REGIONAL DISTRICT OF CENTRAL KOOTENAY

Flood and Steep Creek Geohazard Risk Prioritization

FINAL
March 31, 2019

Project No.:
0268004

Prepared by BGC Engineering Inc. for:
Regional District of Central Kootenay

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March 31, 2019
Project No.: 0268004

Sangita Sudan
General Manager of Development Services
Regional District of Central Kootenay
Box 590, 202 Lakeside Drive
Nelson, BC V1L 5R4

Dear Ms. Sudan,

Re: Flood and Steep Creek Geohazard Risk Prioritization – FINAL

Please find attached the above referenced report for your review. The web application accompanying this report can be accessed at www.cambiocommunities.ca. User name and password information will be provided in a separate transmission.

Should you have any questions, please do not hesitate to contact the undersigned. We appreciate the opportunity to collaborate with you on this challenging and interesting study.

Yours sincerely,

BGC ENGINEERING INC.
per:

Kris Holm, M.Sc., P.Geo.
Principal Geoscientist

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ISSUE	DATE	REV	REMARKS
DRAFT	February 15, 2019		Original issue

LIMITATIONS

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EXECUTIVE SUMMARY

In July of 2012, a fatal landslide at Johnson's Landing brought the issue of geohazard risk to the forefront at the community, regional government and provincial government levels. Johnson's Landing is just one example of many small, rural communities within the RDCK that are subject to geohazards.

The Regional District of Central Kootenay (RDCK, the District) subsequently retained BGC Engineering Inc. (BGC) to carry out a geohazard risk prioritization study for the District. The study objective is to characterize and prioritize flood and steep creek (debris-flood and debris-flow) geohazards in the RDCK 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.

This study provides the following outcomes across the RDCK:

- 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 access to view prioritized geohazard areas and supporting information
- Evaluation of the relative sensitivity of geohazard areas to climate change
- Gap identification and recommendations for further work.

These outcomes support RDCK 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., 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 RDCK.

This study provides results in several ways:

- This **report** summarizes methods and results, with additional details in appendices.
- **Web application** displaying all prioritized geohazard areas on an online map. This application represents the main way to interact with study results, where users can see large areas at a glance or view results for a single site. Appendix B provides a guide to navigate Cambio Communities™.
- **Geodatabase** with prioritized geohazard areas.
- **Appendix I** provides an Excel spreadsheet (separate file) with tabulated results.

BGC identified and prioritized 427 geohazard areas within the RDCK that might impact developed properties (Table E-1). These areas encompass about 1,400 km^2 and include the most populous and developed parts of the District. Compared to the entire RDCK, about 16% of the Census population, 32% of assessed building value, 13% of business locations, and most of the major transportation routes are within or cross these areas. Figure E-1 summarizes the number of prioritized areas in different administrative areas.

The prioritized geohazard areas are also crossed by transportation and utility networks that connect RDCK communities, broader areas across southern BC, and southward into the United States of America. This high degree of connection with provincial, national and cross-border infrastructure networks, which are also subject to a high level of hazard exposure, underscores the importance of coordinated geohazard risk management within the District.

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

Geohazard Type	Priority Level				Grand Total
	High	Moderate	Low	Very Low	
Clear-Water Floods (water courses and water bodies)	27	14	63	0	104
Steep Creeks (Fans)	15	56	180	72	323
Grand Total (Count)	**42**	**70**	**243**	**72**	**427**
Grand Total (%)	**10%**	**16%**	**57%**	**17%**	**100%**

Figure E-1. **Number of prioritized geohazard areas by type and jurisdiction.**

Table E-2 highlights clear-water flood watercourse and steep creek geohazard areas identified as higher priority for further assessment. These areas were selected as examples only, and the full list of prioritized areas should be reviewed for decision making. There are additional factors for risk management and policy making that are outside the scope of this assessment, that RDCK may also consider when reviewing prioritization results.

Hazard Code	Jurisdiction	Hazard Type	Geohazard Process	Name
340	Village of Salmo	Clear-Water Floods	Flood (watercourse)	Salmo River
372	Village of Slocan	Clear-Water Floods	Flood (watercourse)	Slocan River
379	RDCK Electoral Area B	Clear-Water Floods	Flood (watercourse)	Moyie River
393	Town of Creston	Clear-Water Floods	Flood (watercourse)	Goat River – Creston
408	RDCK Electoral Area A	Clear-Water Floods	Flood (watercourse)	Crawford Creek
422	City of Nelson	Clear-Water Floods	Flood (waterbody)	Kootenay Lake
423	Village of Kaslo	Clear-Water Floods	Flood (watercourse)	Kaslo R at Kaslo
425	RDCK Electoral Area B	Clear-water Floods	Flood (watercourse)	Goat River
375	RDCK Electoral Area K	Clear-water Floods	Flood (watercourse)	Burton
376	RDCK Electoral Area I	Clear-water Floods	Flood (watercourse)	Norris Creek
378	RDCK Electoral Area K	Clear-water Floods	Flood (watercourse)	Inonoaklin Creek
424	RDCK Electoral Area H	Clear-water Floods	Flood (watercourse)	Bonanaza Creek
95	RDCK Electoral Area K	Steep Creeks	Flood	Eagle Creek
212	RDCK Electoral Area F	Steep Creeks	Flood	Duhamel
242	RDCK Electoral Area E	Steep Creeks	Debris Flood	Harrop Creek
116	RDCK Electoral Area E	Steep Creeks	Debris Flood	Proctor Creek
251	RDCK Electoral Area E	Steep Creeks	Debris Flood	Redfish
252	RDCK Electoral Area F	Steep Creeks	Flood	Kokanee
249	RDCK Electoral Area C	Steep Creeks	Flood	Corn Creek - E
36	RDCK Electoral Area A	Steep Creeks	Debris Flow	Kuskonook
192	RDCK Electoral Area K	Steep Creeks	Debris Flow	Rokos Creek
205	RDCK Electoral Area K	Steep Creeks	Debris Flow	Unnamed Creek
91	RDCK Electoral Area D	Steep Creeks	Debris Flow	Gar Creek
306	RDCK Electoral Area E	Steep Creeks	Debris Flow	Heather Creek
172	RDCK Electoral Area K	Steep Creeks	Debris Flow	Dixon Creek
154	City of Castlegar	Steep Creeks	Flood	Norns Creek
137	RDCK Electoral Area H	Steep Creeks	Flood	Wilson Creek
238	RDCK Electoral Area F	Steep Creeks	Debris Flood	Sitkum
248	RDCK Electoral Area D	Steep Creeks	Flood	Cooper Creek

Table E-2. Areas highlighted for more detailed assessment. Hazard Code or Name can be used to search for these areas on Cambio Communities.

BGC developed simplified evaluation methodologies based on readily available data at the regional scale to differentiate relative climate change sensitivity between hazard sites within the RDCK. For clear-water floods, regional, relative differences in snowpack depth were used to characterize the relative sensitivity of flood hazard areas with similar watershed characteristics to changes in the timing of freshet floods, in response to region-wide projected declines in snowpack depth due to climate change. 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 different functional groups within RDCK, including district board members, managers, planners, emergency management staff, and geomatics staff. The rationale for each recommendation is described in more detail in the report. BGC encourages RDCK to review this assessment and web tools from the perspective of supporting long-term geohazard risk and information management within the District. This effort would be greatly facilitated by provincial support 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 RDCK as top priority, in the context of geohazard risk management. • 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.

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LIMITATIONS

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Kuskanook Creek debris flow, August 2004.
Photo: P. Jordan

1. INTRODUCTION

1. INTRODUCTION

1.1. Objectives

The Regional District of Central Kootenay (RDCK, the District) retained BGC Engineering Inc. (BGC) to carry out a regional flood and steep creek risk prioritization study (the regional study) for the District (Figure 1-1). Funding was provided by Emergency Management BC (EMBC) and Public Safety Canada under Stream 1 of the Natural Disaster Mitigation Program (NDMP, 2018). This work is being carried out under the terms of a contract between RDCK and BGC dated October 10, 2017.

The primary objective of this study is to characterize and prioritize flood and steep creek (debris-flood and debris-flow) hazards in the RDCK 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 across the RDCK:

- 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)
- Geospatial information management for both geohazard areas and elements at risk
- Web communication tool 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 support RDCK 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, 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)
- 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 RDCK.

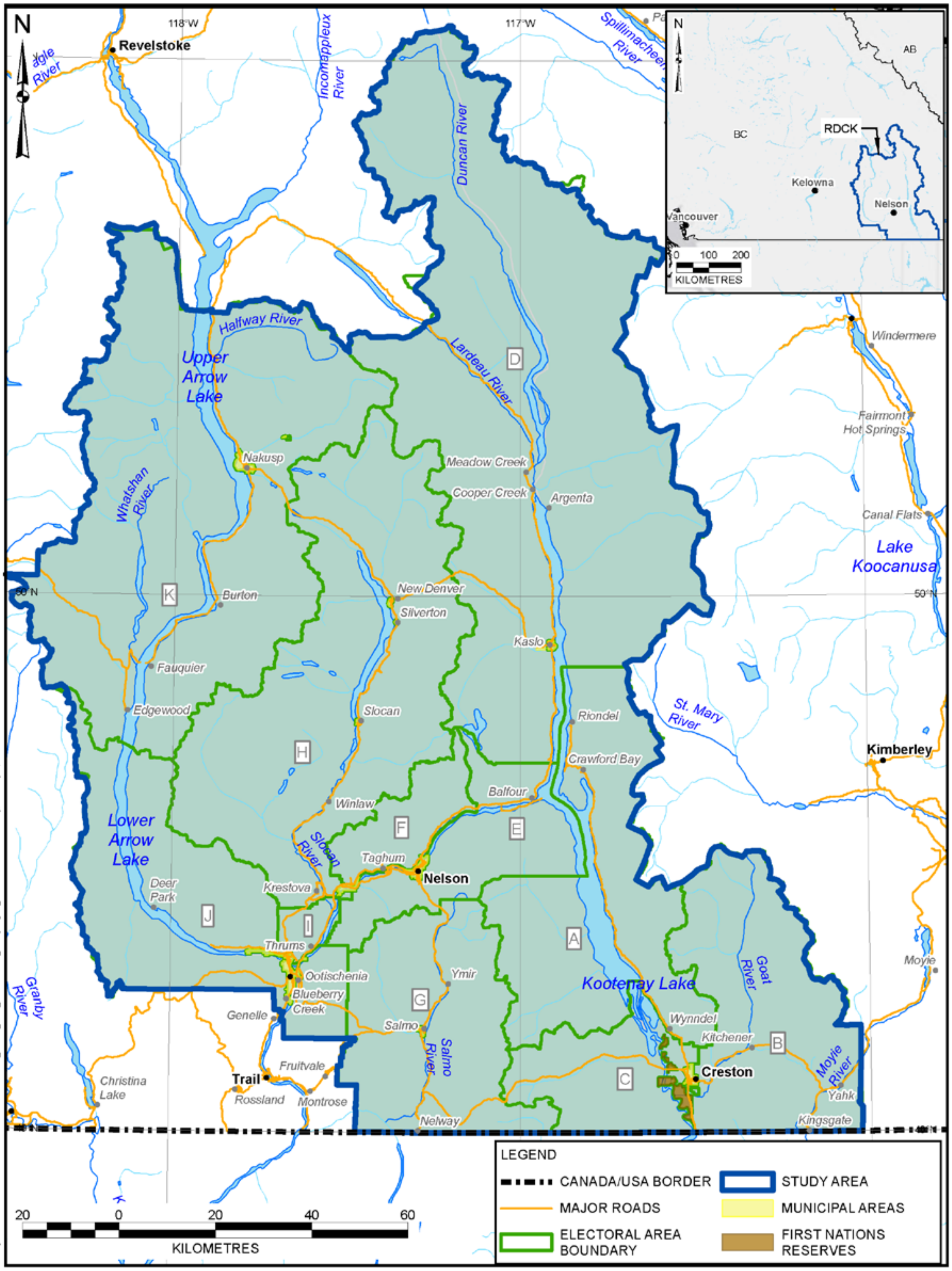

Figure 1-1. Study area.

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[1] (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. Project Scale

Flood geohazard and risk studies support decisions to develop safe and resilient communities, protecting both people and property from flooding and allowing communities to develop risk-informed plans for their development.

Detailed flood mapping studies are expensive and time consuming and therefore undertaken only when there are recognized hazards. Because a key objective of this study is to identify and prioritize areas for detailed mapping, this forms a “chicken and egg” scenario unless preliminary mapping is completed where gaps exist.

Recognizing the cost of detailed flood mapping, organizations responsible for flood management in the USA have begun to consider less costly flood mapping at a screening level of detail. The US Federal Emergency Management Agency (FEMA) refers to this level of assessment as Base Level Engineering (BLE). The BLE approach brings together high-resolution topographic data, regional hydrology evaluations, and highly automated hydraulic modeling, to provide screening-level flood mapping and hydraulic models that can be refined at a later date if more detailed mapping is desired. The flood maps produced using BLE, while not as accurate as maps produced by detailed flood mapping studies, can be used to provide a preliminary understanding of where flood hazards may exist which allows for:

- Identification of sites that may be subject to flood hazards
- Prioritization of sites for detailed study
- Conversations to occur at the community and regional level that centre around flood risk including mitigation strategies to reduce existing or future flood risk.

The methodologies developed by BGC for this project to assess steep creek and clear-water flood hazards were based on a level of detail that reflected the resolution of input data, as well guidance provided by FEMA on BLE benchmarks.

1.3. Why This Study?

In July of 2012, a fatal landslide at Johnson’s Landing brought the issue of geohazard risk to the forefront at the community, regional government and provincial government levels. Johnson’s Landing was just one example of many small, rural communities that exist in areas subject to

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

flood or landslide hazards within the RDCK. While extensive efforts have been made to compile hazard information, gaps exist that have challenge the RDCK to make land development decisions in hazard areas. The hydro-climatic effects of projected climate change are an added complication to this effort.

Specific gaps identified at the outset of this regional study included:

- Incomplete extent: many areas subject to direct and indirect flood hazards have not been identified.
- 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 the RDCK 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).

1.4. Terminology

This report refers to the following key definitions[2]:

- Asset: anything of value, including both anthropogenic and natural assets3, 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 (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 differentiate 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 RDCK are tributary creeks subject to steep creek processes that carry larger volumetric concentrations of debris than clear-water floods. Steep creek processes is used in this report as a collective term for debris flows and debris floods. Appendix F provides a more comprehensive description of steep creek processes.
- Consequence: formally, 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. Consequence ratings considers the value of elements at risk and intensity (destructive potential) of a geohazard, but do not provide 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.

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[2] CSA (1997), EGBC (2017, 2018)

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

- 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.
- 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 1-2).
- Waterbody: ponds, lakes and reservoirs.
- Watercourse: creeks, streams and rivers.

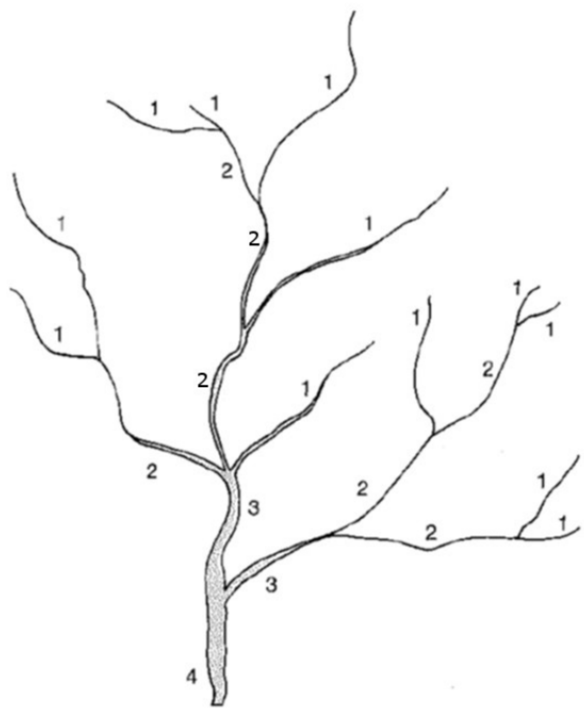


Figure 1-2. Illustration showing Strahler stream order (Montgomery, 1990).

RDCK also has legal definitions for commonly used terms that are used throughout this study. For example, RDCK bylaws define *watercourse, Non-Standard Flooding and Erosional Areas (NSFEAS), flood construction levels (FCLs)* and *development setbacks*. Some of these terms were adapted from those used by the BC Ministry of Water, Land and Air Protection (MWLAP, 2004) or from provincial legislation (e.g., those related to land title).

These legal definitions are not necessarily identical to technical definitions, or there may be nuances that require clarification to ensure terms are properly applied. Appendix A defines flood-related terms referenced in this project and clarifies differences between their use in technical work versus policy.

1.5. Scope of Work

1.5.1. Summary

BGC's scope of work was described in a proposal dated September 30, 2016 and was completed under the terms of RDCK Contract No. 04-1365-20-NDMP, dated October 1, 2017. The work was based on collating previous assessments and collection of desktop-based hazard information. Section 1.5 defines the assessment framework, geohazard types and mechanisms for damage included in our assessment.

This study assesses clear-water flood and steep creek processes within 'settled' urban and rural areas of the RDCK. 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 RDCK that are not included in the scope of work, including flood-related geohazard types (see Section 1.5.2). Although this study was based on the best available information, it is also not exhaustive. Clear-water flood, steep creek and landslide-dam geohazards likely still exist in developed areas that were not detected at the screening level scale of study.

The RDCK is subject to a spectrum of geohazards, of which clear-water floods and steep creek processes (debris flows and debris floods) are considered in the scope of work. Inclusion of clear-water floods and steep creek processes within the mandate of flood hazard assessments is consistent with EGBC (2018). Table 1-1 summarizes tasks for each project stage. The table presents the same scope described in the contract but has been 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.

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 RDCK's GIS 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 RDCK or on behalf of RDCK by other agencies (i.e., Province of BC).

Information shown on Cambio Communities is organized in an ArcGIS SDE Geodatabase[4] stored in Microsoft SQL Server[5], and data sources are indicated with metadata. Information sources cited in this document are provided as references at the end of this report.

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).

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

Activity	Related Tasks	Deliverable(s)
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.

1.5.2. Limitations of Geohazards Assessed

It is important to recognize that flood-related geohazards exist within the RDCK 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
- Dam and dike/levee failure[6]
- Overland urban flooding[7]
- Sewer-related flooding[8]
- Ice jam flooding (Section 2.6.4)
- 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 flood waves)
- Natural hazards other than those listed as being assessed (e.g., fire, seismic, volcanic).

A detailed evaluation of flood risk which is controlled by dams and the artificial management of lake levels, was also not included in the scope of work (Section 2.6.3). 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, hazard prioritization is completed separately for each hazard type.

[6] 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.

[7] 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.

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

1.6. Deliverables/Web Map

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

The prioritized hazard areas are presented on a secure web application, *Cambio Communities* (Figure 1-3) at www.cambiocommunities.ca.

Cambio Communities is the primary way to view study results and shows the following information:

1. Prioritized geohazard areas and information (see Section 0)
2. Elements at risk (i.e., community assets; see Section 3)
3. Additional information provided for visual reference, including geohazard, hydrologic and topographic features.

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

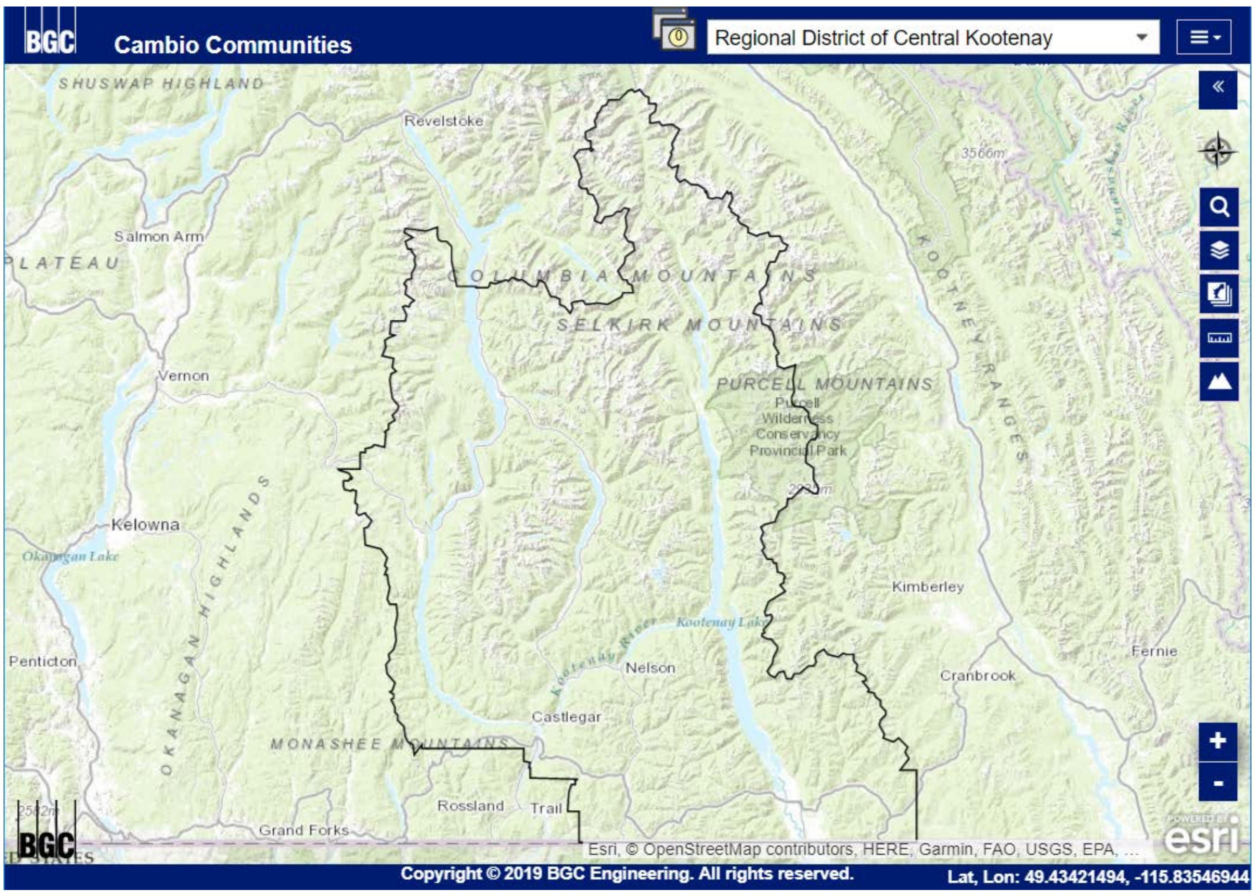


Figure 1-3. Example of Cambio Communities web application.

