer screen displays elevation gain and loss statistics. The precision of the profile tool corresponds to the resolution of the digital elevation model (approximately 25 m DEM). As such, the profile tool should not be relied upon for design of engineering works or to make landuse decisions reliant on high vertical resolution.

H.4. ASSET INFORMATION

Elements at risk, flood reduction, and flood conveyance infrastructure can be added to the map by selecting a given asset type in the layer list. Infrastructure labels will show up for select features at a higher zoom level. BGC notes that the data displayed on the map is not exhaustive, and much data is currently missing for some asset types (i.e. building footprints and stormwater drainage infrastructure).

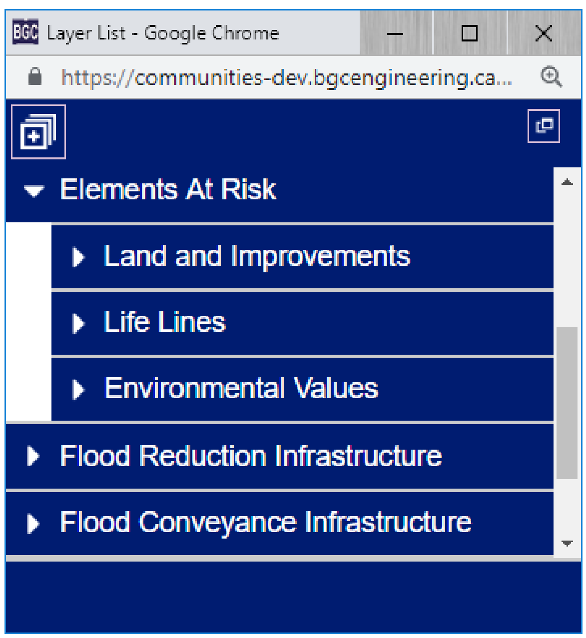

Figure H.4-1. Elements at risk, flood reduction and flood conveyance layers.

H.5. GEOHAZARD INFORMATION

This section summarizes how users can display and access information about geohazard features displayed on the map.

H.5.1. Geohazard Feature Display

Geohazard areas can be added to the map by selecting a given geohazard type under "Hazard Areas" in the layer list. Once selected, the geohazard areas can be colored by hazard type, priority rating, hazard rating, or consequence rating, to view large areas at a glance.

The following geohazard features can be clicked to reveal detailed information:

- Steep creek fans (polygons)
- Clear-water flood areas (polygons)
- River segments containing landslide-dam flood hazards (polylines)[2].

Clicking on an individual geohazard feature reveals a popup window indicating the study area, hazard code (unique identifier), hazard name, and hazard type. At the bottom of the popup window are several options (Figure H.5-1). Clicking the Google Maps icon opens Google Maps in a new browser window at the hazard site. This feature can be used to access Google Street View to quickly view ground level imagery where available. Clicking the "ℹ" opens a sidebar with detailed information about the individual feature, as described in Section H.5.2.

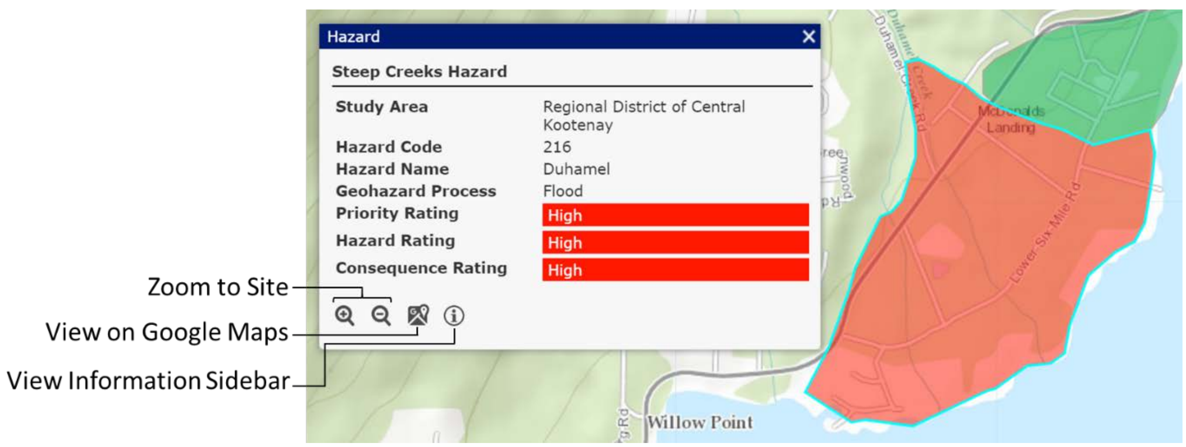

Figure H.5-1. Geohazard feature popup.