The prioritized geohazard areas shown on Cambio Communities are also provided via an ArcGIS Representational State Transfer (REST) API. A REST API is a web link that allows users to retrieve and interact with the data through their ArcGIS Online account. It does not provide the user interface or access to software within Cambio Communities and is intended for geomatics professionals; access details will be provided on request. Attributes assigned to the geohazard areas prioritized in the study are also provided via download in JavaScript Object Notation (JSON) or Comma-Separated Values (CSV) format.

2. BACKGROUND

This section provides an overview description of the study area.

2.1. Administration

The RDCK covers approximately 22,000 km^2 in southeastern British Columbia (Figure 2-1). The RDCK is divided into eleven electoral districts (A to K) and nine municipalities as follows (Figure 2-1; also shown on the web map):

- City of Castlegar
- Village of Kaslo
- Village of Nakusp
- City of Nelson
- Village of Salmo
- Village of New Denver
- Village of Slocan
- Town of Creston
- Village of Silverton

The total Census population is approximately 61,000 people (Canadian Census, 2016), and the region contains an assessed $8.6 billion in building improvements (BC Assessment, 2018).

2.2. Topography

Low resolution (approximately 25 m) Canadian Digital Elevation Model (CDEM)[9] data were predominantly used for this study and presented a significant limitation on the precision and accuracy of estimated geohazard location/extents, likelihoods, and intensities. While the RDCK has now acquired high resolution Lidar topography across much of the developed areas of the District, these data were not processed and available in time to be used in this current study.

Figure E-3 in Appendix E displays the extent of Lidar that was available at the time of study. Cambio Communities shows Lidar hillshade images under “Imagery” in the layer list.

2.3. Physiography and Ecoregions

The RDCK is located entirely within the Columbia Mountains physiographic[10] region, which is a highly mountainous area west of the Rocky Mountain Trench (Holland, 1976). As defined by DeMarchi (2011), the RDCK encompasses four ecoregions, which are areas of major physiographic and minor climatic variation (Figure 2-1). Table 2-1 outlines the characteristics of each ecoregion and associated ecosection.

Mountain ranges within the Columbia Mountains region typically exhibit a north-south trend and are dissected by narrow valleys and large trenches. In the base of these trenches lie large lakes

[9] 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 RDCK, this corresponds to approximately 25 m grid cell resolution (Government of Canada, 2016).
[10] Referring to landforms and geology.

such as Arrow, Kootenay, Duncan, and Slocan Lakes. These lakes predominantly drain south across the border via large river systems including the Columbia, Slocan, and Kootenay Rivers. Lakes and rivers are regulated by dams and hydroelectric facilities (Section 2.6.3). The highest mountain ranges occur in the northern part of RDCK, where the peaks are sculpted by cirques, which are remnants of past glaciers. The mountains transition to more rounded peaks in the southern part of the RDCK, and into the rolling Selkirk foothills on the western margin of the District. The shift in terrain parallels a shift in winter precipitation patterns from cold and snow-dominated in the north to warmer and wetter in the south (DeMarchi, 2011).

The topography of the region influences both the population distribution and hydrology within the RDCK. Owing to the rugged terrain, settled areas are restricted to flatter topography, primarily floodplains and alluvial fans, in the valleys and on lakeshores. Mountainous streams can cause steep creek processes on alluvial fans, such as debris flows and debris floods, which differ from floods in terms of their sediment concentrations, velocities, and destructive potential (Section 0). These hydrogeomorphic events 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 clear-water floods, which are typically controlled by snowmelt (Section 2.6).

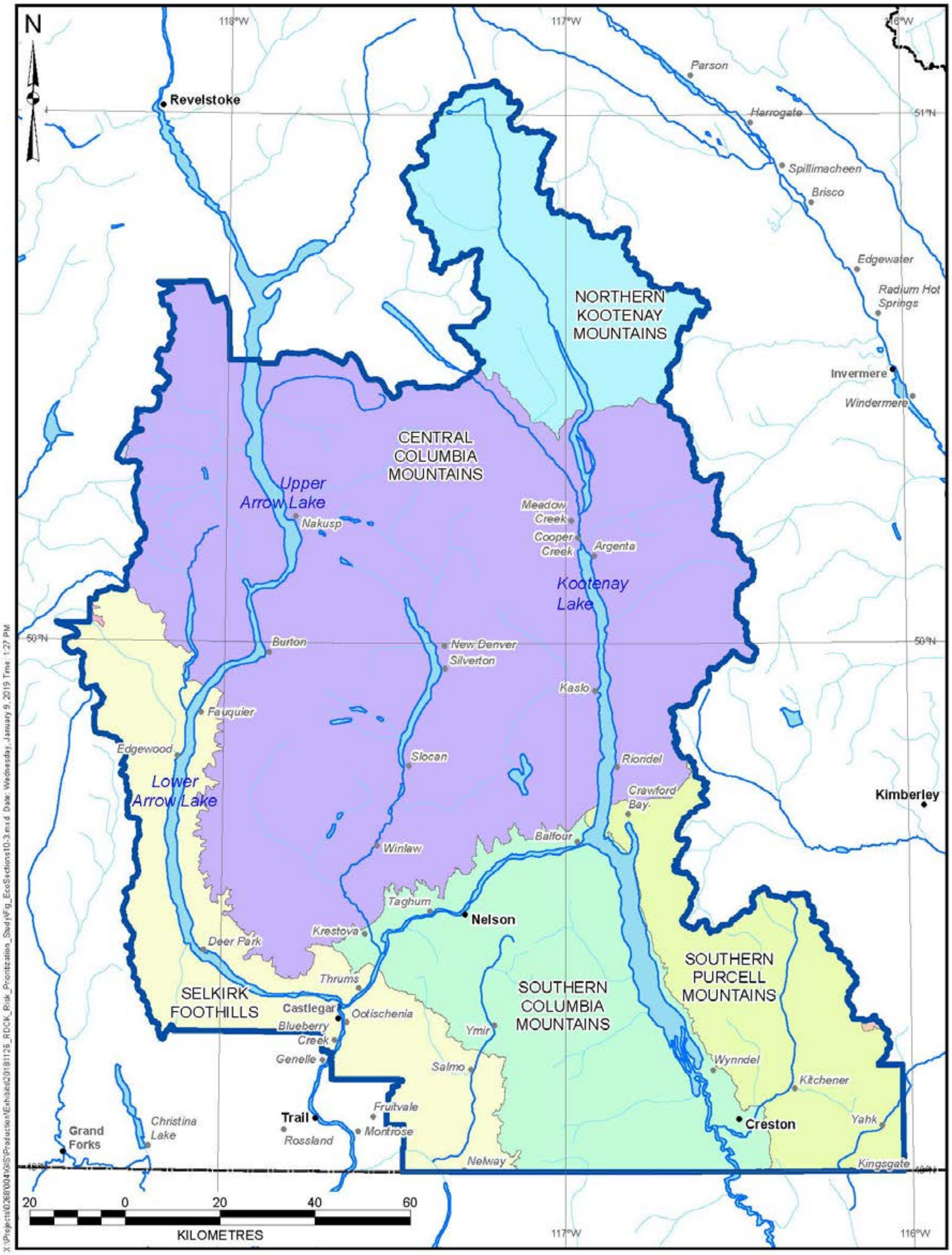


Figure 2-1. Ecosections within the RDCK (Demarchi, 2011).

Table 2-1. Ecoregions and ecosections of the RDCK (as defined by Demarchi, 2011).

Ecoregion	Ecosection	Area Within RDCK (km2)	Physiography	Climate	Major Watersheds	Vegetation
Northern Columbia Mountains	Northern Kootenay Mountains	2,200	High, rugged mountains. Sedimentary, volcanic, metamorphic rocks.	Summer – warm, potentially intense rainfall Winter – cold, potentially intense snowfall	Duncan Lake	Interior Cedar-Hemlock, moist Engelmann Spruce.
	Central Columbia Mountains	11,800	High ridges and mountains, narrow valleys and trenches. Sedimentary, metamorphic, plutonic rocks.	Summer – high humidity, rainfall Winter – cold, deep snow	Columbia, Duncan, Slocan, Upper and Lower Arrow Lake, Little Slocan, Halfway, upper Kootenay Lake	Interior Cedar-Hemlock, moist Engelmann Spruce-Subalpine Fir.
	Southern Columbia Mountains	3,700	Rounded mountains. Predominantly granitic rocks.	Precipitation is high on mountain slopes; relatively lower for Creston, which is in a rain shadow.	Kootenay River, lower Kootenay Lake, Slocan	Interior Cedar-Hemlock, moist Engelmann Spruce-Subalpine Fir.
	Southern Purcell Mountains	2,300	Rounded uplands and wide valleys. Sedimentary rocks.	Summer-high moisture and temperatures Winter – cool with occasional, short-duration cold snaps	Goat, Moyie	Interior Cedar-Hemlock, moist Engelmann Spruce-Subalpine Fir.
Selkirk – Bitterroot Foothills	Selkirk Foothills	3.100	Transitional mountain area. Granitic batholiths and sedimentary rock (in the south). Glacial debris near Castlegar.	Considerable moisture from northwesterly Pacific storms, and highest summer temperatures in entire ecoprovince.	Columbia, Lower Arrow Lake, Kootenay, Granby, Burrell, Eagle, Sandner, Big Sheep, Beaver, Salmo, Pend d'Oreille.	Interior Cedar-Hemlock, moist Engelmann Spruce-Subalpine Fir.

2.4. Geological History

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

2.4.1. Bedrock Geology

The RDCK is located in Omineca Belt of the Canadian Cordillera, which contains distinct regions of different rock types. Much of what is now present as rock in the RDCK was formed when small continents began colliding with the western margin of North America nearly 200 million years ago, causing ocean sediments and older rocks to become pushed eastward and folded and faulted as they deformed (Carr, 1995; Monger & Price, 2002; Webster & Pattison, 2013). In places, these deformed rocks were intruded by magma that was created by the continental collision process. Because of these different geological processes, the geological map of the RDCK 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.

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

- Sedimentary rocks, which are primarily in the eastern half of the RDCK and form a broad curve of rock structures known as the Kootenay Arc and Purcell Anticlinorium (Webster & Pattison, 2013)
- Intrusive rocks, common in the middle and western portions of the RDCK, particularly near the Arrow Lakes
- Metamorphic rocks, west of upper Arrow Lake, and predominantly in the Slocan River watershed
- Volcanic rocks, which are scattered across the region, primarily near Salmo and west of Duncan Lake.

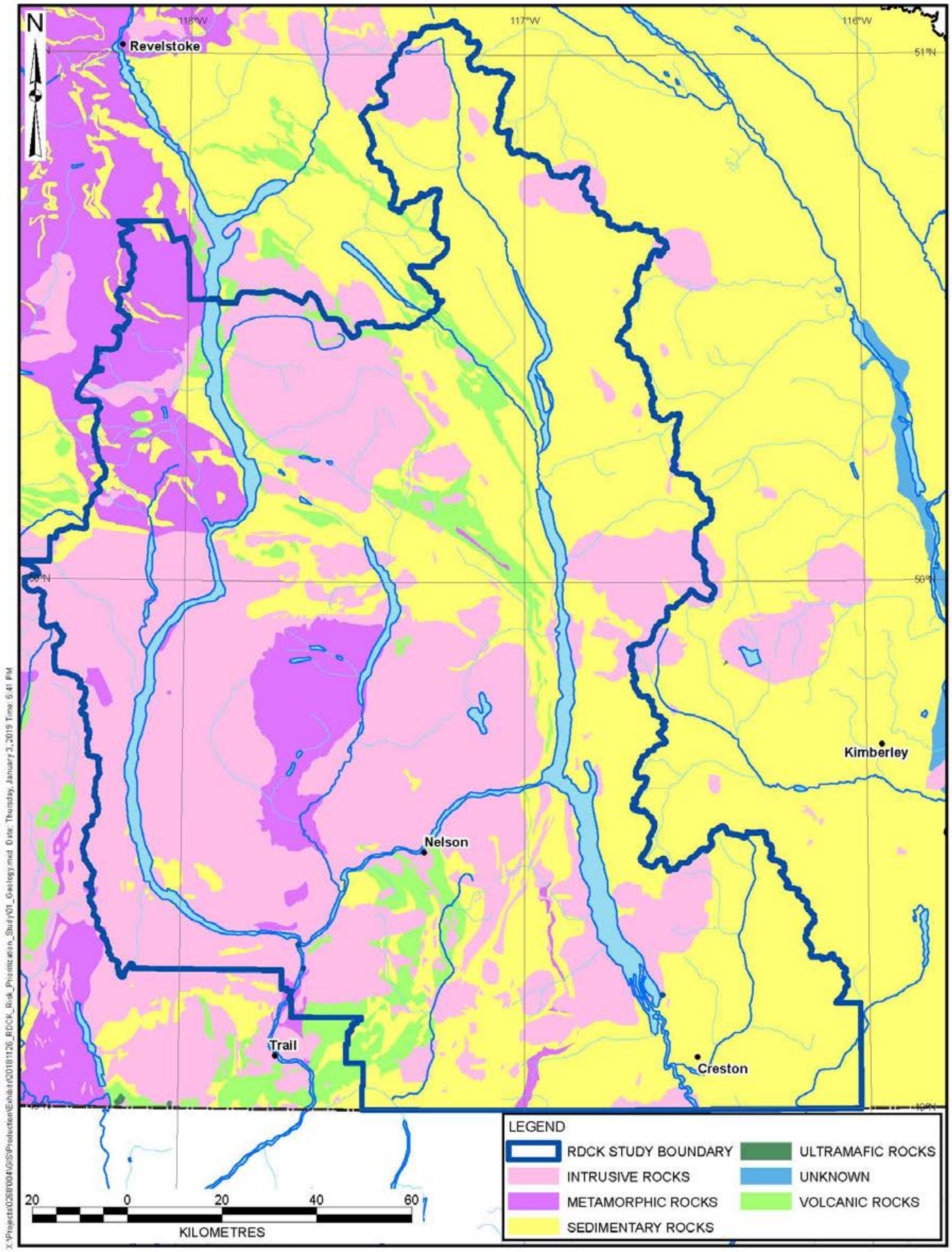


Figure 2-2. Bedrock geology of the RDCK. Digital mapping and bedrock classes from Cui et al. (2015).

2.4.2. Surficial Geology

While the geologic history of the region is the basis for the landscape observed within RDCK, 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 RDCK. 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 features include “U”-shaped valleys, steep mountains with sharp peaks, and angular rock faces caused by cirque glaciers (Holland, 1976). Glacial striae, erratics and debris are also found primarily in the Slocan Ranges found in the Seklirk Mountains to the north. At lower elevations, evidence of glaciers is in the form of sediment, such as elevated glaciofluvial and glaciolactustrine terraces.

As the glaciers covering BC began to melt and retreat northward, extensive glacial lakes were formed in present-day Arrow, Slocan, and Kootenay Lakes (Fulton, 1969, 1970; Peters, 2012; BGC, April 8, 2014). Glacial Lake Kootenai extended south to Libby, Montana in the United States and as far north as Copper Creek, BC (Peters, 2012; BGC, April 8, 2014). The glacial lake deposited sediment, such as silts and sands, into the Creston Valley (Peters, 2012), onto which the city of Creston is built. Similar conditions existed in Glacial Lakes Arrow and Slocan. Massive floods from Glacial Lake Kootenai flowed west, through the western arm of Kootenay Lake, and towards the Columbia River system (Peters, 2012).

As the glacial lakes slowly drained, these glacial deposits were left stranded at higher elevations than the present lake levels. Additionally, the glacial deposits in present-day floodplains have created low-lying areas, which are now extensive networks of wetlands, marshes, side channels and sloughs. Over the last century, many of these wetlands have been eliminated through diking, agricultural development and dam construction (BGC, April 8, 2014). The post-glacial landscape was modified by mass wasting and fluvial sediment transport, which led to the formation of alluvial fans at the outlets of mountainous channels. Many of these fans lie higher than the present lake elevations – they are remnant features of when lake levels were higher following deglaciation (Peters, 2012).

The glacial sediment common throughout the RDCK 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 the Columbia River. Therefore, the location, grain size, and overall stability of the glacial landforms has a significant influence on the volume of sediment transported during flood events.

2.5. Climate

The World Meteorological Organization (WMO) defines climate as follows[11]:

> *"Climate in a narrow sense is usually defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. …These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system."*

All climates are inherently subject to a degree of variability. WMO defines climate variability as:

> "V*ariations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events*."

Climate change is defined by the WMO[12] as:

> *"… a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer)."*

An important distinction between climate variability and climate change is the persistence of unusual conditions, such as previously rare events occurring more frequently. The occurrence and magnitude of the geohazards assessed herein are strongly influenced by the magnitude, rate, and timing of rainfall and snowmelt.

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

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

2.5.1. Regional-Scale Climate Factors

Patterns of temperature differences between different portions of the ocean and of the land, and between ocean and land, are dominant drivers for typical global air circulation patterns. Typical conditions result in weather moving from west to east, bringing moist, marine air across BC. In winter, weather is more typically coming from the southwest, while in summer it is more typically coming from the northwest[13]. The approximately north-south orientation of mountain ranges in the RDCK strongly control the westerly movement of air from the Pacific Ocean. 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).

[11] http://www.wmo.int/pages/prog/wcp/ccl/faq/faq_doc_en.html. Accessed June 18, 2018.

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

[13] http://www.navcanada.ca/EN/media/Publications/Local%20Area%20Weather%20Manuals/LAWM-BC-3-EN.pdf.

Low-lying areas, such as valleys, tend to allow cold air to drain into them, creating higher occurrences of frost and fog. Arctic air is often blocked from the RDCK by the Rocky Mountains, resulting in warmer winter temperatures than those typically seen on the Prairies.

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 (roughly 2000 m difference) results in extreme differences in temperature and precipitation across the region.

Figure 2-3 and Figure 2-4 show the average monthly precipitation and temperature normals for summer and winter for the region using data from the years 1976 to 2016. Precipitation was found to be typically higher in the months around November, and lowest in the months around August (Figure 2-3). Total precipitation in November is highest in the alpine at elevations above 1500 m, which average as high as 300 mm a month. The highest amounts of precipitation seen in the RDCK are generally in the interior mountain ranges east of Nakusp and south of Nelson. This includes the Selkirk, Purcell and Monashee Mountains, which can see upwards of 1000 mm of precipitation in a season. Valley bottoms typically see the least amount of precipitation, including the perimeters of Upper and Lower Arrow Lakes and Kootenay Lake, and the valley bottom communities of Castlegar and Creston.

The highest temperatures occur in July in the valley bottoms, with a mean of approximately 20°C. Alpine temperatures average between 5°C and 10°C during the same month (Figure 2-4). The lowest mean temperatures occur in December, with a mean of 0°C in the valley bottoms and -15°C in the high elevations of the Purcell Mountains in the northeast corner of the RDCK.

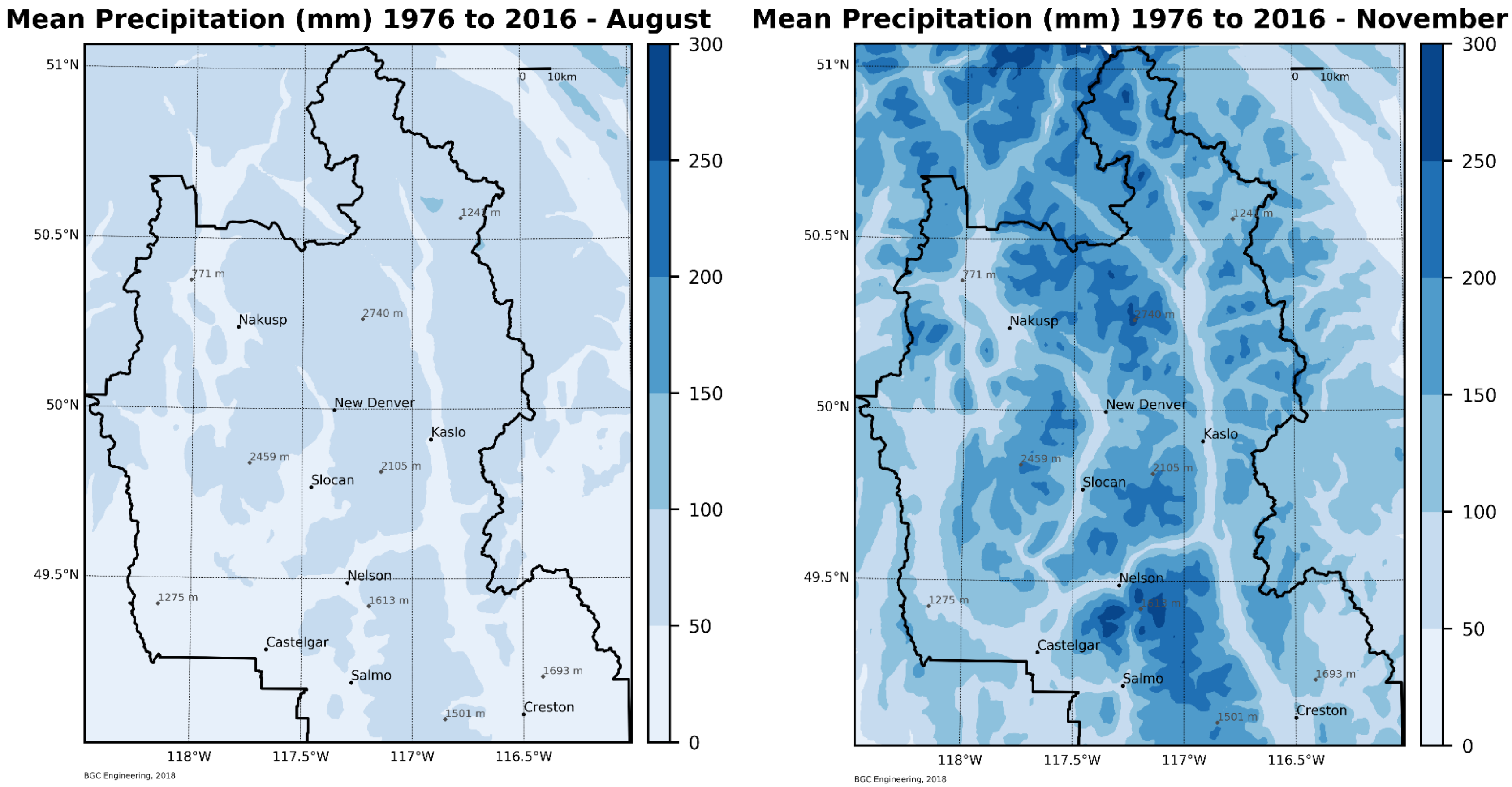


Figure 2-3. **Mean monthly precipitation normal for August and November from 1976 to 2016 for the RDCK (outlined in black). Data compiled and presented by BGC. Source data: ClimateBC (Wang et al., 2016).**

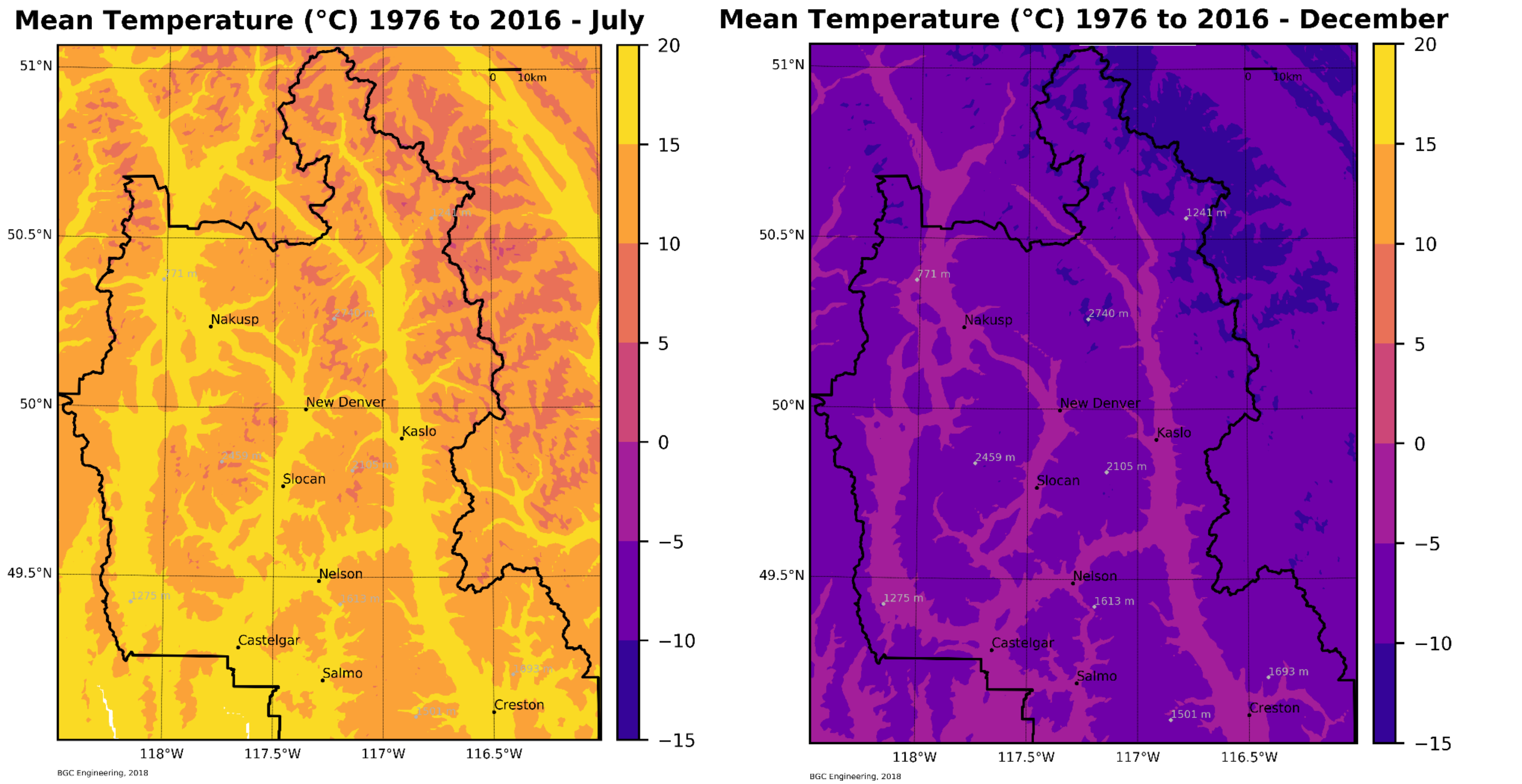


Figure 2-4. **Mean monthly temperature normals for July and December from 1976 to 2016 for the RDCK (outlined in black). Data compiled and presented by BGC. Source data: ClimateBC v5 (Wang et al., 2016).**

2.5.3. Projected Climate Change

A number of temperature, precipitation, and hydrologic climate change impact studies have been completed for the Kootenay region, including reports from the Pacific Climate Impacts Consortium (PCIC) out of the University of Victoria, and from the Columbia Basin Trust (CBT).

Climate change is discussed in more detail in Appendix G; however, the general trends are described below.

Projected changes in average climate variables across the RDCK (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.

Average annual maximum hourly precipitation intensity (i.e., 2-year return period, 1-hour duration rainfall or snowfall peak intensity) for both December/January/February (DJF) and June/July/August (JJA) periods are generally projected to increase in the RDCK relative to the period January 2001 to September 2013 (Prein et al., 2017). The study also found that the frequency of extreme precipitation events is projected to increase in both the summer and winter months.

2.6. Hydrology

2.6.1. Physiographic Characterization of Watercourses

This report defines three general categories of watercourses that are differentiated by scale and physiography as per Table 2-2.

Table 2-2. Physiographic characterization of watercourses.

Category	Watershed Area Range	Strahler Order[1]	Example Watersheds
Major Valley Systems	>3,000 km^2	7+	Columbia River, Kootenay River, Salmo River
Minor Valley Systems	500 - 1000 km^2	5, 6	Goat River, Moyie River, Kaslo River
Tributary Creeks	<200 km^2	1 to 4	Crawford Creek, Kokanee Creek

Note:

1. Strahler stream order classification system (Strahler, 1952) was applied to all the stream reaches within the RDCK. Strahler order is a classification of stream segments by its branching complexity within a drainage system. It is an indication of the significance in size and water conveying capacity at points along a river. 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 3,000 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 500-1,000 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 4. 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). Methods to identify creeks subject to steep creek processes are provided in Section 0.

2.6.2. Historical Hydrology

Annual river flow distribution 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).

Snowmelt-driven and -dominant regimes have their maximum annual flow occur with the spring freshet.

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. Nival streamflow regimes would be anticipated at high altitude locations, while nival-dominant hybrid regimes would be anticipated at lower elevations and more commonly in the Selkirk Mountains.

The majority of the alpine glaciers occur in the northern portion of the RDCK, where the mountains are higher and winter precipitation is greatest. Therefore, glacier-supported nival streamflow regimes, like the Duncan River, are more likely to be found in the north of the region.

Rain-driven and -dominant regimes are more likely to be found in lower elevation watersheds in the warmer and lower snowpack regions of the Inonoaklin and Moyie River watersheds.

Examples showing nival and nival-dominant hybrid regimes within the RDCK region are:

- Water Survey of Canada (WSC) gauge 08NE117, *Kuskanax Creek*, which is located in the northern portion of the region, in the Selkirk Mountains and on the eastern side of Arrow Lake. This gauge is situated at an elevation of approximately at 1040 m and has a watershed area of 113 km^2.
- WSC gauge 08NH016, *Duck Creek near Wynndel*, is located on the east-side of the Creston Valley and flows west into Kootenay lake. This gauge is located in the southeastern portion of the region and is located at approximately 750 m elevation. A watershed area of 57 km^2 reports to this gauge.

Kuskanax Creek exhibits a typical, northern, snowmelt dominated unit discharge graph, with monthly highs occurring in May and June, with a continued decline thereafter (Figure 2-5). Precipitation lows occur over the winter months of January through mid-March with little variability seen in the daily discharge (Figure 2-6). This is attributed to autumn storms occurring at elevations above freezing alpine temperatures.

Duck Creek exhibits a nival dominant hybrid unit discharge graph, again with peak flows occurring in May and June (Figure 2-7). However, peak flows are much smaller, and there is greater variability seen in the daily discharge over the winter months (Figure 2-8). This variability is attributed to the milder temperatures at lower elevations where precipitation may occur as snow or rain.

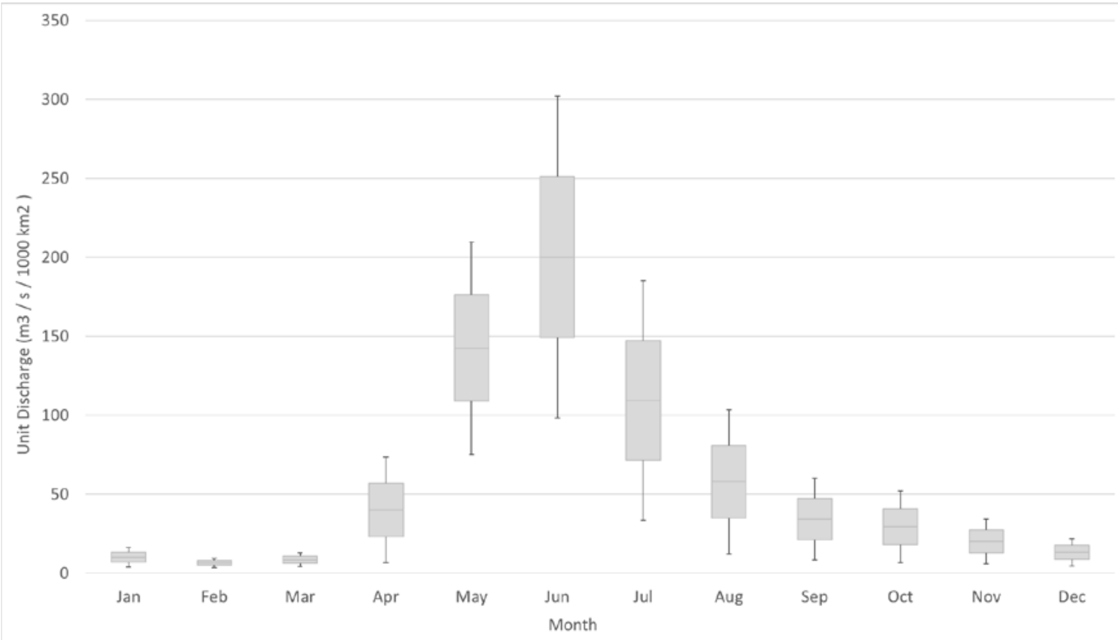


Figure 2-5. **Monthly average unit discharge data for WSC gauge 08NE117 Kuskanax Creek at 1040 m (in the upper watershed above Nakusp) from 1974 to 1995. Graph shows average value as well as the historical ranges including record maximum, minimum, 25th and 75th percentile values. Watershed area is 113 km^2.**

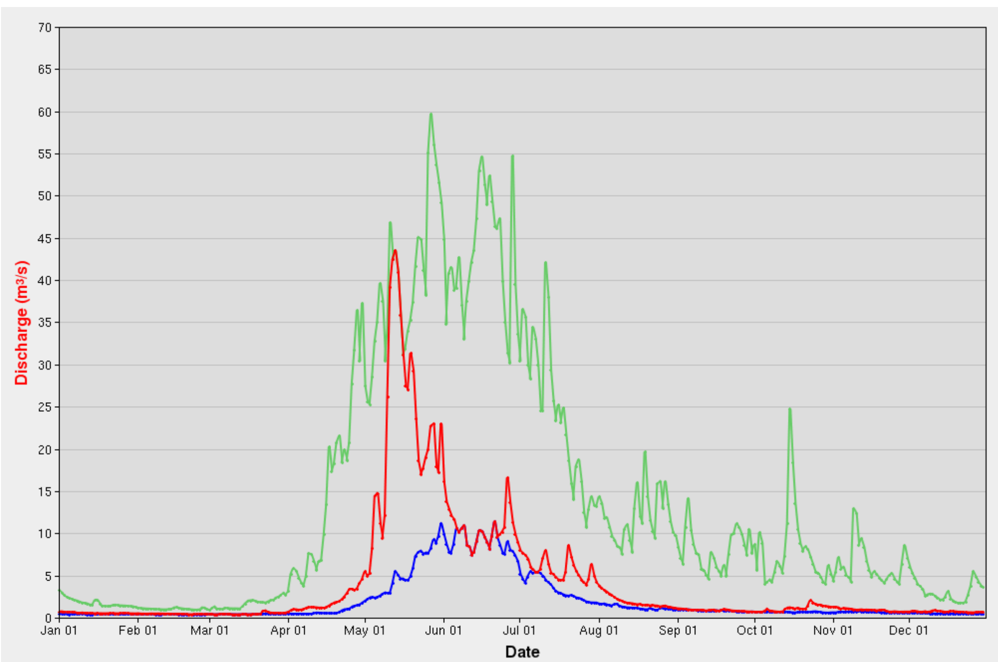


Figure 2-6. **Daily discharge data for for WSC gauge 08NE117 Kuskanax Creek at 1040 m (in the upper watershed above Nakusp) from 1974 to 1995. Graph shows record maximum (green line), record minimum (blue line), and 1993 (red line) daily discharge data.**

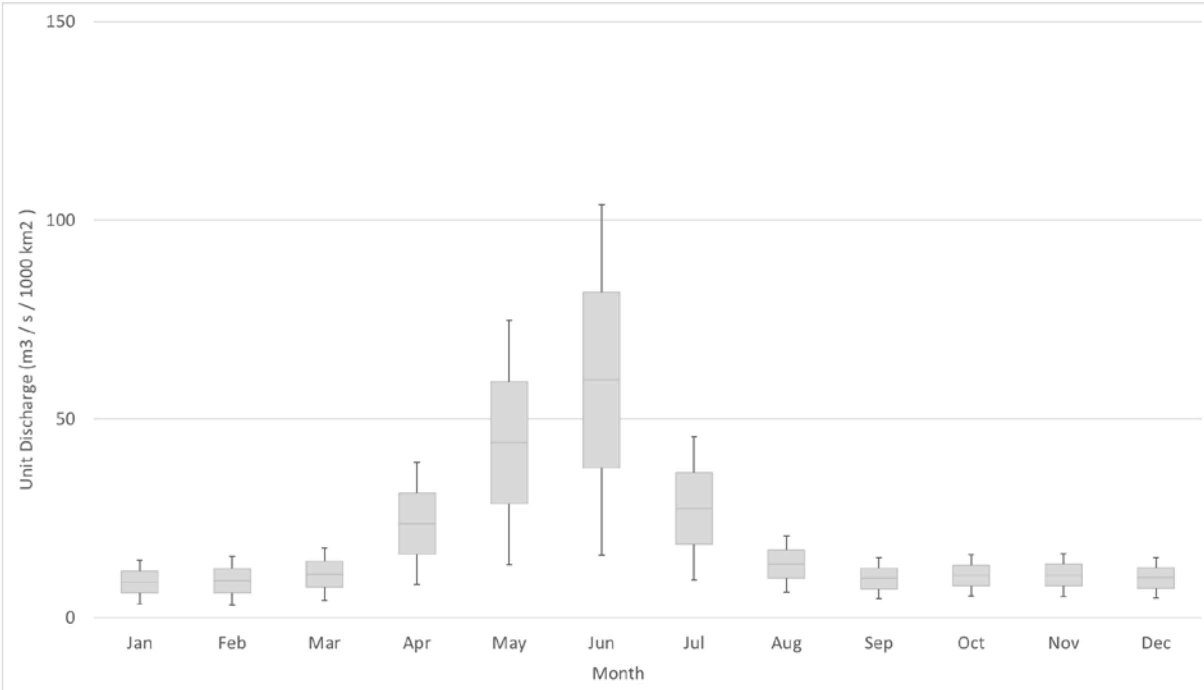


Figure 2-7. Monthly average unit discharge data for WSC gauge 08NH016 Duck Creek near Wynndel (which is located in the Creston Valley) from 1921 to 2016. Graph shows average value as well as the historical ranges including record maximum, minimum, 25th and 75th percentile values. Watershed area is 57 km^2

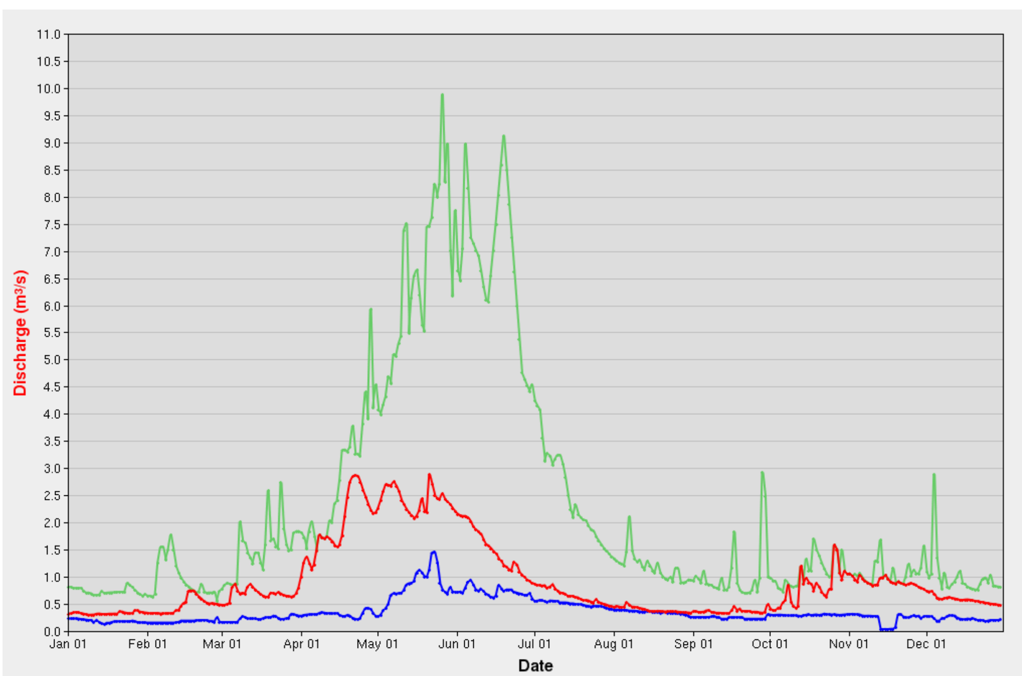


Figure 2-8. Daily discharge data for WSC gauge 08NH016 Duck Creek near Wynndel at 752 m (which is located in the Creston Valley) from 1921 to 2016. Graph shows record maximum (green line), record minimum (blue line), and 2016 (red line) daily discharge data.

2.6.3. Flow Regulation

With the exception of the Slocan Valley, the major valley bottom rivers and lakes within the RDCK have been dammed and their water levels and discharges are managed by a consortium of dam owners (BC Hydro, Fortis, USACE) who coordinate their activities to some degree with each other and with downstream dam owners, and have water level / discharge commitments (biological, dam safety, Columbia River Treaty, International Joint Commission, Kootenay Lake Order, etc.). The first dams were constructed in the 1920s, while most dams were constructed in the late 1960s through late 1970s. Dams in the region include:

- Duncan Dam (Duncan River, BC Hydro)
- Libby Dam (Kootenay River upstream of the RDCK in Montana, USACE)
- Corra Linn Dam (Kootenay River, Fortis)
- Upper and Lower Bonnington Dams, South Slocan Dam Complex (Kootenay River, Fortis)
- Brilliant Dam Complex (Kootenay River, Columbia Power Corporation and Columbia Basin Trust)
- Goat River Dam (Goat River,
- Whatshan Dam (Whatshan River, BC Hydro)
- Seven Mile Dam (Pend d'Oreille River, BC Hydro) The dam is not located in the RDCK, but the reservoir crosses into the RDCK
- Keenleyside Dam (Arrow Lakes, BC Hydro)
- Mica Dam and Revelstoke Dam (Columbia River upstream of the RDCK, BC Hydro)
- Several small provincially-regulated facilities located on small tributary creeks.

Those dams located within the RDCK are shown on Figure 2-9. Cambio Communities displays inventoried dams that are regulated under the *Water Sustainability Act* (SBC, 2014).

The impacts on flood hydrology downstream of the dam are typically a decrease in the peak freshet discharge and an increase in winter discharges, when compared with pre-dam hydrology. Within the reservoir area, high water levels can persist longer than before dam construction.

The Columbia River Treaty (signed in 1961 and ratified in 1964) will be open for renegotiation or termination after 2024, and at present, the potential for large changes to dam operations are being evaluated. With the exception of dam failure inundation studies (which are beyond the scope of this assessment), limited flood hazard data are presently available for these water bodies. Information, where available, has been included in the assessment; however, an evaluation of flood risk which is controlled by artificial management of lake levels, to the same level of detail as the rest of the study area, is beyond the scope of this assessment.