Users can also add layers provided under "Additional Geohazard Information" in the Layer List. Not all layers are available for all study areas.

Additional geohazard information currently includes:

- Historical floodplain mapping boundaries
- Screening level hydraulic flood modelling (where completed)
- Debris flow and debris flood susceptibility modelling
- Boundaries of wildfires for the period 2013-2018

[2] Landslide-dam hazard information is provided for the Thompson River Watershed only.

Also included under the Additional Geohazard Area are select areas not assessed under the current scope of work, but that were flagged as areas of consideration for future assessment:

- Improved Unassessed Steep Creek Parcels.

The above layers are described further in Section 7.2.5 of the main report.

H.5.2. Geohazard Information Sidebars

Clicking a geohazard feature and then the "ℹ" within the popup opens additional information in a sidebar on the left side of the screen (Figure H.5-2). Dropdown menus allow the user to view as much detail as required.

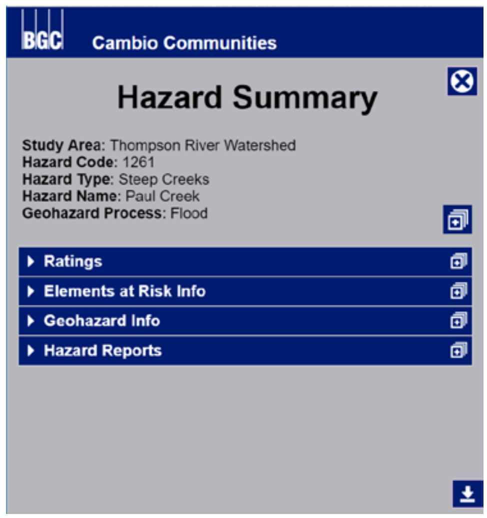

Figure H.5-2. Additional information sidebar.

Table H-1 summarizes the information displayed within the sidebar. In summary, clicking Ratings reveals the site Priority, Consequence, and Hazard Ratings. See Chapter 5.0 of the main document for further description of these ratings. The geohazard, elements at risk, and hazard reports dropdowns display supporting information. Hover the mouse over the ❓ to the right of a row for further definition of the information displayed.

Click the "⬇" icon at the bottom right of the sidebar to download all sidebar information in either comma-separated values (CSV) or JavaScript Object Notation (JSON) format.

Table H-1. Geohazard information sidebar contents summary.

Dropdown Menu	Contents Summary
Ratings	Provides geohazard, consequence and priority ratings for an area, displayed graphically as matrices. The geohazard and consequence ratings combine to provide the priority rating. For more information on ratings methodology, see the main report.
Geohazards Info	Watershed statistics, hydrology and geohazard characterization, event history, and comments. These inputs form the basis for the geohazard rating and intensity (destructive potential) component of the consequence rating for a given area.
Elements at Risk Info	Summary of elements at risk types and/or values within the geohazard area. These inputs form the basis for the consequence rating for a given area.
Hazard Reports	Links to download previous reports associated with the area (if any) in pdf format. This feature is currently only available for some administrative areas (Regional Districts of Central Kootenay and Squamish-Lillooet).

H.6. ADDITIONAL GEOHAZARD INFORMATION

H.6.1. Additional Geohazard Layers

Figure H.6-1 displays additional geohazard-related layers available under "Additional Geohazard Information" in the layer list. These should be reviewed with reference to the main report document for context and limitations.

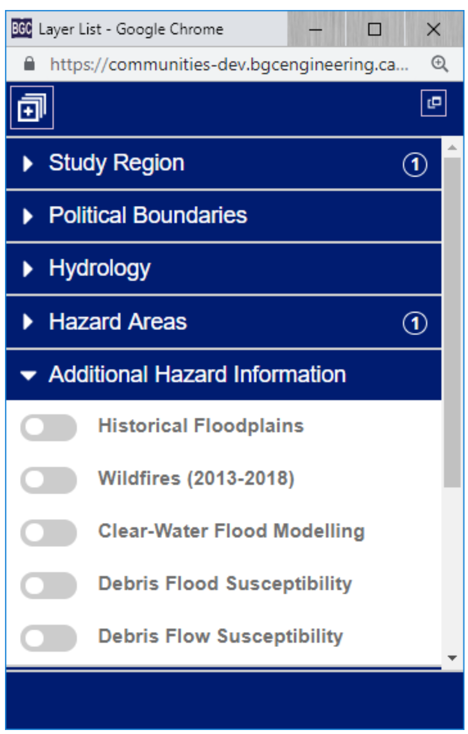

Figure H.6-1. Layers currently available under Additional Geohazard Information.

H.6.2. Imagery

The imagery dropdown provides access to high resolution imagery where available (i.e. Lidar hillshade topography).