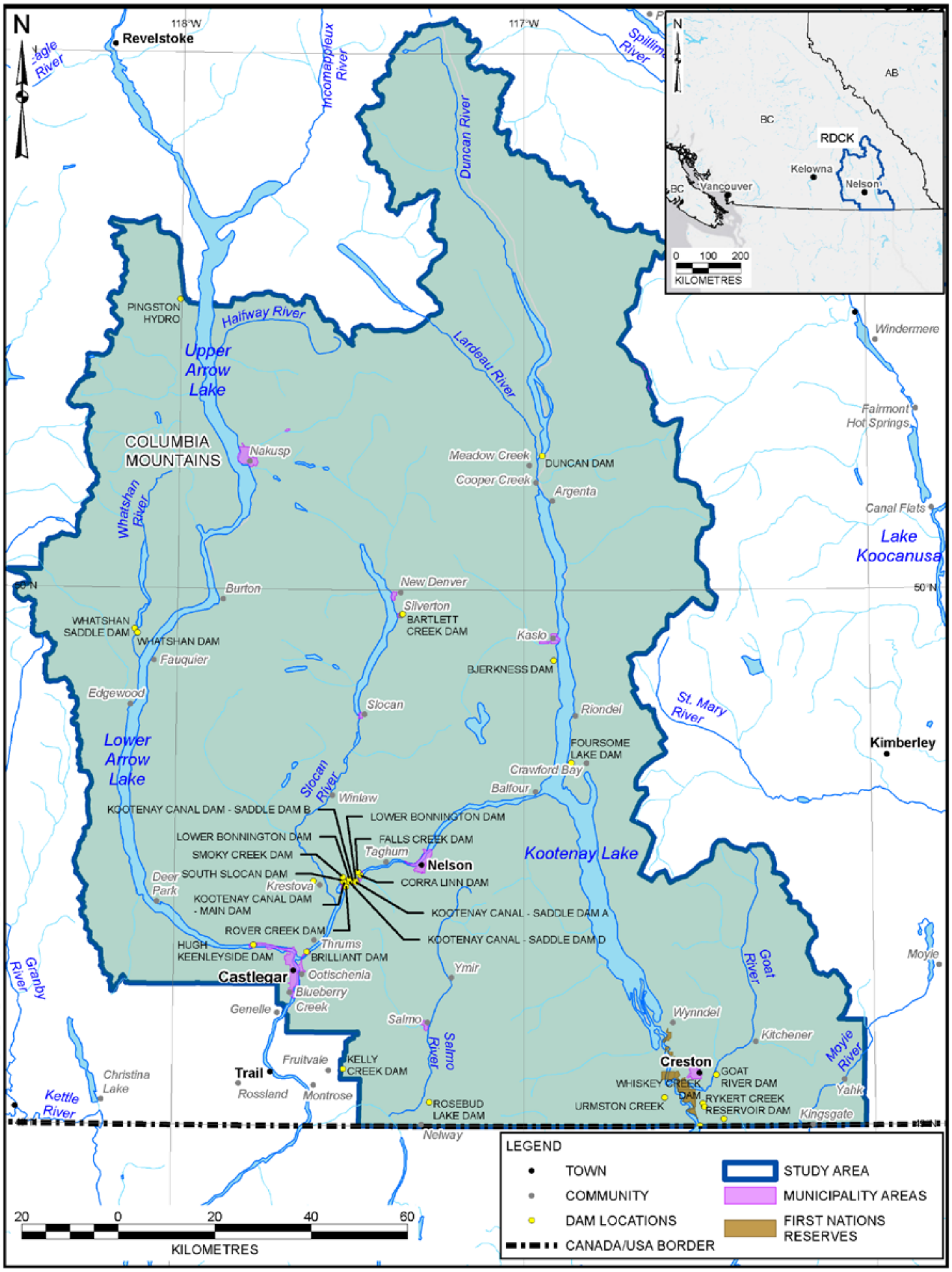


Figure 2-9. Dams in the RDCK.

2.6.4. Ice Jams

Ice jams are formed by accumulation of ice floes. They can obstruct river flow resulting in rapidly rising water levels and their sudden release can also result in flooding. The processes of ice growth and break-up are dynamic, varied and complex. Some sites are more prone to ice-related flooding than others, such as rivers with tight bends, constrictions or an abrupt decrease in slope, or where the upstream reaches warm and melt before the downstream reaches (such as north-flowing rivers). Other sites that can be more prone to ice-related flooding are culverts on small streams, where the small winter flows can freeze to the culvert wall. Over a prolonged cold period, significant ice accumulations can develop which reduce the capacity of the culvert to convey spring runoff.

Without prior field observations, it is generally difficult to predict where or if jams will form (USACE, 2002). Section 2.6.4 describes the flood history database that was compiled for the region. Within the database, few ice jams were identified as being the source of flooding and for those that were, flooding was generally localized and associated with areas where flooding was known to occur, separate from ice jams. Ice jams were therefore not included as a flood source in the flood hazard assessment and risk prioritization.

2.7. Historical Event Inventory

BGC reviewed historical accounts of floods and debris flow events across the RDCK. Appendix C summarizes the details of these reports. Data bias is typically inherent in historical accounts of past events due to gaps in recorded storms or geohazard events, because media reports tend to generalize effects of large region-wide events (e.g., 1948 region-wide floods) rather than smaller and more localized impacts.

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)
- 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
- Historical media reports of floods and geohazard events in the region compiled by RDCK and provided to BGC
- Geotechnical reports compiled by RDCK and provided to BGC[14].

The 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. These locations were referenced during geohazard identification (Section 4.0).

[14] RDCK maintains a spreadsheet inventory of geotechnical reports within the district. Due to the number of reports (several hundred), citations are not provided in this document but are available on request. Reports compiled for this assessment are available for download on Cambio Communities by clicking on a relevant geohazard area. See Appendix B for further details on the use of Cambio Communities.

Recorded events at steep creek fans are listed in supporting information for a given site on Cambio Communities.

The RDCK has a long history of damaging flood events, with recorded flood history dating as far back as 1808. The most notable findings from review of historical and anecdotal data indicate that most large floods occur in the months of May and June. The years with the largest interpreted flood inundation occurred in 1808, 1894, 1933, 1948 and most recently, in 2012 and 2013. These findings are largely supported by the monthly and daily discharge data within the region described in Section 2.6.2.

2.8. Floodplain Management Policies and Bylaws

The RDCK administers polices and bylaws that rely on flood hazard information and reference flood-related terminology. The main policy documents referencing flood hazard information include Floodplain Management Bylaw No. 2080, 2009, and land use bylaws for different electoral districts (e.g., Comprehensive Land Use Bylaw, Official Community Plan, Rural Official Community Plan). In addition, the following documents include at least minor reference to flood-related information:

- Zoning Bylaw No. 1675, 2004
- Subdivision Bylaw No. 2159, 2011
- Building Bylaw No. 2200, 2010, Consolidated up to April 12, 2012
- Soil Removal and Deposit Permit Bylaw No. 1183, 1996, consolidated to December 13, 2008
- Manufactured Home Parks Bylaw No. 1082, 1995, consolidated to March 19, 2009.

Appendix A provides background on aspects of floodplain bylaws and other policies that relate to this assessment. In particular, that appendix:

- Highlights key definitions contained in bylaws and provides comments on technical nuances and details to these terms that affect their application in policy versus geohazards assessments or that have bearing on the scope of work
- Provides a table of geohazard risk terminology and definitions assumed in this study
- Provides commentary on aspects of the Floodplain Management Bylaw from a geohazards management perspective (floodplain, primary and secondary effects of flooding, floodplain setbacks and flood construction levels, NSFEAs)
- Provides an overview of how flood hazards are included in land use management bylaws
- Provides a background summary on freeboard and discusses how it is incorporated in to floodplain mapping and policy.

The bylaws do not appear to include dam safety considerations relating to the controlled or uncontrolled release of water from reservoirs. Any proposed changes to land use in areas that could be impacted by an uncontrolled release of water (for example a full or partial dam failure), should be reviewed alongside scenario mapping from dam owners.

This background information on floodplain bylaws and policies is described because the results of this study post-date bylaw-development and may trigger requirements for review and updates.

3. EXPOSURE ASSESSMENT METHODS

This section summarises the elements at risk identified in geohazard areas and how exposure ratings were assigned to a given area. Section 5 describes how exposure ratings were used as inputs for risk prioritization. Appendix D describes methods to compile and organize elements at risk data.

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.

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.

Table 3-2 provides a more detailed breakdown of how weightings were assigned to critical facilities based on the BCEMS response goals according to feedback provided by RDCK in an email dated October 24, 2018. 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 Infrastructure	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

Note:

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 infrastruc-ture (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

Notes:

1. The actual use value descriptions shown in this table were a starting point to compile an inventory of critical facilities, which were checked and provided by RDCK to BGC. RDCK completed additional manual effort to check facility locations and types. 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.

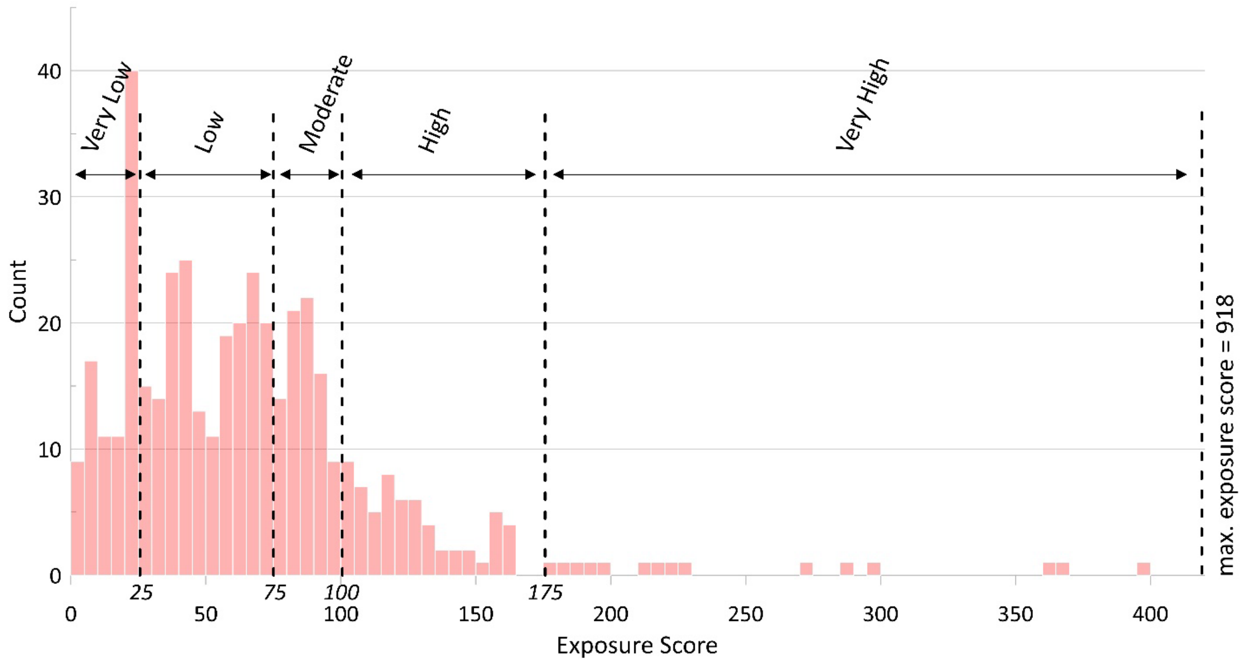


Figure 3-1. Distribution of exposure scores in the RDCK and definition of associated exposure ratings.

Table 3-3. Hazard exposure rating.

Hazard Exposure Rating	Criteria	Total Weighting Value
Very High	Greater than 95th percentile	> 174
High	Between 80th and 95th percentile	100 to 174
Moderate	Between 60th and 80th percentile	75 to 99
Low	Between 20th and 60th percentile	25 to 74
Very Low	Smaller 20th percentile	0 to 24

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. BGC also notes that the exposure rating is relative to the study area, which is defined by the RDCK boundary. Different choices of study area would affect this relative rating. In summary, applying different weightings would result in different priorities, and this factor should be considered in decision making based on the study results.

4. GEOHAZARD ASSESSMENT METHODS

This section summarizes how BGC identified and characterized the geohazard extents prioritized in this study. Areas considered in this inventory both contained cadastral parcels of interest[15] and were subject to clear-water floods or steep creek processes. Appendices E and F provide further details on geohazard identification and characterization for clear-water flood and steep creek geohazards, respectively.

Climate change was not directly incorporated into the prioritization of geohazard areas. However, Appendix G describes how 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 RDCK. The results provide insight for planning purposes into how these hazards could change in the future, and also supports more detailed future assessment of changes to clear-water flood and steep creek geohazards in the RDCK.

4.1. Clear-water Flood Geohazards

4.1.1. Hazard Area Delineation and Characterization Overview

Table 4-1 summarizes the approaches used to identify and characterize clear-water flood hazard areas. Locations of known dams, flood risk reduction infrastructure, and flood conveyance structures were inventoried but not included in the prioritization of hazard areas. Hazard areas generated from the methods shown in Table 4-1 that were found to be located on or adjacent to cadastral parcels of interest were identified, and adjacent areas were amalgamated[16] into geohazard areas for prioritization. The resulting geohazard areas for prioritization are shown on the web application accompanying this report. Also shown on the web application are all mapped stream segments and their associated geohazard process type, as well as historical mapped floodplains and flood depth results from the screening-level hydraulic models.

Appendix E provides further details on the methodology and associated limitations.

[15] Cadastral parcels of interest were defined as those parcels identified in the BC Assessment dataset for 2018 as having a gross general improvement value greater than $0, and a land use code not equal to 428 (Managed Forest (Improved)).

[16] Amalgamation was based on the concept of "consultation zones", which define a geographic area considered for geohazard safety assessment (Geotechnical Engineering Office 1998; Porter et al, 2009). Geographic areas were selected on the basis of hazard type and characteristics, jurisdiction/community continuity, future detailed study funding considerations and study efficiencies.

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

Approach	Area of RDCK 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 floodplain mapping	All mapped watercourses and waterbodies prone to clear-water flooding where existing information was available.	Identification of floodplain extents from publicly available historical mapping sources and estimates of flood depths across the floodplain.
Screening-level hydraulic modelling	Select unregulated watercourses prone to clear-water flooding, not previously mapped. Generally areas with a higher concentration of elements at risk(1), a Strahler stream order(2) of 4 or greater, and sufficient topographic relief to be captured in the low-resolution topography.	Identification of flood inundation extents and depths based on a digital elevation model.
Lake level prediction	All lakes with active gauge stations or previous lake level modelling.	Lake levels or elevations predicted for the 200-year return period event (AEP of 0.5%) used to generate flood inundation extents and depths.
Proxy metrics for impounded reservoirs	Major reservoirs.	Identification of potential inundation extents and depths resulting from extreme water levels.
Floodplain extent prediction for watercourses and waterbodies.	All remaining watercourses and waterbodies with a Strahler stream order(2) of 4 or greater, and prone to clear-water flooding, but not associated with an alluvial fan.	Identification of low-lying areas adjacent to streams using a topographic elevation offset applied to mapped centrelines. The unregulated stream discharge was used as a proxy for flood hazard intensity.
	All remaining watercourses and waterbodies with a Strahler stream order(2) of 3 or less, and prone to clear-water flooding, but not associated with an alluvial fan.	Identification of low-lying areas adjacent to streams using a 30 m horizontal buffer applied to mapped centrelines. The unregulated stream discharge was used as a proxy for flood hazard intensity.

Note:

1. Elements at Risk considered in this study are described in Section 3.
2. 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 1.4.

The accuracy of clear-water flood identification approaches listed in Table 4-1 was strongly influenced by the resolution of available digital elevation models (DEM). While the RDCK has now acquired high resolution Lidar topography across much of the developed areas of the District, these data were not processed and available in time to be used in this current study. Topographic data in most clear-water flood areas assessed was limited to the approximately 25 m resolution Canadian Digital Elevation Model (CDEM).

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.

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, 2017).

RNT™ also contains hydrometric data collected from WSC gauging 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 4.1.3.

4.1.3. Flood Frequency Analysis (FFA)

In RNT™, flood quantiles are either pro-rated from a nearby single gauge or estimated by regional FFA from multiple gauges, depending on the location relative to available WSC gauge stations. A total of 358 WSC gauges stations are located within the RDCK (DataBC, 2017). Of these gauges, 31 are active stations and 327 are discontinued. Of the 31 active stations, 18 are used by WSC for real-time monitoring (Figure 4-1).

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 RDCK. Because RNT™ is applied as a screening level tool to predict flows over a large geographical area, the flow estimates have a number of limitations which are detailed in Appendix E.

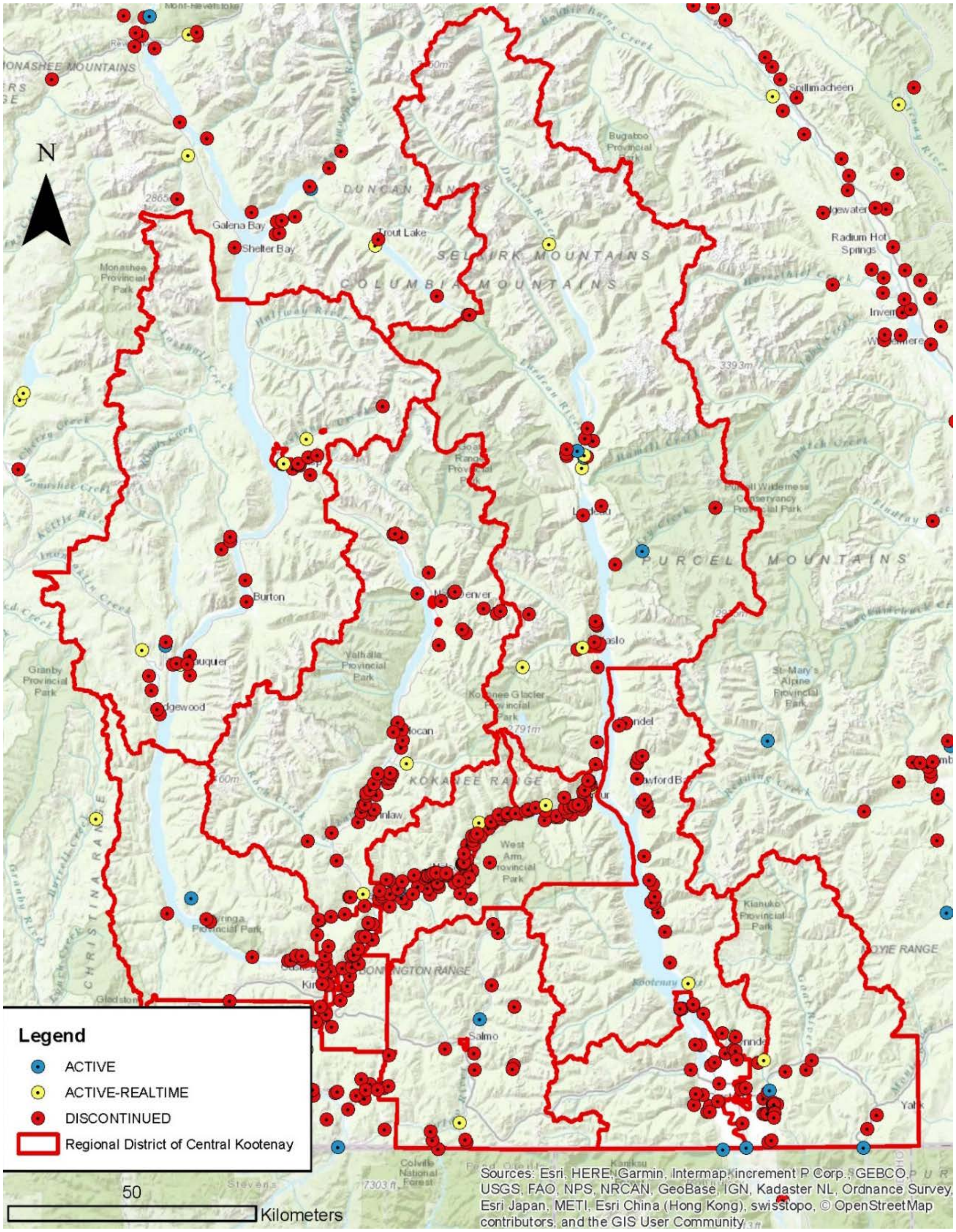


Figure 4-1. WSC active, active-real time, and discontinued gauges within the RDCK.

4.1.4. Geohazard Process Type

Every mapped stream segment in the RDCK was assigned a predicted process type (flood, debris-flood or debris flow) based on a statistical analysis of Melton Ratio[17] and watershed length[18]. 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 4-2. The web map displays every stream segment in the RDCK and its associated predicted geohazard process type (clear-water flood, debris flood or debris flow).

Table 4-2. 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 RDCK 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 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 E.

4.1.5. Hazard Likelihood

Frequency analysis estimates how often geohazard events occur, on average. Historical 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 clear-water flood sites across the RDCK. Appendix E provides further description of methods and uncertainties.

[17] Melton ratio is watershed relief divided by the square root of watershed area (Melton, 1957).
[18] 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.

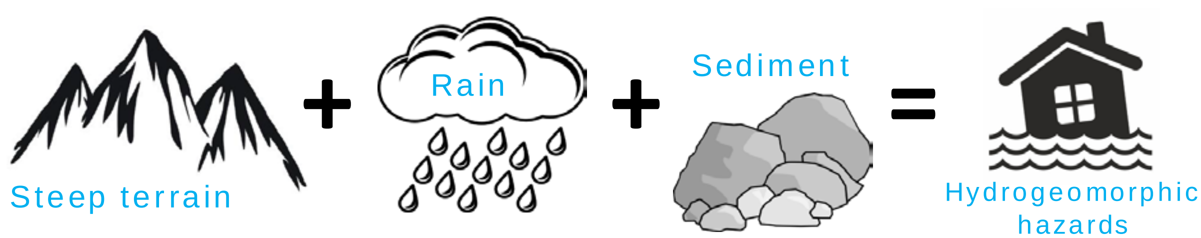
4.1.6. Hazard Intensity

Hazard intensity describes the destructive potential of uncontrolled flows that could impact elements at risk (as defined by cadastral parcels of interest). Hazard intensity ratings were used to define a consequence rating for each hazard area, as described in Section 5.3.3.

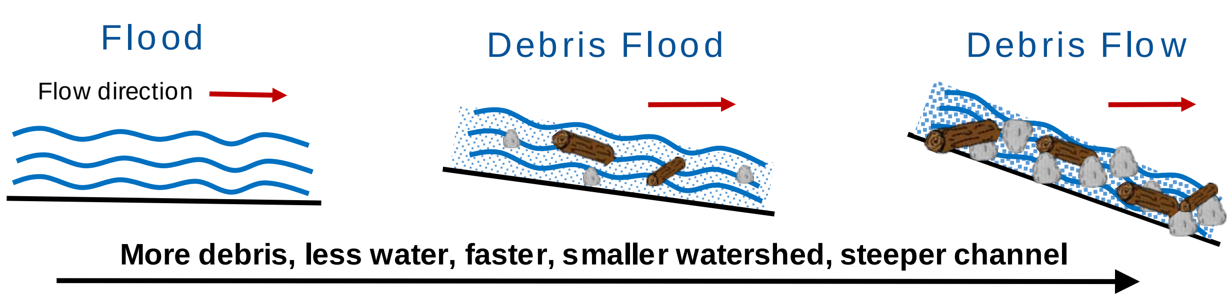
In a detailed hazard assessment, hazard intensity is quantified by parameters such as flow depth and velocity. At regional scale, these parameters are difficult to estimate, because they are site-specific. To address this limitation, at the scale of the RDCK, and in the context of the current prioritization study, BGC used either: peak flood depth above the ground surface; or flood event peak discharge (see Section 4.1.3) as a proxy for flood depth where it was not available (such as sites where floodplain extent prediction techniques were used). Appendix E provides further details about the approach used to assign intensity ratings.