H.6.3. River Network

In addition to geohazard areas, the river network displayed on the map (when set to viewable) is sourced from the National Hydro Network and published from BGC's hydrological analysis application, River Network Tools™. Clicking any stream segment will open a popup window indicating characteristics of that segment including Strahler stream order, approximate average gradient, and cumulative upstream catchment area (Figure H.6-2). Streams are colored by Strahler order. Clicking on the Google Maps icon in the popup will open Google Maps in the same location. All statistics are provided for preliminary analysis and contain uncertainties. They should be independently verified before use in detailed assessment and design.

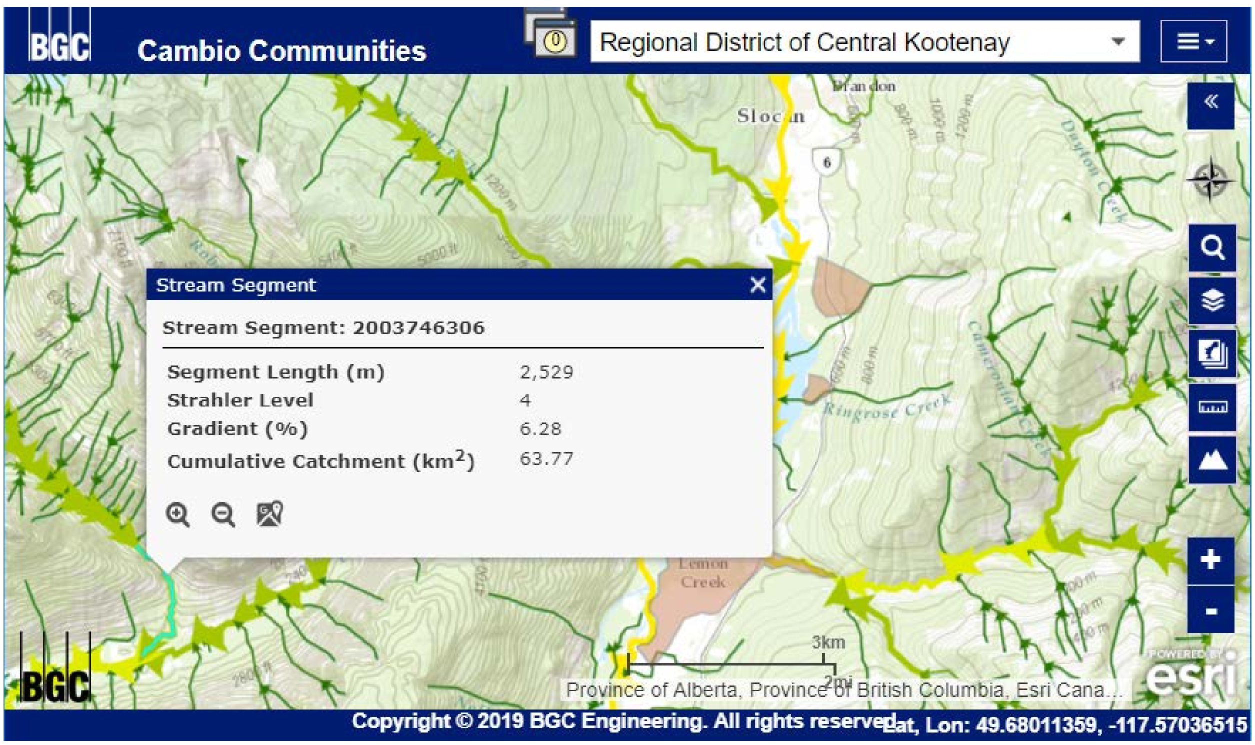

Figure H.6-2. Interactive Stream Network. The popup shows information for the stream segment highlighted in green.

H.7. FUTURE DEVELOPMENT

The current version is the first release of Cambio Communities. BGC may develop future versions of the application, and the user interface and features may be updated from time to time. Site development may include:

- Further access to attributes of features displayed on the map
- Ability to upload information via desktop and mobile applications

- Access to real-time[3] stream flow, lake level, and precipitation monitoring and forecasts.
- Automated alerts for monitored data (i.e. stream flow or precipitation)
- Automated alerts for debris flow occurrence locations and characteristics.
- Inclusion of other types of geohazards (i.e. landslides and snow avalanches).

BGC welcomes feedback on Cambio Communities. Please do not hesitate to contact the undersigned of this report with comments or questions.

[3] i.e., information-refresh each time flow monitoring data is updated and provided by third parties.