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 F.



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 4-3 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 F.

Table 4-3. 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. BGC mapped a total of 330 fans, based on the interpretation of available aerial and satellite imagery, Lidar Digital Elevation Models (DEM), and review of previous fan mapping (e.g., NSFEA areas and previous reports). Geobase terrain models and satellite imagery available within the ESRI web map were used for terrain interpretations where Lidar was not available. Previous reports used as reference can be downloaded by clicking on a given fan in Cambio Communities.

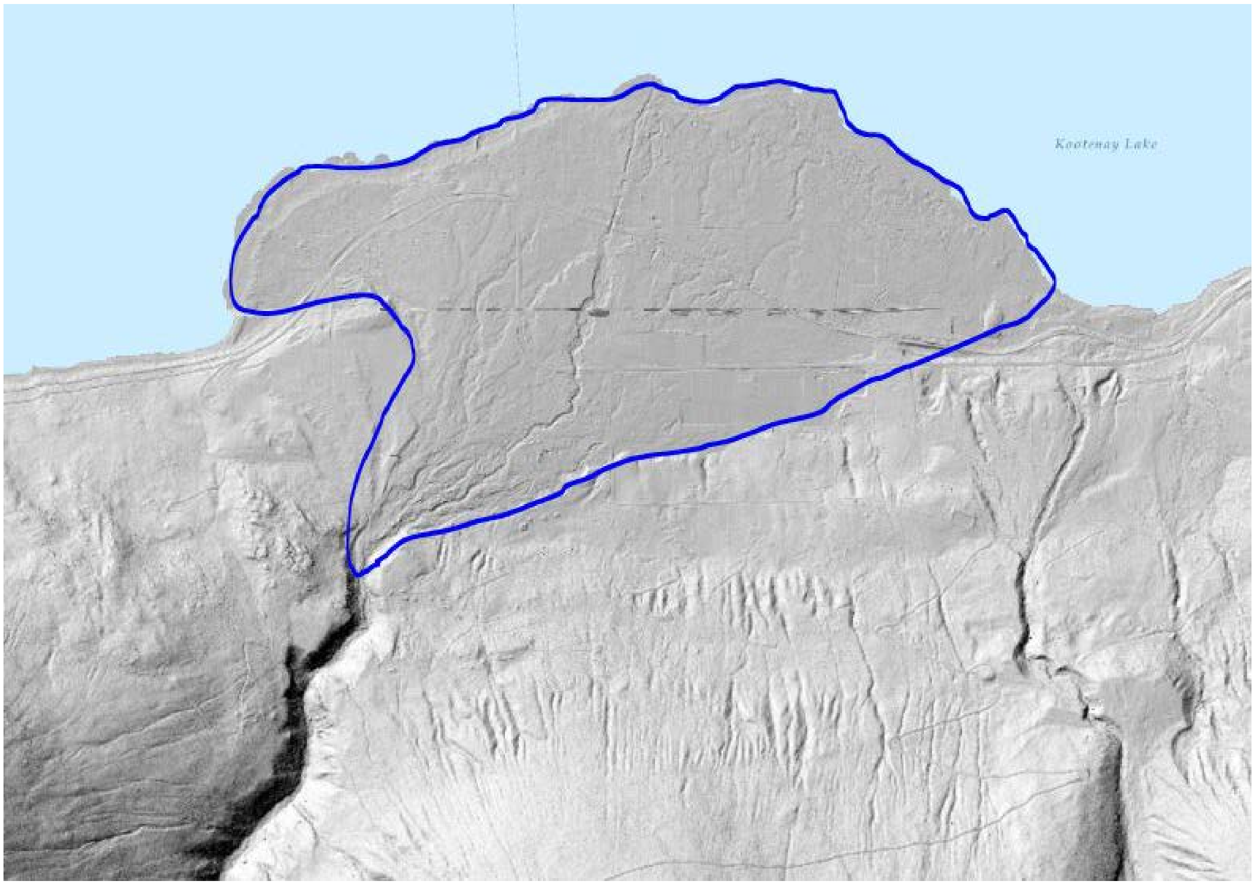


Figure 4-2. Example alluvial fan boundary at Harrop Creek on the south side of West Arm Kootenay Lake.

Although this study was based on the best available information, the fan inventory is not exhaustive. Fans likely exist in some developed areas that were not 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[19]. 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 RDCK 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. The term "paleofan" was used to describe portions of fans interpreted as no longer active (i.e., with negligible potential for channel avulsion and flow propagation) due to deep channel incision. Table 4-4 summarizes the number of fans by process type.

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

Process Type	Number of fans mapped
Debris Flood	172
Debris Flow	73
Flood	72
Paleofan	13
Total	**330**

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 F 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 F 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.

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

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

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 RNT™, morphometric statistics (Section 4.1.4.), and the Flow-R model[20] 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.

4.2.6. Intensity Estimation

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 regional scale, these parameters are difficult to estimate, because they are specific to individual watersheds. To address this limitation, at the scale of the RDCK, and in the context of the current prioritization study, BGC used peak discharge as a proxy for flow intensity. Appendix F provides further details about the approach used for determination of intensity ratings.

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

5. GEOHAZARD RISK PRIORITIZATION METHODS

5.1. Introduction

This section describes how geohazard areas were prioritized across the RDCK. 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.

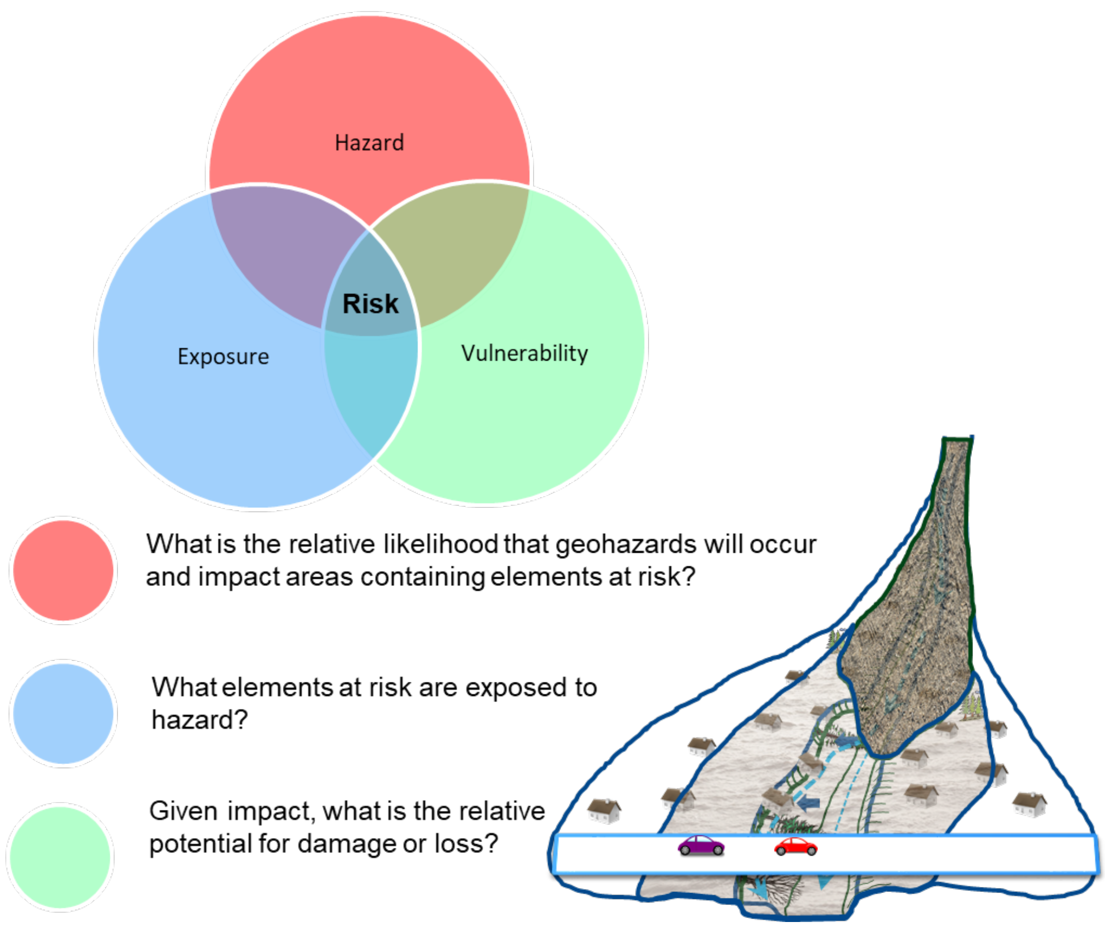


Figure 5-1. Elements of the prioritization approach.

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 management and resiliency 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 F and G provide detailed description of methods to determine geohazard ratings for clear-water and steep creek 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 G provides additional assessment on the sensitivity of geohazard to 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 potentially control hazard likelihood, whereas structural mitigation (i.e., dikes) can potentially 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 describes how hazard and impact likelihood were defined for each hazard type. Table 5-3 defines approximate frequency and return period ranges for hazard likelihood categories[21]. Appendix E and Appendix F describe criteria used to assign impact likelihoods, and the methods used to estimate the values of the hazard and impact likelihood ratings.

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
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 0.005 AEP (200-year) flood.

Table 5-3. 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).

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,

[21] Note that geohazard events outside the ranges shown are possible, such as the occurrence of extremely rare events. The categories included reflect the objectives of this study and types of geohazards assessed.

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. Hazard 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.

As noted in Sections 4.1.6 and 4.2.6, Appendices E and F provide further description of methods to estimate destructive potential and assign ratings for each geohazard type, as well as limitations and uncertainties.

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. The alphanumeric priority codes shown in the matrix indicate the basis for the rating (for example to clarify whether a "high" priority is due to high hazard or high potential consequence, or both).

As noted in Section 5.4, the original data used to generate each rating are provided on the web map and via data services and downloads. 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				
VH (1)	M	H	H	VH	VH
H (2)	L	M	H	H	VH
M (3)	L	L	M	H	H
L (4)	VL	L	L	M	H
VL (5)	VL	VL	L	L	M
Consequence Rating	**VL (a)**	**L (b)**	**M (c)**	**H (d)**	**VH (e)**

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 did not normalize ratings by unit area. The rationale for this 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 landslide 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 landslides, and where fatalities arising from one or more concurrent landslides would be viewed as a single catastrophic loss” (Porter et al., 2009). This definition can be generalized across geohazard types (i.e., not only landslides) and consequences (i.e., not only fatalities). The chosen approach reflects societal perception of risk, where higher priority areas are those where there is a greater chance of more significant consequences. For steep creeks, the consultation zone is the prioritized fan. For clear-water floods, geographic areas were selected based on geohazard characteristics, jurisdiction/community continuity, future detailed study funding considerations and study efficiencies.

6. RESULTS

This study provides baseline results in several ways:

- **This report section** provides a summary overview of results.
- **Cambio Communities (www.cambiocommunities.ca)** displays all geohazard areas and 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 B provides a guide to navigate Cambio Communities.
- **Appendix I** provides an Excel spreadsheet with tabulated results.
- **ArcGIS Representational State Transfer (REST) API** provides access to geohazard area layers in a format accessible through an ArcGIS Online account. This option is intended for geomatics professionals on request.
- **Data download** of prioritized, attributed geohazard areas in geodatabase format.
- **Appendix H** provides the example RAIT form required by the NDMP.

In total, BGC prioritized 427 geohazard areas encompassing about 1,400 km^2 of the RDCK (Table 6-1). Table 6-2 lists the results worksheets provided in Appendix I, and Figure 6-1 provides summary statistics by jurisdiction.

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

Geohazard Type	Priority Level				Grand Total
	High	Moderate	Low	Very Low	
Clear-Water Floods (water courses and water bodies)	27	14	63	0	104
Steep Creeks (Fans)	15	56	180	72	323
Grand Total (Count)	**42**	**70**	**243**	**72**	**427**
Grand Total (%)	**10%**	**16%**	**57%**	**17%**	**100%**

Compared to the entire RDCK, 16% of the Census population, 32% of assessed building value, 13% of business locations, and most of the major transportation routes are in these areas. Note that the Census data under-represents the actual population in these areas because it does not include all population sources.

Table 6-3 highlights clear-water flood watercourse and steep creek geohazard areas considered high priority for further assessment. These areas were selected as examples only, and the full list of prioritized areas should be reviewed for decision making. There are additional factors for risk management and policy making that are outside the scope of this assessment, that RDCK may also consider when reviewing prioritization results.

For example, Arrow Lake is noted to be a high priority site; however, assessment of the potential hazard inundation extent was limited by the high degree of regulation (and therefore lack of data on the true hazard magnitude) and the poor resolution of the topographic dataset. This site's prioritization should be reviewed in that context during the next phase of work.

The Creston Valley (Kootenay River (to US Border)) is also identified as a high priority site; however, a study by BGC (April 8, 2014) for the Lower Kootenay Indian Band noted that upstream flow regulation has reduced the hazard magnitude and the 200-year flood elevation is below the dike crest. The presence of dikes was excluded from the original floodplain mapping (and therefore from this prioritization study). This site's prioritization should also be reviewed in that context during the next phase of work.

Fry Creek is also identified as a high priority site given a Very High hazard rating. However, it was not highlighted in Table 6-3 given a low level of development. This site's prioritization should also be reviewed if new development is proposed.

The prioritization completed in this assessment also depends strongly on the relative weightings applied to elements at risk (Section 3). The weightings applied in this study are intended to convey screening level understanding of the overall "important" of assets in a geohazard area, for the purpose of policy, planning, legislation and emergency management. Different weightings will result in different priorities. 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. This factor should be considered in decision making based on study results.

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

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 (digital version of Table 6-1).
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.

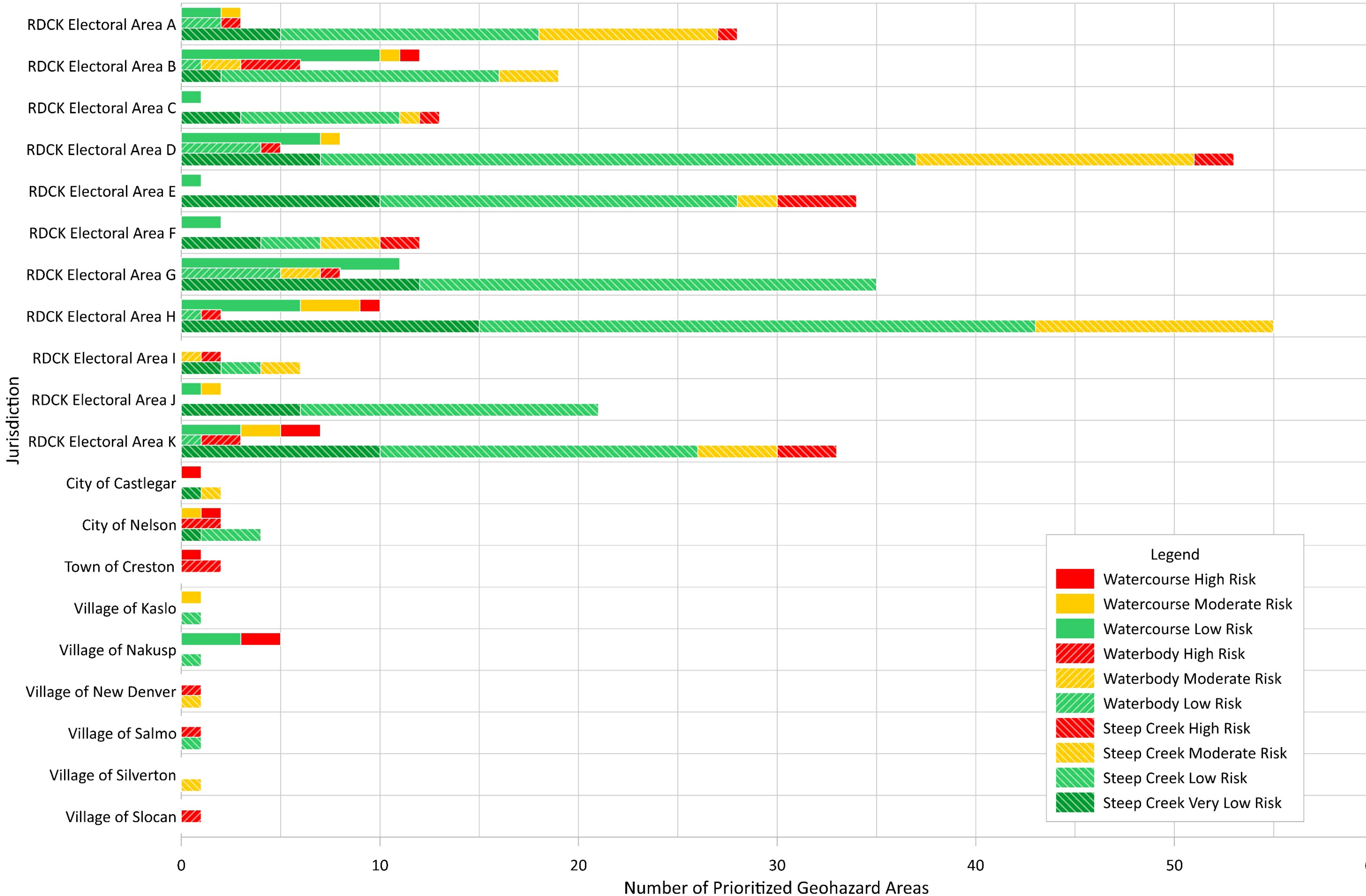


Figure 6-1. Number of prioritized areas in each jurisdiction within the RDCK.

Table 6-3. Geohazard areas highlighted as high priority for more detailed assessment.

Hazard Code	Jurisdiction	Hazard Type	Geohazard Process	Name	Geohazard Rating	Consequence Rating	Priority Rating
340	Village of Salmo	Clear-Water Floods	Flood (watercourse)	Salmo River[1]	Moderate	High	High
372	Village of Slocan	Clear-Water Floods	Flood (watercourse)	Slocan River[2]	Moderate	High	High
379	RDCK Electoral Area B	Clear-Water Floods	Flood (watercourse)	Moyie River[3]	Moderate	High	High
393	Town of Creston	Clear-Water Floods	Flood (watercourse)	Goat River – Creston[4]	Moderate	High	High
408	RDCK Electoral Area A	Clear-Water Floods	Flood (watercourse)	Crawford Creek[5]	Moderate	High	High
422	City of Nelson	Clear-Water Floods	Flood (waterbody)	Kootenay Lake	Moderate	Very High	High
423	Village of Kaslo	Clear-Water Floods	Flood (watercourse)	Kaslo R at Kaslo[6]	Moderate	Low	Low
425	RDCK Electoral Area B	Clear-water Floods	Flood (watercourse)	Goat River	Moderate	High	High
375	RDCK Electoral Area K	Clear-water Floods	Flood (watercourse)	Burton	Moderate	High	High
376	RDCK Electoral Area I	Clear-water Floods	Flood (watercourse)	Norris Creek	Moderate	High	High
378	RDCK Electoral Area K	Clear-water Floods	Flood (watercourse)	Inonoaklin Creek	Moderate	High	High
424	RDCK Electoral Area H	Clear-water Floods	Flood (watercourse)	Bonanaza Creek	Moderate	High	High
95	RDCK Electoral Area K	Steep Creeks	Flood	Eagle Creek	High	High	High
212	RDCK Electoral Area F	Steep Creeks	Flood	Duhamel	High	High	High
242	RDCK Electoral Area E	Steep Creeks	Debris Flood	Harrop Creek	High	High	High
116	RDCK Electoral Area E	Steep Creeks	Debris Flood	Proctor Creek	Moderate	High	High
251	RDCK Electoral Area E	Steep Creeks	Debris Flood	Redfish	Moderate	High	High
252	RDCK Electoral Area F	Steep Creeks	Flood	Kokanee	Moderate	High	High
249	RDCK Electoral Area C	Steep Creeks	Flood	Corn Creek - E	High	High	High
36	RDCK Electoral Area A	Steep Creeks	Debris Flow	Kuskonook	High	High	High
192	RDCK Electoral Area K	Steep Creeks	Debris Flow	Rokos Creek	Moderate	High	High
205	RDCK Electoral Area K	Steep Creeks	Debris Flow	Unnamed Creek	Moderate	High	High
91	RDCK Electoral Area D	Steep Creeks	Debris Flow	Gar Creek	High	Moderate	High
306	RDCK Electoral Area E	Steep Creeks	Debris Flow	Heather Creek	Moderate	High	High
172	RDCK Electoral Area K	Steep Creeks	Debris Flow	Dixon Creek	High	Moderate	High
154	City of Castlegar	Steep Creeks	Flood	Norns Creek	Moderate	High	High
137	RDCK Electoral Area H	Steep Creeks	Flood	Wilson Creek[7]	Low	High	Moderate
238	RDCK Electoral Area F	Steep Creeks	Debris Flood	Sitkum	Low	High	Moderate
248	RDCK Electoral Area D	Steep Creeks	Flood	Cooper Creek[7]	Moderate	Moderate	Moderate

Notes:

(1) During the 2018 freshet, despite the Village of Salmo having historical mapping, BGC completed emergency hydraulic modelling for RDCK to provide flood depths, velocities and inundation extents for the forecasted freshet peaks to assist in emergency operations and sandbagging efforts.

(2) Slocan River includes the confluence and a portion of Little Slocan River. For study efficiencies, portions of Goose Creek (moderate priority) and the Lemon Creek fan could also be grouped together. Geomorphic changes have occurred at Little Slocan River and Lemon Creek since the original floodplain mapping and were identified as high priority areas by MWLAP personnel. At Goose Creek near the confluence with the Slocan River, Ministry personnel identified an avulsion hazard. At this site is a water supply to 60+ home settlement.