APPENDIX I
RISK ASSESSMENT INFORMATION TEMPLATE (RAIT)

APPENDIX J
RESULTS TABULATION
(PROVIDED SEPARATELY IN EXCEL FORMAT)

APPENDIX K
RECOMMENDATIONS – GEOHAZARDS STUDIES

K.1. INTRODUCTION

Section 8.0 of the Main Document made the following recommendations

- *Complete detailed clear-water floodplain mapping for the areas identified by FBC or stakeholders as top priority, following review of this assessment.*
- *Complete detailed steep creek geohazards assessments for areas identified by or stakeholders as top priority, following review of this assessment.*

This appendix provides additional detail on recommended assessment approaches. BGC recommends that any new geohazards assessments and mapping be integrated into the current regional study and used to update the geohazard ratings.

K.2. CLEAR-WATER FLOODPLAINS

K.2.1. Approach and Overview

Modernized floodplain maps should be consistent with the EGBC Guidelines for Floodplain Mapping and Flood Assessments in BC (2017). Flood Hazard Assessments at “Class 2 to 3” level of effort (EGBC, 2018) are recommended for clear-water flood sites. The suggested approach described herein should be adapted for individual sites. In summary, this level of effort includes the following components:

- Review Lidar and historical imagery to identify features such as historical channels
- Review of stakeholder input
- Site visit and qualitative assessment of flood hazards, including documentation of existing flood and erosion protection
- Bank erosion quantitative assessment using historical air photographs
- Watershed-scale land use change consideration
- Climate change predictions for precipitation and runoff as inputs to hydraulic modelling
- Hydraulic modelling with possible dike breach scenarios, where applicable
- Flood hazard inundation maps for 200-year and possibly 500 to 1,000-year flood event.

K.2.2. Suggested Work Plan

Table K-1 lists recommended tasks for each area to be mapped. Each task is described in the sections which follow. BGC notes that tasks will differ in detail for individual areas.

Table K-1. Recommended clear-water floodplain mapping work plan.

Activities	Tasks	Deliverables/Products	Resources
Data Compilation	Survey and Base Data Collection	Base inputs for hazard analyses and study integration such as historical air photographs, regional geology maps and land use coverage maps	• Bathymetric surveyors • Qualified Professionals • District staff • Project stakeholders
	Asset and Elements at Risk Inventory Update	Base inputs for hazard analyses and study integration	• BGC team • Qualified Professionals • Project stakeholders
Analysis	Hydrology and Climate Change Assessment	Hydrologic inputs for hydraulic modelling including climate-change adjusted precipitation and runoff inputs	• Qualified Professionals
	Hydraulic Modelling	Model outputs showing flood extent, flow depth and velocity.	• Qualified Professionals
	Channel Stability Investigation	Geomorphological inputs for flood hazard maps to show areas prone to erosion. Bank erosion assessment results and rates.	• Qualified Professionals
	Study Integration	Integration of new hazard mapping with this current study, including updates to risk prioritization results and web application display.	• Qualified Professionals • District staff • Project stakeholders
Final Deliverables	Hazard Map Production	Clear-water flood hazard maps showing the areas of inundation at different return periods	• Qualified Professionals
	Reporting and Data Services	Description of methods, results, and limitations, and data and web services for dissemination of study results	• District staff • Project stakeholders

Base Data Collection

Lidar is used in flood mapping to provide detailed topographic information that is not evident on topographic maps generated from photogrammetry. However, Lidar surveys are unable to penetrate water surfaces. To account for channel capacity below the previously surveyed water elevation, bathymetric surveys would be required. These surveys develop cross-sections at set intervals for the length of the study watercourse.

Post-processing of the bathymetric data is required to integrate the bathymetry with the Lidar to generate a digital elevation model (DEM) for use in hydraulic modelling. The survey would also include items such as: thalweg delineation, top of bank, bridge details, culvert details, geometry details for all flood control structures, cross sections of structures such as dikes and berms, elevations of buildings located in the floodplain, geo-referenced photos of surveyed features, and interviews with stakeholders as feasible.

Additional items that require compilation from available sources beyond the information collected in this current regional study include:

- Lidar DEMs
- Channel bathymetry data
- Historical airphotos
- High resolution ortho imagery
- Gauge rating curves and historical cross-section surveys
- Lake levels
- Historical highwater marks
- Detailed survey, condition assessment and geotechnical stability data for dikes, where applicable
- More detailed review of previous reports (e.g., flood hazard, risk assessments, terrain maps, watershed assessments, resource inventory maps, geological/geotechnical reports and/or maps).

A site visit will be required to evaluate bank and channel bed conditions, such as existing bank protection, grain size, vegetation type and rooting depths. This information will inform channel stability evaluations.

The asset and elements at risk inventory compiled as part of this assessment may also need to be updated if needed. This will include details not captured in the current work but required for hydraulic model setup.