(3) Hawkins Creek at Moyie River was identified as a problematic area by Ministry of Environment personnel.

(4) Goat River (includes confluences of Russell Creek, Kitchener Creek, Arrow Creek, Okell Creek). Ministry of Environment (2009) notes that the orphan dikes "on Russel Creek at Kitchener and Hawkins Creek in Yahk are in better shape [than others in the RDCK] but still do not have diking authorities." No analysis documentation available for historical floodplain mapping. Geomorphic changes visible in imagery since the original mapping.

(5) For previous floodplain mapping, limited analysis was conducted and no digitized results. Identified as a high priority area by Ministry personnel. Ministry of Environment (2009) notes that the Crawford Creek orphan dike "is deteriorating and overgrown with vegetation putting several homes, businesses and the highway at risk of flood damages.". The dike was not considered in the priority rating.

(6) Although a Low rating, the rating does not account for dike breach which would result in a different inundation pattern and intensity than overland flooding.

(7) Wilson Creek and Cooper Creek were identified as problematic areas by Ministry of Environment personnel.

7. RECOMMENDATIONS

The following sections provide recommendations for consideration by RDCK. They may require review by different groups within RDCK, 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 7.1 to 7.6. Each section starts with an italicized, bulleted list of recommendations, followed by background and justification. Appendix J 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, 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 RDCK 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 Integration	7.4	• Review Development Permit Areas (DPAs) • 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	7.5	• In partnership with stakeholders, data providers and risk management specialists, develop a strategy for the integration and sharing of asset data and geohazard information across these functional groups. 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 hazard 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. This also limited the number of sites that could be evaluated with screening-level hydraulic modelling.	Precision and accuracy of estimated geohazard location/extents, likelihood, and intensity.	• Lidar acquisition and processing. This action has already been initiated for most prioritized areas and is expected to be completed by Spring 2019. 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	The screening-level hydraulic models did not consider river bathymetry	Precision and accuracy of estimated geohazard location/extents and intensity.	• At the screening-level of investigation, excluding bathymetry from the models is a reasonable approximation; however, for more detailed, site-specific studies, bathymetry would be required.
Stream network	Not all watercourses present within the RDCK 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 RDCK's definition of watercourse contained in the Floodplain Management Bylaw No. 2080. The stream network used in this assessment is defined according to the channel thalweg location as mapped at the time 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 water courses 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 RDCK 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[22] 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 steep creek geohazards in the RDCK based on detailed investigations.	• Precision and accuracy of estimated geohazard location/extents, likelihood, and intensity.	• Advocate for improvements to WSC gauging in the RDCK. • Advocate for dam owners to conduct hydrologic and hydraulic modeling of rivers and lakes regulated by dams and to share the results with the RDCK. Review and update the clear-water hazard area delineation and characterization following receipt of results. • 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	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

[22] 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
	available for small wildfires. However, small fires occurring in basins prone to steep creek processes can still result in elevated geohazard levels.		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. • 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 RDCK, 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.

7.2. Further Geohazards Assessments

Recommendations:

- Clear-water floods and steep creek geohazards: complete more detailed assessments for areas chosen by RDCK as top priority*, within the context of a geohazard risk management plan*.
- Reservoirs: complete more detailed reservoir flood impact assessments for regulated water bodies.
- 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 rowspan="8">**Risk Communication and Consultation**
Informing stakeholders about the risk management process</th><th>**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</th><th rowspan="8">**Monitoring and Review**
Ongoing review of risk scenarios and risk management process</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>**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>**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>**4. Risk Analysis**
a. Develop geohazard risk scenarios
b. Determine geohazard risk parameters
c. Estimate geohazard risk</td></tr>
<tr><td>**5. Risk Evaluation**
a. Compare the estimated risk against tolerance criteria
b. Prioritize risks for risk control and monitoring</td></tr>
<tr><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 RDCK 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., wild fire, resource roads).
- Consider the effect of dikes on flood inundation extents, nor the possibility of dike failures.

New mapping would include both modernizing existing flood maps and developing new flood maps; addressing the limitations of the historical floodplain mapping. Flood hazard maps recommended to be produced 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 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 proposed assessment methodology are provided in Appendix J.

7.2.4. Rationale – Reservoir Flood Impact Assessments

Reservoir flood impact assessments have similar objectives to clear-water and steep creek geohazard assessments in that they support risk management decision making but differ in approach given the regulation of lake levels. BGC recommends that such work build on the current regional study as it relates to reservoir management, focusing on the following tasks:

- Assessment of flood hazard and direct consequences to development along reservoir shorelines, for a spectrum of lake elevations, and the development of a stage-damage relationship.
- Development of a risk-based framework that would facilitate the future inclusion of additional geohazard mechanisms beyond flooding.

The outcomes of this would support next steps including:

- Optimizing reservoir levels to limit damages from flooding.
- Readily incorporating more detailed analysis of additional geohazard mechanisms within the reservoir area such as groundwater mounding, wind- and boat-generated waves, fan-delta avulsions and bank erosion during steep creek geohazard events, and landslides and their associated impulse waves.
- The future development of a bank erosion model to predict downstream impacts for design reservoir discharges.
- The future development of a forecast model for backwater effects at tributary creeks. Specifically, such a forecast model would increase understanding of hazards due to the combined effects of high reservoir levels and large storm events. The model would provide decision makers with a tool to support reservoir level management decisions.

7.2.5. Out-of-Scope Assessment Areas

This section discusses two areas RDCK may wish to consider for future assessments that were identified but not further assessed in this study.

<u>“Remnant” NSFEA</u>

The RDCK Floodplain Management Bylaw No. 2080 references “Non-Standard Flooding and Erosion Areas (NSFEA)”, which are “areas where standard floodplain setbacks and flood construction levels may not be adequate to provide the necessary level of protection against flooding, erosion and/or debris flow; including alluvial fans, debris flow fans and floodway areas subject to flooding and erosion hazards which require special flooding and erosion precautions”.

NSFEA is a term defined principally by what it is not (e.g., areas where standard flood protection measures may not be adequate), rather than what it is (e.g., it is not defined in terms of specific geohazard types or damage mechanisms). NSFEA extents were considered when defining clear-water flood or steep creek hazard prioritization areas. The results of the current study are expected to supersede the use of NSFEA polygons to define hazard extents in these areas.

However, additional NSFEA polygons exist that were not included in the scope of assessment, but where the potential for geohazards could also not be ruled out. These ”remnant areas” are shown on Cambio Communities under the “Unassessed Areas” dropdown in the layer list. However, they were not further characterized or prioritized.

BGC suggests RDCK consider these ‘remnant” areas when identifying requirements for future geohazards assessments.

Steep Creek Geohazards: Upper Basins

As noted in Section 1.5, this study assesses clear-water flood and steep creek processes within ‘settled’ urban and rural areas of the RDCK. For steep creeks, the assessment focused on fans at the outlet of steep creeks because these are the areas that are typically developed. However, improved parcels exist in the RDCK 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:

- Add real-time stream flow and precipitation monitoring functions to geohazard web applications.
- Develop criteria for hydroclimatic alert systems informing emergency response.
- Develop capacity for the automated delivery of alerts and supporting information.

Real-time precipitation and stream flow monitoring are key inputs informing flood-related emergency monitoring and response.

Environment and Climate Change Canada (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 RNT[23]. 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.

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

The WSC maintains approximately 1900 real-time stream flow gauges across Canada, of which 18 are located in the RDCK. 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.

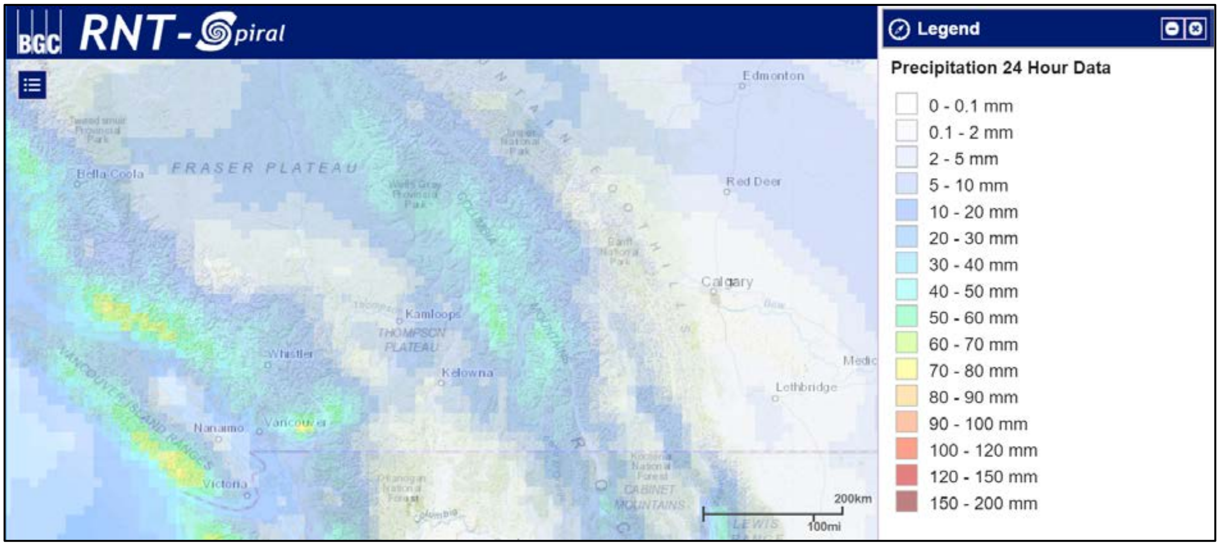


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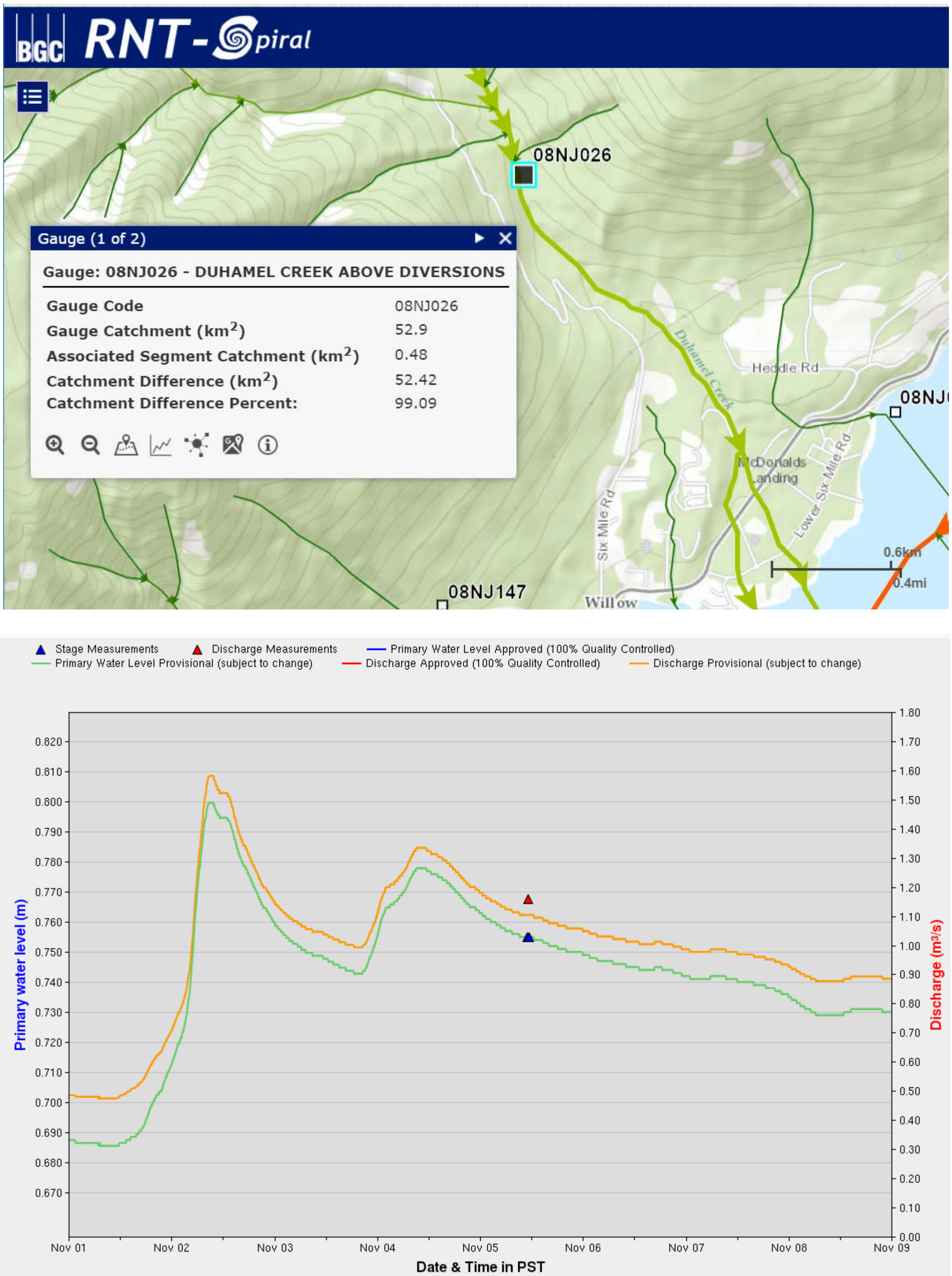
Figure 7-1. Example of 24-hour accumulated precipitation in southern British Columbia on November 3, 2018. Source: CaPA (2018, via BGC RNT™).

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 to a web application for view alongside prioritized geohazard areas.
- 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).



(A)

(B)

Figure 7-2. Example of a real-time streamflow gauge on Duhamel Creek (08NJ026). (A) Displayed on BGC's RNT™, with a direct weblink to (B) real-time hydrograph (WSC).

Completion of the first step, to view flow and regional precipitation monitoring data alongside the results of this study, could help support emergency response decision making in advance of warning systems. Because the input data are available North-America wide, initiatives triggered by RDCK could be extended province-wide with minimal additional effort, 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. Such work could be accomplished for select water courses in combination with the detailed geohazards assessments already proposed for 2019 under Stream 2 of the NDMP.

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 developing a potential hydroclimatic warning system for MoTI to assist with managing highway operations. The work was motivated by damaging debris flows that occurred in 2018 after the 2017 Elephant Hill Fire near the communities of Ashcroft, Cache Creek, and Clinton BC. The first phase of study involves development of a rainfall threshold model for post-fire debris flows and debris floods. The second phase would include methodology to incorporating the rainfall threshold model, forecasted rainfall conditions, and on-site weather stations to identify warning levels that correspond to increasing post-wildfire debris-flow and debris-flood hazards. Once developed, the resulting methods and tools would have broader application than the sites for which it is directly being developed.

7.4. Policy Integration

Recommendations:

- Review Development Permit Areas (DPAs)
- 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)

7.4.1. Policy Review

The RDCK administers policies and bylaws that rely on flood and steep creek hazard information and reference flood-related terminology. The main policy documents referencing flood hazard information include Floodplain Management Bylaw No. 2080, 2009, and land use bylaws for different electoral districts (e.g., Comprehensive Land Use Bylaw, Official Community Plan, Rural Official Community Plan). In addition, the following documents include at least minor reference to flood-related information:

- Zoning Bylaw No. 1675, 2004
- Subdivision Bylaw No. 2159, 2011
- Building Bylaw No. 2200, 2010, Consolidated up to April 12, 2012

- Soil Removal and Deposit Permit Bylaw No. 1183, 1996, consolidated to December 13, 2008
- Manufactured Home Parks Bylaw No. 1082, 1995, consolidated to March 19, 2009.

While standards-based approaches to flood risk management do exist across Canada, risk-informed approaches that target a level of risk reduction, rather than a standard flood return period, are also 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 RDCK 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. The RDCK has defined such areas where permits are required to ensure that development or land alteration is consistent with objectives outlined within applicable Official Community Plans.

BGC recommends that RDCK review the prioritized geohazard areas from the perspective of defining flood and steep creek DPAs within the District. Application of study results to define DPAs should consider geohazard mapping uncertainties and the limitations listed in Section 1.5.2.

7.5. Information Management

Recommendations:

- Review approaches to integrate and share asset data and geohazard information 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 asset data across multiple levels and sectors of government.

Because asset 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 asset 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 if it was supported provincially, which would take advantage of efficiencies of scale.

7.5.2. Requirements for Updates

The results of this study help the RDCK 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).

For example, detailed geohazards studies currently proposed for the RDCK under NDMP Stream 2, as well as a proposed reservoir impact assessment on Kootenay lake, will draw from the existing body of knowledge and results will be added to Cambio Communities on completion.

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 RDCK staff 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 RDCK 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 within RDCK, 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 J 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-density 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.

Abbott-Chapman Report (Quoted from the Report)			Comments About This Assessment	
#	**Description**	**Rationale**	**Study Results**	**Study Recommendations**
42	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.	We believe that strengthening available planning tools is essential to meeting this objective.	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.	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.
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. Section 7.1 highlights data gaps related to the identification and assessment of elements at risk located on First Nations reserves.

Abbott-Chapman Report (Quoted from the Report)			Comments About This Assessment	
#	Description	Rationale	Study Results	Study Recommendations
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.	The results of this study support conversations between and among community members and their governments based on a common understanding of flood and steep creek geohazards.	A key tenet of the current and proposed work is to complete assessments at watershed scale, with RDCK coordinating on behalf of Electoral Areas and Municipalities within the District. A key task following stakeholder engagement will be to integrate the results back into the current study as part of a growing knowledge base, particularly to incorporate traditional and local knowledge.
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 7.4recommends 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 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
TERMINOLOGY AND BYLAW OVERVIEW

A.1. INTRODUCTION

This appendix clarifies flood-related terminology and provides commentary on the use of various terms. Consistent application of flood-related terminology is essential to ensure this assessment is interpreted as intended. This assessment uses terms consistent with RDCK Floodplain Management Bylaw No. 2080, 2009, with amendments to 2015. However, technical nuances and details to some terms affect their application in policy versus geohazards assessment, or that influence the scope of work.

Section A.2 compares terms cited within the bylaw to those used in this assessment, while Section A.3 defines additional geohazard risk–related terms. An outcome of this study is to support efforts by RDCK to:

- Continue operating under existing flood-related policies and bylaws, but based on improved flood hazard information and information management tools
- Review and potentially revise flood policies and bylaws.

Therefore, Section 0, provides background on aspects of floodplain bylaws and other policies that relate to this assessment.

A.2. FLOOD – RELATED TERMINOLOGY

Definitions are provided in italics, followed by comments.

A.2.1. Watercourse

From RDCK Floodplain Management Bylaw No. 2080:

WATERCOURSE means any natural or man-made depression with well-defined banks and a bed 0.6 metres (2.0 feet) or more below the surrounding land serving to give direction to a current of water at least six months of the year and/or having a drainage area of two square kilometres (0.8 square miles) or more upstream of the point of consideration.

Comments:

- This assessment considers only those rivers mapped in Natural Resources Canada's (NRCan's) National Hydro Network (NHN) at a resolution of 1:50,000 and imported into BGC's proprietary River Network Tools (RNT™) and enhanced to ensure proper connectivity of the stream network. The RNT stream network includes select modifications based on review of satellite imagery. Unmapped / alternatively mapped, natural and human-made watercourses exist within RDCK that would fit this bylaw definition, but that were not considered in this assessment.
- Differences may exist between local stream names and those officially defined by the BC Gazeteer. BGC has been involved with assessments where conflicts arose from members of the public disagreeing with local government about watercourse naming conventions, or there were inconsistencies in naming conventions across different data sources. Moreover, stream names usually relate to a main channel and do not differentiate between smaller sub-tributaries. This can result in inconsistent channel naming conventions

between different assessment reports. BGC maintains a detailed stream network with unique identifiers assigned to individual stream segments.

- Watercourse is defined in terms of level of channel confinement (minimum 0.6 m), seasonality of flow (minimum 6 months), and minimum drainage area (2 km2). However, stream channels exist in the RDCK that are unconfined, contain flows for less than 6 months per year, or that have watershed areas less than 2 km^2, that represent a hazard but would not be defined as a watercourse. Examples include debris flow fans at the outlet of small (e.g. <2 km^2) watersheds, alluvial fans where water flow is below-grade for much of the year, and relic channels that may be active during low frequency (high return period) floods. Where such channels were included in the stream database, they were included in BGC's assessment, although they do not meet the RDCK's strict definition of a watercourse.
- The stream network used in this assessment is defined according to the channel thalweg location as mapped at the time, but existing bylaw requirements and definitions are relative to the high-water mark, which is not contained in stream network data. Channel thalwegs also change over time and the current position may be different than the mapped position.

A.2.2. Watercourse Characteristics

From RDCK Floodplain Management Bylaw No. 2080:

DESIGNATED FLOOD means a flood, which may occur in any given year, of such magnitude as to equal a flood having a 200-year recurrence interval, based on a frequency analysis of unregulated historic flood records or by regional analysis where there is inadequate stream flow data available. Where the flow of a large watercourse is controlled by a major dam, the designated flood shall be set on a site-specific basis.

FLOODPLAIN means an area that is susceptible to flooding from a watercourse, lake, or other body of water and for administrative purposes is taken to be that area submerged by the Designated Flood plus freeboard.

NATURAL GROUND ELEVATION means the undisturbed ground elevation prior to site preparation.

TOP OF BANK means the point at which the upward ground level becomes less than one (1.0) vertical to four (4.0) horizontal, and refers to the crest of the bank or bluff where the slope clearly changes into the natural upland bench; or as otherwise designated from time to time by the authority having jurisdiction.

FLOODPLAIN SETBACK means the minimum required distance from the natural boundary of a watercourse, lake or other body of water to any landfill or structural support required to elevate a floor system or pad above the flood construction level, so as to maintain a floodway and allow for potential land erosion.