Hydrology Assessment

Relevant historical flow data from the systematic record will need to be gathered for each site, reviewed and compiled. Additional values will need to be incorporated based on historical accounts, where available. A flood frequency analysis (FFA) will need to be completed to develop return period design discharge values.

As part of the hydrology assessment, climate change predictions for the study area will also need to be reviewed and considered in the time-series analysis for climate (e.g., precipitation, temperature) and runoff used to develop peak flows for hydraulic models.

Hydraulic Modelling

A hydraulic model – preferably two-dimensional – should be generated from the DEM and FFA for each site in order to develop inundation extents, flood depths and peak flow velocities for clear-water floods. Site-specific historical flood discharge and elevation, where available, would be used to validate the modelling. Discharge and survey water levels should also be collected as part of the bathymetric survey to help with model calibration. A sensitivity analysis would also be conducted for key parameters (e.g., roughness). Flood model scenarios may need to include dike breach modelling, where appropriate.

Channel Stability Investigation

The main objectives of this task item is to provide qualitative and quantitative information about the lateral channel stability along a given study reach. Depending on site specific conditions, the main tasks could include:

- Georeference and orthorectify historical air photos
- Delineate channel banks and thalweg from historical air photos
- Compare channel cross-sections, where historical surveys exist
- Evaluate Lidar for relict channels
- Quantitative analysis of bank erosion threshold flows and erosion extents
- Evaluate and map areas with avulsion potential and bank erosion potential for design flood discharges.

K.3. STEEP CREEKS

K.3.1. Approach and Overview

As per EGBC Guidelines for Legislated Flood Assessments in BC (2018), BGC suggests that “Class 3” Flood Hazard Assessments for Debris Floods or Debris Flows be completed for the prioritized steep creek flood hazard sites. A Class 3 assessment is semi-quantitative, in that steep creek flood hazards are described using both empirically derived values, as well as limited computation of site-specific parameters (e.g., magnitude or velocity).

The objective of the assessment would include a detailed characterization of in-scope steep creek flood hazards, in particular:

- Development of a preliminary frequency-magnitude (F-M) curve for steep creek flood hazards.
- Identification of active and inactive[1] portions of the alluvial fan and areas potentially susceptible to avulsion or bank erosion during the specified steep creek flood hazard return periods.
- Numerical modelling of geohazard scenarios to estimate impact areas, flow velocity, and flow depth for a spectrum of return periods where appropriate from the F-M analysis.
- Consideration of climate change impacts on the frequency and magnitude of steep creek flood hazard processes.
- Consideration of long-term aggradation scenarios on the fan.
- Consideration of processes specific to fan-deltas (rapid channel backfilling during times of high lake levels).

F-M relations are defined as sediment volumes or peak discharges related to specific return periods (or annual frequencies). This relation forms the backbone of any hazard assessment because it combines the findings from frequency and magnitude analyses is the basic input to any future numerical modeling and hence informs components of hazard mapping.

K.3.2. Recommended Work Plan

Table K-2 lists tasks suggested for each steep-creek hazard study area. Each task is further described in the sections which follow. BGC notes that tasks included in the table are generalized and will differ in detail for individual project areas.

[1] Active alluvial fan – The portion of the fan surface which may be exposed to contemporary hydrogeomorphic or avulsion hazards. Inactive alluvial fan – Portions of the fan that are removed from active hydrogeomorphic or avulsion processes by severe fan erosion, also termed fan entrenchment.

Table K-2. Suggested steep-creek hazard mapping work plan.

Activities	Tasks	Deliverables/Products	Resources
Data Compilation	Base Data Collection	• Base inputs for hazard analyses and study integration.	• Qualified Professional • District staff
	Asset and Elements at Risk Inventory Update	• Base inputs for hazard analyses and study integration.	• Qualified Professional • District staff
Analysis	Steep Creek hazard characterization and analysis (desktop and field)	• Field observations to inform hazard analyses and modelling • Regional F-M relationships • Hydrologic inputs for hazard modelling.	• Qualified Professional
	Climate Change Assessment	• Qualitative description of anticipated changes to F-M under climate change scenarios	• Qualified Professional
	Hazard Modelling	• Model outputs showing flow intensity (flow extent, flow depth and velocity), that form the basis for hazard mapping	• Qualified Professional
	Channel Stability Investigation	• Geomorphological inputs for flood hazard maps.	• Qualified Professional
	Study Integration	• Integration of new hazard mapping results with previous study.	• Qualified Professional • District staff
Final Deliverables	Hazard Map Production	• Steep creek hazard maps.	• Qualified Professional • District staff
	Reporting and Data Services	• Description of methods, results, and limitations, and data and web services for dissemination of study results.	• Qualified Professional • District staff

<u>Data Compilation</u>

The base data collection would include compiling all relevant site data relating to steep creek flood hazards. These data would be used as base inputs for the steep creek flood hazard mapping. Items to collate would include:

- Lidar DEMs
- Historical airphotos
- High resolution ortho imagery
- Gauge rating curves and historical cross-section surveys (if applicable/available)
- Historical highwater marks (if readily available)

- Bathymetric maps for fan-deltas (if available)
- Accounts of historical steep creek floods and records of sediment deposition (if available)
- Previous reports (e.g., flood hazard, risk assessments, terrain maps, watershed assessments, resource inventory maps, geological/geotechnical reports and/or maps).

Derivative high-resolution DEMs from Lidar would be used to identify the locations of previous avulsions, aggradation, and historical steep creek flood deposits.

Analysis

Steep creek flood hazard characterization and mapping involves: developing an understanding of the underlying geophysical conditions (geological, hydrological, atmospheric, etc.); identifying and characterizing steep creek flood processes in terms of mechanism, causal factors, trigger conditions, intensity (destructive potential), extent, and change; developing steep creek F-M relationships; and identifying and characterizing geohazard scenarios to be considered in the steep creek flood hazard maps.

Desktop Study: Prior to field work, a desktop study would be completed to assess the frequency of past steep creek flood hazards from airphotos, previous reports, and historical records. Qualitative observations would be made of any changes in watershed condition over the historical record (e.g., clear cuts, road construction, wildfires, insect infestations), as well as changes in the steep creek geomorphology (e.g., aggradation, erosion, avulsion, changes in sediment input, landslide frequency,) and artificial fan surface alterations (excavations, fill placements, developments). The desktop study would inform the key locations to be observed during field work. BGC suggests that prior to field work being conducted, the FBC or stakeholders (i.e., those commissioning the work) should inform residents of the purpose and proposed timing for this field work.

Fieldwork: Fieldwork would provide key information for the steep creek flood hazard analysis. The steep creek channels would be traversed from the fan margins to as high as what can be accessed safely. Upper watersheds should also be accessed (on foot if possible) when important sediment sources have been identified that require field confirmation (e.g., landslides or artificial instabilities such as active or deactivated logging roads, waste rock placement, sumps). Helicopter overview flights would be used for channel sections that are not safely accessible from ground traverses. Stakeholder input would also be gathered during fieldwork, as feasible.

Surface field observations would include:

- Location and extent of past steep creek floods from surface geomorphic evidence (e.g., channel levees, boulder lobes, paleochannels, etc.)
- Channel measurements to identify high water/scour marks to estimate the peak flow of previous steep creek floods
- Channel cross-sections
- Grain size distributions where appropriate
- Sediment supply sources
- Stratigraphy of natural exposures

- Areas of channel aggradation and/or erosion
- Location and extent of sedimentological evidence of past steep creek events
- Visual assessment of existing steep creek flood mitigation structures (e.g., bridges, dikes, rip rap, fills, groins, deflection berms, debris basins).

Where possible, dendrogeomorphological methods can be used to determine the timing and magnitude of past steep creek flood hazards. This sampling involves coring trees using a 4 mm-diameter incremental tree borer. Under ideal conditions, this method allows dating of past steep creek flood events several hundred years into the past. The dendrogeomorphological record can complement the historical airphoto record for developing a preliminary F-M assessment. The feasibility of applying dendrogeomorphological methods is usually determined during the site inspection.

Following field work, a preliminary F-M relationship would be developed for steep creek flood hazards and used to develop scenarios for numerical hazard modelling.

Numerical Modelling

Hazard modelling is necessary to estimate flow inundation area, flow velocities, flow depth, erosion, and sediment aggradation. The most appropriate two and three-dimensional modelling software would typically be selected after an initial assessment of site conditions. As new software packages constantly emerge, a decision as to the most appropriate model would be made at the time of the study. The modelling process may include:

- Model calibration of rheological and sediment entrainment parameters using the extents, thicknesses, and velocities (where available/applicable) of previous steep creek flood events, and measured sediment volumes in the channel. This calibration would be compared to empirical relationships.
- Predictive modelling of flows for the range of peak discharges associated with the return periods determined from the hazard analysis with rheological parameter combinations determined via the calibration process.

Additional Considerations

Very low hazard areas on fans, which are sometimes defined as “inactive” portions of the fan, and which are often paleofans, formed during a particularly active period in the early Holocene, can also be identified, if they exist. These areas are often hydraulically removed from the steep creek channel due to deep channel erosion or other factors and identifying these areas can be helpful for land use and development planning.

Most fans are active landforms that change over time. Areas subject to aggradation, channel erosion, or channel avulsions will need to be identified through desktop studies, site visits, and from the hazard modelling. In particular, fan-deltas (fans entering into water bodies) can have higher frequencies of aggradation and avulsions than land-based alluvial fans due to the interactions between the channel and still-water processes (van Dijk et al., 2012). All areas subject to these noted processes will be identified in the final hazard map.