From RDCK Floodplain Management Bylaw No. 2080; MWLAP (2004); BC Land Act:

> *NATURAL BOUNDARY means the visible high watermark of any lake, river, watercourse, or other body of water where the presence and action of the water are so common and usual and so long continued in all ordinary years as to mark upon the soil of the bed of the lake, river, watercourse, or other body of water a character distinct from that of the banks thereof, in respect to vegetation, as well as in respect to the nature of the soil itself. In addition, the natural boundary includes the best estimate of the edge of dormant or old side channels and marsh areas.*

Comments:

- This assessment was based on the Q_{200} (200-year return period peak discharge) or an approximated representative proxy of the Q_{200}, which is consistent with the above bylaw definition of "Designated Flood".
- In this assessment, the equivalent term for "Floodplain" (as defined above in the bylaw) is the clear-water hazard area (which is based on the designated flood). The term "Geomorphic Floodplain" is defined herein as the area overlain by fluvial deposits and is not associated with any particular flood return period. The "Active Floodplain" has a similar definition to geomorphic floodplain; however, the geomorphic floodplain may include paleofeatures, where as the active floodplain does not.
- In this assessment, BGC has not evaluated the "Natural Boundary" (as defined above in the bylaw). Within the earth sciences community, the term "bankfull" is typically defined as the water elevation associated with the 2-year (maximum annual) to 5 -year return period peak discharge. The bankfull elevation is commonly marked by a vegetation boundary.
- In this assessment, a horizontal buffer was used to identify clear-water hazard areas for small watercourses where site-specific flood modelling had not been completed. The buffer was established from the mapped stream centerline and is not equivalent to the term "Floodplain Setback" (as defined above in the bylaw).

A.2.3. Lakes and Wetlands

From RDCK Floodplain Management Bylaw No. 2080; MWLAP (2004):

> *LAKES are defined as those over 15 kilometres in length, or any pond, backwater, slough, swamp or marsh area affected by the lake.*

From RDCK Floodplain Management Bylaw No. 2080:

> *SMALL LAKES are defined as those lakes less than 15 kilometres in length and where there is no history of severe flooding or concern for shoreline erosion, and for ponds, swamps or marsh areas.*
>
> *WETLAND means land seasonally or permanently covered by water and dominated by water tolerant vegetation. Wetlands include swamps, marshes, bogs and fens but do not include lands periodically flooded for agricultural purposes."*

CONTOUR INTERVAL means a line of constant elevation that runs along the shoreline of a reservoir and is used as a reference point to measure a floodplain setback.

From Section 16 (Development Permit Areas) Development Permit Area #1: Environmentally Sensitive Development Permit (ESDP) Area:

LAKE means any area of year-round open water covering a minimum of 1.0 hectares (2.47 acres) of area and possessing a maximum depth of at least 2.0 metres. Smaller and shallower areas of open water may be considered to meet the criteria of a wetland.

Comments:

- The RDCK contains thousands of waterbodies that fit the definition of small lakes and wetlands. These waterbodies may be subject to flood hazard that was not included in this assessment.
- By the floodplain management bylaw definitions, there is no category for lakes less than 15 km in length where there is a history of severe flooding.
- There are inconsistencies between the definition of lake and wetland between land management bylaws.
- Within this assessment, "contour interval" refers to the elevation difference between mapped elevation contours

A.2.4. Alluvial Fan

From RDCK Floodplain Management Bylaw No. 2080; MWLAP (2004):

ALLUVIAL FAN means a deposit of a stream where it issues from a steep mountain valley or gorge upon a plain or at the junction of a tributary stream with the main stream. Source: RDCK Floodplain Management Bylaw No. 2080; MWLAP (2004)

Comments:

- Alluvial fans are a depositional landform that accumulates at the outlet of a steep creek. This landform is properly called a colluvial fan when formed by debris flows, and an alluvial fan when formed by clear-water floods, but for simplicity and consistency with the floodplain management bylaw, the term alluvial fan is used in this assessment irrespective of geohazard type. The term "paleofan" is used to describe portions of fans interpreted as no longer active (i.e., with negligible potential for channel avulsion and flow propagation) due to deep channel incision.
- BGC notes that geohazards on alluvial fans do not necessarily end at the boundary of the alluvial fan. For example, a debris flow or debris flood could also result in flooding that extends beyond the fan boundary. While not part of the current scope of work, it may sometimes be important to delineate hazard zones that extend beyond the alluvial fan boundary as part of more detailed study.
- It is important to recognize that alluvial fans can be formed from the deposits of different types of geohazards, such as debris flows, debris floods, and floods. Distinguishing between these process types is important because it influences the characteristics of the

fan landform, methods to assess hazard and risk, and the determination of appropriate risk reduction measures.

A.2.5. Non-Standard Flooding and Erosional Areas (NSFEA)

From RDCK Floodplain Management Bylaw No. 2080:

NON-STANDARD FLOODING AND EROSION AREAS (NSFEA) are areas where standard floodplain setbacks and flood construction levels may not be adequate to provide the necessary level of protection against flooding, erosion and/or debris flow; including alluvial fans, debris flow fans and floodway areas subject to flooding and erosion hazards which require special flooding and erosion precautions.

Comments:

- NSFEA is a catch-all term defined principally by what it is not (e.g., areas where standard flood protection measures may not be adequate), rather than what it is (e.g., it is not defined in terms of specific geohazard types or damage mechanisms). It is also defined in terms of flood protection measures, not hazard process type. Further information about NSFEAs is contained in Section A.4.1.2.
- NSFEA extents were considered when defining clear-water flood or steep creek hazard prioritization areas. However, additional NSFEA polygons also exist that were not included in the scope of assessment, but where the potential for geohazards could also not be ruled out. These ‘remnant areas” are shown on the web map but are not further characterized or prioritized.
- This report distinguishes between “steep” creeks potentially subject to debris flows or debris floods, and lower gradient channels potentially subject to clear-water floods. “Steep” is defined as channel gradients exceeding 3° (5%), where channel gradient is too great to permit unconstrained alluvial sediment accumulation. Areas potentially subject to debris floods and debris flows would fall under the NSFEA definition.

A.3. GEOHAZARD RISK TERMINOLOGY

Table A-1 provides defines terms that are commonly used in geohazard risk assessment. BGC notes that the definitions provided are commonly used, but international consensus on geohazard terminology does not fully exist. **Bolded terms** within a definition are defined in other rows of Table A-1.

Table A-1. Geohazard risk terminology

Term	Definition	Source
Acceptable Risk	A risk within a range that society accepts to secure certain net benefits. In countries governed under Napoleonic Law (e.g., the Netherlands), it is a range of risk below which no further risk reduction is required. In countries governed under the framework of British Common Law (e.g., Canada, not including Quebec), the term **tolerable risk** is preferred, and represents a starting point beyond which further risk reduction occurs according to the **ALARP** Principle.	Ale (2005); Fell, Whitt, Miner, & Flentje (2007),
Action [component of the geohazard risk management framework]	As part of the **Geohazard Risk Management Framework**, includes the implementation of chosen **risk control** options, and defining and documenting ongoing monitoring and maintenance requirements	Adapted from VanDine (2012)
Annual Exceedance Probability (P_H) (AEP)	The Annual Exceedance Probability (AEP) is the estimated **probability** that an event will occur exceeding a specified magnitude in any year. For example, a flood with a 0.5% AEP has a one in two hundred chance of being reached or exceeded in any year. AEP is increasingly replacing the use of the term **'return period'** to describe flood recurrence intervals.	Fell et al. (2005)
As Low As Reasonably Practicable (ALARP)	ALARP compares a quantum of risk against the effort (financial, time, or other sacrifice) required to reduce the risk. If it is shown that one is in gross disproportion to the other, e.g., that the effort required to reduce risk is grossly disproportionate to the additional level of risk reduction achieved, then the risk is ALARP and there should be no additional burden placed to reduce the risk.	HSE (1988)
As Low As Reasonably Practicable (ALARP) zone on F-N curve	Region of an **F-N curve**, where risk should be reduced to As Low As Reasonably Practicable (**ALARP**).	GEO (1998)
Asset Management	Strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on both engineering and economic analysis based upon quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the life cycle of the assets at minimum practicable cost.	U.S. Highways Administration (unaltered legal definition)
Broadly Acceptable zone on F-N curve	Region of an **F-N curve** where risk is considered acceptable and no further risk reduction is required.	GEO (1998)
Consequence (C)	In relation to risk analysis, the outcome or result of a **geohazard** being realised. Consequence is a product of **vulnerability** (V) and a measure of the **elements at risk** (E)	Fell et al. (2005); Fell et al. (2007), BGC

Term	Definition	Source
Consultation Zone	The Consultation Zone (CZ) includes all proposed and existing development in a geographic zone defined by the approving authority that contains the largest credible area affected by specified **geohazards**, and where damage or loss arising from one or more simultaneously occurring specific **geohazards** would be viewed as a single catastrophic loss.	Adapted from Porter et al. (2009)
Cumulative Frequency (F)	Sum of the frequencies in a **frequency** distribution. For example, the cumulative **frequency** (F) of at least N fatalities is the summed **frequency** of one *or more* fatalities, and thus describes the cumulative risk of all **geohazard risk scenarios**. The 1:100 cumulative annual **frequency** of a debris flow is the **probability** of the 1:100-year debris flow *or larger*.	BGC
Elements at Risk (E)	This term is used in two ways: a) To describe things of value (e.g., people, infrastructure, environment) that could potentially suffer damage or loss due to a **geohazard**. b) For risk analysis, as a measure of the value of the elements that could potentially suffer damage or loss (e.g., number of persons, value of infrastructure, value of loss of function, or level of environmental loss).	BGC
Encounter Probability	This term is used in two ways: a) **Probability** that an event will occur and impact an element at risk when the element at risk is present in the **geohazard** zone. It is sometimes termed **"partial risk"** b) For quantitative analyses, the **probability** of facilities or vehicles being hit at least once when exposed for a finite time period L, with events having a **return period** T at a location. In this usage, it is assumed that the events are rare, independent, and discrete, with arrival according to a statistical distribution (e.g., binomial or Bernoulli distribution or a Poisson process).	BGC
F-N Curve	**Cumulative frequency**, **F**, of all conceivable **geohazard scenarios** that each lead to N or more **consequences** (e.g., fatalities or economic loss). The data are graphed as a continuous curve against logarithmic axes for both **F** and N. This allows comparison with thresholds for **intolerable**, **ALARP**, **broadly acceptable**, and "**intense scrutiny**" levels of risk.	Adapted from GEO (1998)

Term	Definition	Source
f-N Pair	Estimate of the **frequency** of a **geohazard scenario** of a given magnitude per year, **f**, and the associated number of fatalities, N, for each identified **geohazard event** and its possible outcome. The resulting data are expressed as f-N pairs. Note the use of the lower case "**f**" to distinguish it from an **F-N pair**, which is a **cumulative frequency** calculated from f-N pairs.	Adapted from GEO (1998)
F-N Pair	**Cumulative frequency**, **F**, of all conceivable **geohazard scenarios** that each lead to N or more **consequences** (e.g., fatalities or economic loss). F-N pairs are constructed by ranking **f-N pairs** for all **geohazard scenarios** from lowest N to highest N, and accumulated into F-N pairs, where each **F** value is the sum of all f values associated with N or more fatalities. F-N pairs are used to construct an **F-N curve**.	BGC
Frequency (f)	Estimate of the number of events per time interval (e.g., a year) or in a given number of trials. Inverse of the **recurrence interval** (**return period**) of the **geohazard** per unit time. Recurring **geohazards** typically follow a **frequency**-magnitude (F-M) relationship, which describes a spectrum of possible **geohazard magnitudes** where larger (more severe) events are less likely. For example, annual **frequency** is an estimate of the number of events per year, for a given **geohazard event magnitude**. In contrast, annual **probability** of exceedance is an estimate of the **likelihood** of one or more events in a specified time interval (e.g., a year). When the expected **frequency** of an event is much lower than the interval used to measure **probability** (e.g., **frequency** much less than annual), **frequency** and **probability** take on similar numerical values and can be used interchangeably. When **frequency** approaches or exceeds 1, defining a relationship between **probability** and **frequency** is needed to convert between the two. The main document provides a longer discussion on **frequency** versus **probability**.	Adapted from Fell et al. (2005)

Term	Definition	Source
Geohazard	Geophysical process that is the source of potential harm, or that represents a situation with a potential for causing harm. Note that this definition is equivalent to Fell et al. (2005)'s definition of Danger (threat), defined as an existing or potential natural phenomenon that could lead to damage, described in terms of its geometry, mechanical and other characteristics. Fell et al. (2005)'s definition of danger or threat does not include forecasting, and they differentiate Danger from Hazard. The latter is defined as the **probability** that a particular danger (threat) occurs within a given period of time.	Adapted from CSA (1997), Fell et al. (2005).
Geohazard Analysis	Procedure to: 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.	
Geohazard Assessment	Combination of **geohazard analysis** and evaluation of results against a **hazard tolerance standard** (if existing). Geohazard assessment includes the following steps: a. **Geohazard analysis**: 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**. b. Comparison of estimated hazards with a hazard tolerance standard (if existing)	Adapted from Fell et al. (2007)
Geohazard Event	Occurrence of a **geohazard**. May also be defined in reverse as a non- occurrence of a **geohazard** (when something doesn't happen that could have happened).	Adapted from ISO (2018)
Geohazard Intensity	A set of parameters related to the destructive power of a **geohazard** (e.g. depth, velocity, discharge, impact pressure, etc.)	Adapted from BGC.
Geohazard Inventory	Recognition of existing **geohazards.** These may be identified in geospatial (GIS) format, in a list or table of attributes, and/or listed in a **risk register**.	Adapted from CSA (1997)

Term	Definition	Source
Geohazard Magnitude	Size-related characteristics of a **geohazard**. May be described quantitatively or qualitatively. Parameters may include volume, discharge, distance (e.g., displacement, encroachment, scour depth), or acceleration. In general, it is recommended to use specific terms describing various size-related characteristics rather than the general term magnitude. Snow avalanche magnitude is defined differently, in classes that define destructive potential.	Adapted from CAA (2016)
Geohazard Risk	Measure of the **probability** and severity of an adverse effect to health, property the environment, or other things of value, resulting from a geophysical process. Estimated by the product of **geohazard probability** and **consequence**.	Adapted from CSA (1997)
Geohazard Risk Analysis [component of the geohazard risk management framework]	Combination of steps to estimate the level of **geohazard risk.** Includes the **scope definition**, **geohazard analysis**, **elements at risk analysis**, and **risk estimation** components of the **geohazard risk management framework**.	Adapted from CSA (1997), Fell et al. (2005)
Geohazard Risk Assessment (GRA)	Combination of **risk analysis** and **risk evaluation**. Includes the following steps of the **geohazard risk management framework: scope definition, hazard analysis, elements at risk analysis, risk estimation, and risk evaluation**.	Adapted from Fell et al. (2007)
Geohazard Risk Control (Mitigation) [component of the geohazard risk management framework]	The implementation and enforcement of **actions** to control **geohazard risk**, and the periodic re-evaluation of the effectiveness of these **actions**. Steps of geohazard risk control include: a. Identify options to reduce risks to levels considered tolerable by the client or governing jurisdiction b. Select option(s) fulfilling risk control objectives, as well as other objectives that may have bearing on the selection process (e.g., economic cost, social, environmental and political considerations). c. Estimate **residual risk** for preferred option(s)	Fell et al. (2007)
Geohazard Risk Evaluation [component of the geohazard risk management framework]	The stage at which values and judgement enter the decision process, explicitly or implicitly, by comparing risk estimates to levels of risk tolerance. Steps of geohazard risk evaluation include: a. Compare the estimated risk against local or other acceptance or tolerance criteria b. Prioritize risks for **risk control** and monitoring	Adapted from Fell et al. (2007)

Term	Definition	Source
Geohazard Risk Identification [component of the geohazard risk management framework]	Combination of **geohazard analysis** and **elements at risk analysis**.	Adapted from VanDine (2012)
Geohazard Risk Management	Systematic application of physical measures, management policies, procedures, and practices to the tasks of analyzing, evaluating, controlling, and communicating about **geohazard risk** issues.	CSA (1997), Fell et al. (2005)
Geohazard Risk Management Framework	Steps of **geohazard risk management**, as illustrated by Table A-2.	CSA (1997); Fell et al. (2005); Fell et al. (2007); VanDine (2012); ISO (2018)
Geohazard Risk Register	Document and/or table describing the results of **geohazard risk identification** and, where completed, the input parameters and results of qualitative or quantitative **geohazard risk analysis**.	Adapted from Public Safety Canada, CSA (1997)
Geohazard Scenario	Defined sequences of events describing a **geohazard** occurrence. Geohazard scenarios characterize parameters required to estimate risk such **geohazard extent** or **runout exceedance probability,** and **intensity.** Geohazard scenarios (as opposed to **geohazard risk scenarios**) typically consider the chain of events up to the point of impact with an element at risk, but do not include the chain of events following impact (the **consequences**).	Adapted from Fell et al. (2005)
Geohazard Risk Scenario	Defined sequences of events where a **geohazard scenario** occurs and reaches the **geohazard** zone while the element at risk is present, and results in **consequences**. **Geohazard scenarios** consider both the chain of events up to the point of impact with an element at risk, and the chain of events that follows impact (e.g. the entire sequence of events for which risk is being estimated).	Adapted from Fell et al. (2005)
Geohazard Tolerance Standard	Standard for **geohazard** reduction defined by a certain **geohazard** exceedance **probability**, without consideration of **consequences**. An example is legislative requirements for 1:200-year flood protection (irrespective of the **consequences** of flood impact).	Adapted from Fell et al. (2007)
Individual Risk (Safety)	Risk of fatality or injury to a particular individual due to a **geohazard**.	Adapted from Fell et al. (2007)

Term	Definition	Source
Individual Risk to Life	The increment of risk imposed on a particular individual by the existence of a **geohazard**. This increment of risk is an addition to the background risk to life, which the person would live with on a daily basis.	Fell et al. (2005)
Intense Scrutiny zone on F-N curve	Region on an **F-N curve** defined as very high potential loss of life (>1000 persons). The risk tolerance threshold for the Intense Scrutiny Zone is vertical, implying near-zero risk tolerance for such high loss of life.	Adapted from GEO (1998)
Intolerable zone on F-N curve	Region on an **F-N curve** where risks are not considered **tolerable**.	
Likelihood	Conditional **probability** of an outcome given a set of data, assumptions and information. Also used as a qualitative description of **probability** and **frequency**.	Fell et al. (2005)
Partial Risk	Risk associated with one of several **geohazard scenarios** that must be summed to determine total risk. This term is also used synonymously with **encounter probability**, but this usage is discouraged (better to just use the term **encounter probability**, which itself has dual meanings!).	BGC
Probability	A measure of the degree of certainty. This measure has a value between zero (impossibility) and 1.0 (certainty) and must refer to a set like occurrence of an event in a certain period of time, or the outcome of a specific event. It is an estimate of the **likelihood** of the magnitude of the uncertain quantity, or the **likelihood** of the occurrence of the uncertain future event. There are two main interpretations: i) Statistical – **frequency** or fraction – The outcome of a repetitive experiment of some kind like flipping coins. It includes also the idea of population variability. Such a number is called an "objective" or relative frequentist probability because it exists in the real world and is in principle measurable by doing the experiment. ii) Subjective (or Bayesian) probability (degree of belief) – Quantified measure of belief, judgement, or confidence in the **likelihood** of an outcome, obtained by considering all available information honestly, fairly, and with a minimum of bias. Subjective probability is affected by the state of understanding of a process, judgement regarding an evaluation, or the quality and quantity of information. It may change over time as the state of knowledge changes.	Fell et al. (2005)

Term	Definition	Source
Probability of Death of an Individual (PDI)	Estimated annual **probability** of loss of life for an individual.	GEO (1998), BGC
Project Initiation [component of a geohazard risk management framework]	First phase of the **geohazard risk management framework**, including recognition of a potential **geohazard**, defining the study area and level of effort, defining project team roles, and identifying 'key' **consequences** to be considered for risk estimation.	BGC
Qualitative Geohazard Risk Analysis	**Geohazard risk analysis** based on word form, descriptive or numeric rating scales of **probability**, vulnerability and **consequences**, and that results in a non-numerical value of the risk.	Adapted from Fell et al. (2007)
Quantitative Geohazard Risk Analysis (QRA)	**Geohazard risk analysis** based on numerical values of the **probability**, **vulnerability** and **consequences**, and that results in a numerical value of the risk.	Adapted from Fell et al. (2007)
Residual Risk	The risk remaining after all **risk control** strategies have been applied.	BGC
Return Period (Recurrence Interval)	Estimated time interval between events of a similar size or **intensity**. Return period and **recurrence interval** are equivalent terms. Inverse of **frequency**.	BGC
Risk-based geohazards assessments	**Geohazard assessments** that consider more than one, but not all, parameters in the quantitative risk equation. Risk-based methods can be quantitative, semi-quantitative, or qualitative. They follow the principles of risk assessment and often provide estimates of relative risk. Risk prioritization studies are an example of risk-based assessments.	BGC
Semi-Quantitative Risk Analysis	A risk analysis based on a combination of numerical and word form, descriptive or numerical parameters. For example, many **geohazard risk** matrices combine numerical **geohazard probability** estimates with word form, descriptive or numeric rating scales to describe the magnitude of potential **consequences**.	BGC
Societal (Group) Safety Risk	Measure of the overall risk to life associated with a **geohazard event**. It accounts for the likely impact of all **geohazard events** on all individuals who may be exposed to the risk, and it reflects the number of people exposed. For **geohazard risk assessment**, group safety risk is usually represented on an **F-N curve**.	Adapted from GEO (1998)
Spatial Probability ($P_{S,H}$)	Conditional **probability** ($P_{S:H}$) that the **geohazard**, should it occur, impacts the location of the element at risk.	BGC
Temporal Probability ($P_{T,H}$)	Conditional **probability** ($P_{T:H}$) that the **element at risk** would be in the impact zone at the time of impact.	BGC

Term	Definition	Source
Tolerable Risk	A risk within a range that society accepts as tolerable to secure certain net benefits. In countries governed under the framework of British Common Law, tolerable risk is a range of risk regarded as non-negligible, and is a starting point for further risk reduction according to the **ALARP** Principle.	Fell et al. (2007), Ale (2005)
Uncertainty	Indeterminacy of possible outcomes. Two types of uncertainty are commonly defined: a) Aleatory uncertainty includes natural variability and is the result of the variability observed in known populations. It can be measured by statistical methods, and reflects uncertainties in the data resulting from factors such as random nature in space and time, small sample size, inconsistency, low representativeness (in samples), or poor data management. b) Epistemic uncertainty is model or parameter uncertainty reflecting a lack of knowledge or a subjective or internal uncertainty. It includes uncertainty regarding the veracity of a used scientific theory, or a belief about the occurrence of an event. It is subjective and may vary from one person to another.	
Vulnerability (V)	**Probability** that **elements at risk** will suffer **consequences (N)** given **geohazard** impact with a certain severity. For example, vulnerability for persons can be defined as the **likelihood** of fatality given **geohazard** impact, or **likelihood** of some level of injury. For buildings, it could be defined as the level of damage, measured as a proportion of the building replacement cost or as an absolute cost. May also be defined as the degree of loss to a given element or set of elements.	Adapted from Fell et al. (2007)

Table A-2. Risk management framework (adapted from CSA (1997); Fell et al. (2005); Fell et al. (2007), VanDine (2012); ISO (2018)).