K.4. LANDSLIDE-DAM FLOODS

K.4.1. Approach and Overview

A landslide-dam flood is a flooding event that can occur when a landslide blocks the flow of a watercourse (e.g., stream or river), leading to the impoundment of water on the upstream side of the dam (Landslide Dam Impoundment Flood, LDIF) and potentially the rapid downstream release of the impounded water following dam failure (Landslide Dam Outbreak Flood, LDOF).

The current study characterizes landslide-dam flood geohazards and prioritizes landslide-dam flood prone areas in proximity to developed areas within the TRW. The assessment only considers landslide-dam flood hazards along the Thompson River and its main tributaries[2].

In the current study, landslides pose a hazard source, but the geohazard that is prioritized is landslide dam-related flooding (LDIF or LDOF). The formation and failure of a landslide dam is a complex geomorphic process because it involves the interaction of multiple geomorphic hazards. Moreover, the upstream and downstream extent of LDIF/LDOF can extend several kilometres upstream and downstream of the dam (and more in extreme cases).

The current study identifies and prioritizes LDIF/LDOF geohazards at a regional level of detail. However, the current study does not:

1. Assess individual landslide sites within watercourse segments that could result in specific landslide-dam flood scenarios.
2. Assess upstream flood impoundment or downstream outbreak floods for specific landslide-dam scenarios, or the associated risk of these scenarios.
3. Does not consider potential landslide dam-related floods in watercourses with a Strahler order of < 6.

These limitations increase uncertainty in the following areas:

- Characterization of landslide-dam flood hazard source locations and scenarios.
- Estimates of the likelihood that landslide-dam flood scenarios will occur and reach developed areas and result in some level of damage and loss (i.e., estimates of risk).

This section summarizes two work phases to help address these uncertainties at high priority areas identified in this study. The work phases could be undertaken as separate projects or in parallel. The two phases are as follows:

- Remote-sensed hazard identification and monitoring of landslide geohazard source areas.
- Landslide-dam flood geohazard assessment for high priority areas.

[2] This extent is represented by Strahler order ≥6 watercourses within the TRW.

K.4.2. Remotely-Sensed Hazard Identification and Monitoring

The objective of this work would be to improve the identification and monitoring of large landslides that could block high priority watercourses. BGC proposes to leverage a 2017-2019 initiative funded by the Canadian Space Agency, titled the Wide Area Landslide Alerting System (WALAS). The objective is to develop an operational, satellite Interferometric Synthetic Aperture Radar (InSAR)-based landslide alerting system for wide areas (Figure K-1). InSAR is a radar technique used in earth sciences to generate maps of surface deformation, and the WALAS initiative study area encompasses British Columbia.

BGC reviewed an early deliverable of this initiative, which included processed ALOS-1 satellite data from 2007 to 2011 (3vG, 2018). The ALOS-1 satellite was decommissioned after 2011. As part of WALAS, 3vG also processed Sentinel-1 satellite data, which is being acquired on an ongoing basis and provides the opportunity to continue to monitor areas into the future.

This work would involve the following tasks:

- Review WALAS initiative results at high priority sites to evaluate suitability for landslide-dam flood hazard source assessment.
- Develop a framework to apply InSAR, in combination with other earth science information, to identify potential landslide-dam flood scenarios, and analyse movement characterstics indicating elevated landslide-dam flood scenario likelihood.
- Discussion of limitations and uncertainties.

The intended outcomes of the study would include a framework for InSAR-based, wide-area monitoring of landslide-dam flood hazard source areas in the TRW, and information supporting more detailed landslide-dam flood hazard assessment (Section K.4.3).

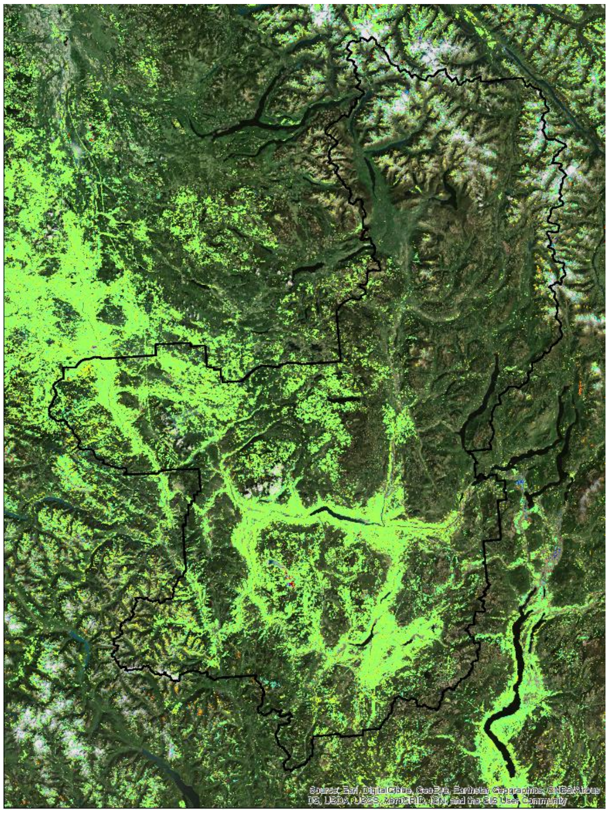

Figure K-1. Displacement rates scaled at 5 cm/year over the Thompson Nicola Regional District (3V Geomatics, 2018).

K.4.3. Landslide-dam Flood Hazard Assessment

The objective of this work would be to:

- Refine estimates of the likelihood that landslide-dam flood scenarios will occur and reach developed areas.
- Refine estimates of the extent of areas that could be impacted.
- Integrate the results with the current study, to update priority ratings at a given site.

These objectives can be framed as questions as follows:

- Within the areas (river sections) proposed to be assessed, where are landslides likely to occur that are capable of blocking watercourses?
- Given areas where landslides are likely to occur that are capable of blocking watercourses, which could lead to an LDIF forming and/or LDOF occurring?
- What is the combined probability of the landslide and the LDIF/LDOF occurring?

- Given occurance of the LDIF/LDOF, what is the likely extent, discharge and arrival time[3] of flood inundation and what would be the anticipated destructive potential of the flood waters?

Table K-3 lists typical tasks that would be undertaken for a given study area. BGC notes that tasks will differ in detail for each project area and would need to be refined as part of a specific scope of work. The tasks shown include integration of hazard results with the current study to provide a screening level estimate of risk. They do not include detailed risk estimation, but would form the basis for such work if required.

Table K-3. Landslide-dam flood hazard mapping work plan.

Activities	Tasks	Deliverables/Products	Resources
Project Management	Meetings, project management and administration	• Presentations and updates	• Qualified Professionals • District staff • Project stakeholders
Data Compilation and Review	1. Data Collection	• Base inputs for hazard analyses and study integration (i.e., previous work, air photos and orthographic imagery, LiDAR data, InSAR data, river bathymetry)	• Qualified Professionals • District staff • Project stakeholders
	2. Asset Inventory Update	• Base inputs for model setup and study integration.	• Qualified Professionals • District staff • Project stakeholders
	3. Hazard Source Inventory	• Location of existing and potential (first-time) landslide locations. • Evaluate these sites to determine a subset of landslide source areas capable of creating dams with potential to impact elements at risk.	• Qualified Professionals • District staff • Project stakeholders
Site Visit	4. Site Visit	• Perform site visit to gain information to aid scenario development for modeling.	• Qualified Professionals

[3] Arrival times are important as they inform emergency response.

Activities	Tasks	Deliverables/Products	Resources
Analysis	5. Hazard Source Characterization and Analysis	• Evaluation of the subset of landslide dam sources identified in Tasks 3 and 4. • Identify/characterize landslide mechanics; empirically or numerically estimate landslide runout and representative dam geometry. • Determine rating scheme to relate detection of slope movement areas (i.e., InSAR results) to hazard likelihood estimates.	• Qualified Professionals
	6. Flood Hazard Modelling	• Determine impounded lake volumes; empirically derive outbreak flood peak flows with assumptions for base flow; complete upstream flood inundation modelling; complete dam breach and outbreak flood modelling for best estimate and maximum (95% percentile) breach rate[4]. • Generate model outputs showing flow extent, flow depth and velocity, that form the basis for hazard mapping upstream (impoundment) and downstream (outbreak flood) of the landslide dam.	• Qualified Professionals
	7. Study Integration	• Integration of new hazard mapping results with previous study.	• Qualified Professionals • District staff • Project stakeholders
Deliverables	8. Hazard Map Production (via Web Map)	• Landslide-dam flood hazard maps (digital)	• Qualified Professionals • District staff • Project stakeholders

[4] Breach rates (i.e., the rate at which a landslide dam incises due to overtopping) will heavily influence the peak discharge. Higher breach rates, result in higher peak flows. Breach rates depend on the geometry and geotechnical characteristics of a landslide but cannot be calculated. Breach rates can be considered a probabilistic entity, and for the purpose of this assignment, the best estimate and highest (95% percentile) will be modeled.

Activities	Tasks	Deliverables/Products	Resources
	9. Reporting and Data Services	• Description of methods, results, and limitations, and data and web services for dissemination of study results.	• Qualified Professionals • District staff • Project stakeholders

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