<table>
<tr><th colspan="5">Assessment Type</th><td rowspan="8">Risk Communication and Consultation
Informing stakeholders about the risk management process</td><td rowspan="2">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="8">Monitoring and Review
Ongoing review of risk scenarios and risk management process</td></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></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 (Action)
a. Implement chosen risk control options
b. Define and document ongoing monitoring and maintenance</td></tr>
</table>

A.4. FLOODPLAIN MANAGEMENT POLICIES AND BYLAWS

The RDCK administers polices and bylaws that rely on flood hazard information and reference flood-related terminology. The main policy documents referencing flood hazard information include Floodplain Management Bylaw No. 2080, 2009, and land use bylaws for different electoral districts (e.g., Comprehensive Land Use Bylaw, Official Community Plan, Rural Official Community Plan). In addition, the following documents include at least minor reference to flood-related information:

- Zoning Bylaw No. 1675, 2004
- Subdivision Bylaw No. 2159, 2011
- Building Bylaw No. 2200, 2010, Consolidated up to April 12, 2012
- Soil Removal and Deposit Permit Bylaw No. 1183, 1996, consolidated to December 13, 2008

- Manufactured Home Parks Bylaw No. 1082, 1995, consolidated to March 19, 2009.

The Floodplain Management Bylaw is discussed in Section A.4.1, and land use bylaws are discussed in Section A.4.2. Freeboard and its inclusion in floodplain mapping and policy is discussed in Section A.4.3.

The bylaws do not appear to include dam safety considerations relating to the controlled or uncontrolled release of water from reservoirs. Any proposed changes to land use in areas that could be impacted by an uncontrolled release of water (for example a full or partial dam failure), should be reviewed alongside scenario mapping from dam owners.

A.4.1. Floodplain Management Bylaw No. 2080, 2009

The primary bylaw controlling land development is RDCK's Floodplain Management Bylaw No. 2080, 2009 (floodplain bylaw). The bylaw is standards based, not risk-based, in that requirements are based on the potential for flooding, but not the level of consequences. It applies to "all persons who construct, reconstruct, move, extend or locate a building, manufactured home or unit, modular home or structure or any part of them on land within Electoral Areas A, B, C, D, E, F, G, H, I, J and K of the Regional District of Central Kootenay designated as 'floodplain'…".

The following two areas are designated as 'floodplain':

- Land defined as Floodplain in Schedule "B"
- Land defined as "Non-Standard Flooding and Erosion Area" (NSFEA).

The schedules do not contain maps, but reference floodplain mapping maintained by the RDCK's planning department. Within areas defined as "floodplains", the floodplain bylaw addresses the following primary effects of flooding from either the presence of water or debris resulting from inundation from lakes/rivers due to natural runoff, debris flow/debris floods or waves:

- Presence water or debris, or
- Physical force of their movement through an affected area.

The bylaw scope also addresses, to varying degrees, the following secondary effects of flooding:

- Structural instability (considering hydrostatic force loads on infrastructure and foundations)
- Geotechnical instability resulting from ground failure or deformation (e.g., saturated soils, soil erosion)
- Risk transfer (i.e., not reducing flood conveyance capacity by building in the floodway)
- Flood recovery/resiliency (i.e., setbacks for shoreline erosion)
- Non-flood related ground instabilities where there are steep ravines and cliffs located adjacent to a watercourse.

The floodplain bylaw does not include dam safety considerations (e.g., it does not consider either controlled or uncontrolled release of water from reservoirs).

The following text provides additional background on designated floodplain areas according to bylaw Schedules A and B.

A.4.1.1. Floodplain Areas (Floodplain Bylaw Schedule A)

Areas defined as 'floodplain' according to Schedule A include land where proposed development could potentially be damaged by clear-water flood or wave inundation from rivers or lakes. The bylaw uses two main tools to minimize flood hazard in these areas: flood construction levels (FCLs) and floodplain setbacks. The floodplain bylaw defines these tools as follows:

> *FLOOD CONSTRUCTION LEVEL means the Designated Flood Level plus the allowance for freeboard and is used to establish the elevation of the underside of a wooden floor system or top of concrete slab for habitable buildings....*
>
> *FLOODPLAIN SETBACK means the minimum required distance from the natural boundary of a watercourse, lake or other body of water to any landfill or structural support required to elevate a floor system or pad above the flood construction level, so as to maintain a floodway and allow for potential land erosion.*

Ideally, each of these would be defined by detailed flood inundation mapping for the designated flood (which in BC is defined as the 200-year return period flood, except for the Lower Fraser River, which is the flood of record (approximately 500-year return period)). However, as detailed flood mapping has not been performed for the majority of the region, the bylaw includes a complex list of values to be used in unmapped areas. The values contained in the bylaw for unmapped areas appears to have been derived from MWLAP's 2004 document titled, "Flood Hazard Area Land Use Management Guidelines". The guidelines were developed as part of the jurisdictional transfer of responsibility for floodplain management from the Province to local governments that occurred in 2004.

The MWLAP (2004) guidelines define FCLs and floodplain setbacks in a way that gives a clue as to their intention:

> *Floodplain setbacks are established to keep development away from areas of potential erosion and avoid restricting the flow capacity of the floodway.*
>
> *Flood Construction Levels (FCLs) are used to keep living spaces and areas used for the storage of goods damageable by floodwaters above flood levels.*

As such, the purpose of FCLs is to prevent flooding of buildings, while the purpose of setbacks is less to prevent flooding of properties, but rather for secondary effects (erosion) and to avoid risk transfer to other areas (by restricting floodplain capacity).

Where specific setback values are provided in MWLAP (2004), they are one of three values: 7.5 m; 15 m; and 30 m. The smallest value (7.5 m, i.e. 25 ft) likely has its origin in the dike guidelines, while the other two correspond, perhaps coincidentally, to environmental setback requirements contained in the provincial Riparian Areas Regulation. The corresponding FCL elevation values provided in the MWLAP (2004) guidelines are 1/10th of the setback values. It is noted that the setback values are not specific to the local geomorphology or geotechnical properties of the soil.

In establishing FCLs, where historical floodplain mapping is available, it can be used to determine the design floodwater elevation (ideally the flood hazard intensity should be selected based on risk assessment rather than a designated flood return period), and a freeboard added to the predicted water level based on the intended purpose of the freeboard. A discussion on freeboard can be found in Section A.4.3.

A.4.1.2. NSFEA Areas (Floodplain Bylaw Schedule B)

NSFEAs are defined as areas where "standard floodplain setbacks and flood construction levels may not be adequate to provide the necessary level of protection against flooding, erosion and/or debris flow". NSFEA is a catch-all term defined principally by what it is not (e.g., areas where standard flood protection measures may not be adequate), rather than what it is (e.g., it is not defined in terms of specific geohazard types or damage mechanisms).

Potential damage mechanisms in NSFEAs include water damage, structural instability due to impact by water or debris, and ground instability resulting from ground failure or deformation. Note that these damage mechanisms are not exclusive to NSFEAs; for example, bank erosion can also cause ground instability in areas subject to "normal" clear-water flood processes (i.e., areas defined under bylaw Schedule A subject to standard floodplain setbacks).

The Floodplain Bylaw cites NSFEA "Non-Standard Flood and Erosion Ratings" to define bylaw requirements, which originate from a 2004 transfer of responsibility for subdivision and bylaw approval from the province to local governments[1]. As part of the transfer of responsibility, MWLAP prepared an inventory of maps and accompanying files showing areas where geohazard and flood control information had been gathered by the Ministry. Based on this compilation, which included studies at varying levels of detail, MLWAP defined areas defined as subject to "high" flood and/or debris flow hazard. The term "high hazard" was defined from a regulatory perspective as areas where recommendations for flood construction levels (FCLs) and floodplain setback distances (FPS) alone may not provide adequate protection.

Table A-3 lists the "high" hazard types from MWLAP (2004) that are cited in the floodplain bylaw. Table A-4 lists descriptions applied to these hazard types. These descriptions relate to hazard intensity (destructive potential) but do not indicate hazard likelihood. While not quantified, hazard levels implied by the descriptions have bylaw implications. Areas rated E, F, G and P require site-specific assessment by a Qualified Professional (QP). Areas rated S, 1, or 2 do not require site-specific assessment, but bylaw requirements include minimum elevations 'above natural ground' or 'above [an] obstruction that could cause ponding', where the raised foundation "shall be protected against scour and erosion from the flood flows, wave action, ice and other debris" (floodplain bylaw, Section 9.4). Note that the minimum elevations are measured from ground

[1] Flood Hazard Statutes Amendments Act (2003)

surface to the underside of the floor system or top of pad, and thus do not explicitly consider flood depth.

The classifications in Table A-3 and Table A-4 were referenced as background information, but were not directly used to prioritize the areas assessed in this study.

Given the overlap between NSFEA and the results of this assessment, BGC suggests that RDCK review the use of NSFEA in policies and bylaws in light of the information provided in this report and digital deliverables (web application).

Table A-3. Hazard types mapped as "High" hazard areas (MWLAP, 2004).

MWLAP Symbol	Description
A	Alluvial fan
AD	Alluvial and debris-flow fan
D	Debris-flow fan
F	Floodway, or meandering river reach, or braided high channel, or "high" risk of avulsion, or back channels potentially activated
O	Combination
X	Type not specified

Table A-4. Hazard descriptions for "High" hazard areas (MWLAP, 2004).

MWLAP Symbol	Hazard Description
S	Superficial flooding: local ponding or inundation by very low velocity flow possible; may include inactive low gradient alluvial/debris flow fans or stable areas on the flattest most distant edges of larger alluvial/debris flow fans.
1	Shallow flooding with low velocity flow possible: may include inactive alluvial/debris flow fans of streams with moderate slopes or the stable run-out areas of larger alluvial/debris flow fans.
2	Flooding with low velocity flows possible: may include the stable areas of alluvial/debris flow fans of small streams, small streams with moderate slopes, or the stable run-out areas of larger alluvial/debris flow fans.
F	Flooding by moderate velocity flows possible: may include the stable areas of alluvial and debris fans of moderate size streams, small streams with steeper slopes, or the stable transition zone of larger alluvial and debris flow fans.
E	Damage to habitable areas and occupants from exposure to deep water, high velocity flows, and/or debris impact possible: may include areas exposed to hazards associated with deep inundation, debris flow, channel avulsion (on alluvial/debris flow fans and/or in river floodplain areas), tsunami, coastal storm surges, bluffs or rapid and extensive bank or shoreline erosion.
G	Used to identify areas suspected to have hazards similar to those described for hazard description 'E'. In most instances, detailed site inspections were not undertaken to assess and confirm the hazard or to accurately define area boundaries. Boundaries for these geological features were determined by interpretation of aerial photography or some other general means.

MWLAP Symbol	Hazard Description
P	Used to identify areas with hazards similar to those described for hazard ‘E’ areas. In these areas MWLAP staff had undertaken site inspections and/or a suitably qualified professional had completed an assessment to identify the hazard; however, the boundaries of the hazard area were not accurately determined.

A.4.2. Land Use Management Bylaws

Outside of the Floodplain Management Bylaw, each electoral district has some form of land use bylaw (Comprehensive Land Use Bylaw, Official Community Plan, Rural Official Community Plan) that describes community values, objectives, and requirements that overlap to some degree with the Floodplain Management Bylaw.

These plans typically include objectives to protect environmentally sensitive lands (including those where geohazards exist[2]) and to limit the use of land that is subject to hazards. Some of the bylaws define environmentally sensitive areas and areas designated as Environmental Reserves based on setback values from specific watercourses and waterbodies. The watercourses and waterbodies identified in the land use bylaws may or may not be specifically identified in the Floodplain Management Bylaw.

Some land use bylaws identify specific geohazard areas. For example, Electoral Area G Rural Land Use Bylaw No. 1335 (1998) identifies the following hazard lands:

> *“77. The watershed upstream of the alluvial fans of Hall Creek, Barrett Creek, Ymir Creek, Hidden Creek, Porcupine Creek and Rumbling Creek, are sensitive to future change caused by extreme meteorological events, logging or wild fire. The extent and severity of the flood hazard on the alluvial fans of these creeks could be modified by such changes upstream. The watersheds of these creeks are therefore identified as Sensitive / Hazardous (S/H) on Map 1 of Schedule ‘B’.*
>
> *78. The alluvial fans of Hall Creek, Barrett Creek, Ymir Creek, Hidden Creek, Porcupine Creek, Rumbling Creek are subject to significant flood hazards and are subject to any applicable floodplain management bylaw currently in effect.”*

Some land use bylaws identify flood protection requirements. For example, Section 12 (Hazard Lands and Fire Management) of Electoral Area ‘A’ Comprehensive Land Use Bylaw No. 2315, 2013, consolidated to May 2017:

> *“8. [The Regional Board] Requires that the construction and siting of buildings and structures to be used for habitation, business, industry, or the storage of goods damageable by flood waters to be flood proofed to geotechnical standards and certified by a registered professional*

[2] For example: Electoral Area ‘A’ Comprehensive Land Use Bylaw No. 2315, 2013, consolidated to May 2017 Section 10: “3. To protect environmentally sensitive lands such as steep slopes, floodplains, alluvial fans, watersheds and soils subject to erosion from land uses.”; and “7. To limit the use of land that is subject to hazardous conditions or that are environmentally sensitive to development. Sensitive and hazardous areas are lands that are located in alluvial fans or floodplain on Kootenay Lake.”

where land that may be prone to flooding is required for development and no alternative is available."

Therefore:

- Redundancy or conflict may exist between land use bylaws and the Floodplain Management Bylaw
- There is overlap between development/land use restrictions for geohazard areas and environmentally sensitive areas, which has not been addressed in this report but should be considered by RDCK when reviewing development permit applications.

A.4.3. Freeboard

A.4.3.1. Background

Freeboard in BC is commonly applied as defined in the BC Dike Design and Construction manual: a fixed amount of 0.6 m (2 feet) for mean flows or 0.3 m (1 foot) for instantaneous flows.

BGC and Ebbwater examined the application of freeboard on the Lower Fraser River for MFLNRO (2017). The 0.6 m may have had its origins in the late 1940s when the Fraser Valley Dyking Board developed a dike design standard to quickly build dikes and restore public faith in government in the aftermath of the 1948 floods on the Fraser River (and elsewhere in the province). In their own words, the Dyking Board described this design as **based only on judgment and experience [which] had to replace the usual tedious surveys and calculations**. There was an implied expectation that this design standard would be reviewed in the near future, and in fact that an overall flood management program for the river, to include more than structural dikes, would be developed.

The 0.6 m freeboard developed in the immediate aftermath of the 1948 flood and has become the de facto standard today. It was determined:

- On the basis of rule-of-thumb: The Board did not have the time or resources to consider and develop an engineering or scientific basis for freeboard
- At a time when the population and infrastructure assets and economic activity in the floodplain was substantially lower than it is today
- At a time when scientific understanding of flood mechanisms and processes were less developed than today.

Today, the 0.6 m freeboard is supposed to account for uncertainties in the flood profile, however:

- These uncertainties have not been identified nor quantified, and it is unknown if 0.6 m is a reasonable approximation or if it is too low or too high.
- It is commonly applied assuming it accounts for all uncertainties in addition to select physical effects that impact water levels
- It is applied without quantifying the potential for flood losses and the implicit assumption that potential flood losses are the same everywhere along Fraser River.

There is no consistent definition, either within Canada or around the world, for freeboard. Further, the variables accounted for within freeboard are extremely diverse. Overall, freeboard is used to account for two distinct factors:

1. Uncertainties in the calculation of a base flood elevation.
2. To compensate for quantifiable physical effects (e.g., local wave conditions or dike settlement).

Both factors can vary spatially and temporally.

A.4.3.2. Freeboard and Floodplain Mapping in the RDCK

For areas of the RDCK where historical floodplain mapping exists, a floodplain has been delineated for the designated flood (i.e. 200-year return period) and includes inundation extents, and for most cases, 1-meter flood elevation contours have also been provided. Both the extents and the elevations include a freeboard; however, the amount of freeboard assumed varies and is not stated on the maps themselves, but in the accompanying reports. Some maps do not have reports, and those that do, contain varying types of information and levels of detail.

RDCK's Floodplain Management Bylaw defines the Flood Construction Level as the designated flood level plus the allowance for freeboard. The designated flood level is to be obtained from the historical floodplain maps, where available, which already includes a freeboard. As the maps do not indicate what factors or considerations (see Section A.4.3.1) are accounted for in the freeboard value included in the designated flood level, applying an additional freeboard on top of the designated flood level could be double-counting some factors, while neglecting others.

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APPENDIX B
CAMBIO COMMUNITIES

B.1. INTRODUCTION

B.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?

These questions are addressed by bringing together three major components of the application:

Hazard information:

- Type, spatial extent, and characteristics of geohazard areas, presented on a web map.
- Supporting information such as hydrologic information, geohazard mapping, and imagery.

Exposure information:

- Type, location, and characteristics of community assets, including elements at risk and risk management infrastructure.

Assessment tools and matrices:

- 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.

B.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:

1. Local/Regional Government users: Access to a single study area of interest (e.g. administrative or watershed area of interest for the user).
2. 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.

B.2. NAVIGATION

Figure B.2-1 provides a screen shot of Cambio Communities following user login and acceptance of terms and conditions. Section B.3 describes map controls and tools, including how to turn layers on and off for viewing. Section B.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 B.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.

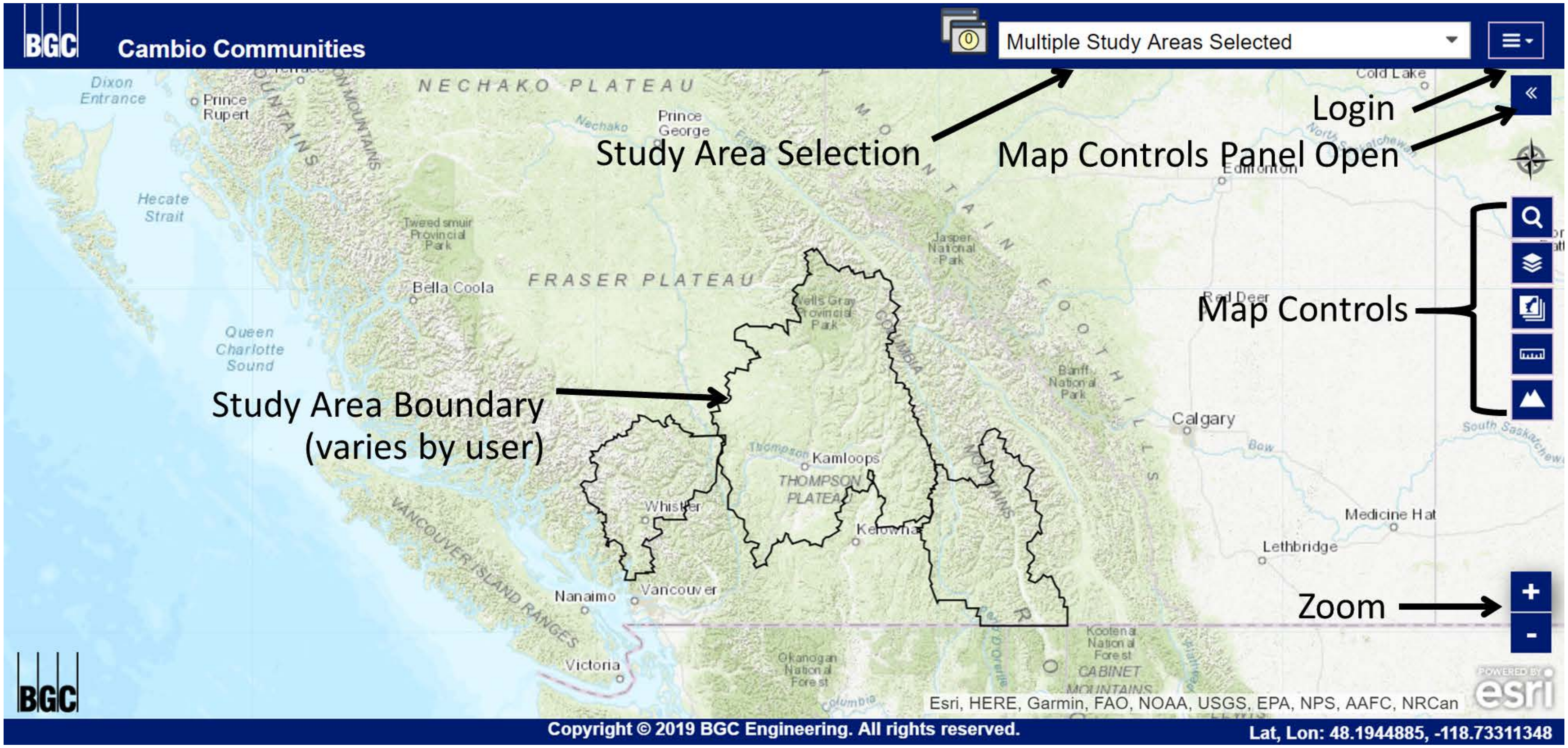

Figure B.2-1. Online map overview.

B.3. MAP CONTROLS

Figure B.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 B.3-1, Figure B.3-2). Sections B.3.1 to B.3.5 describe the tools in more detail.

Figure B.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 B.3-2. Example of the top of the Layer List window, with the control icons defined.

B.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.

B.3.2. Layer List

This control (Figure B.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.

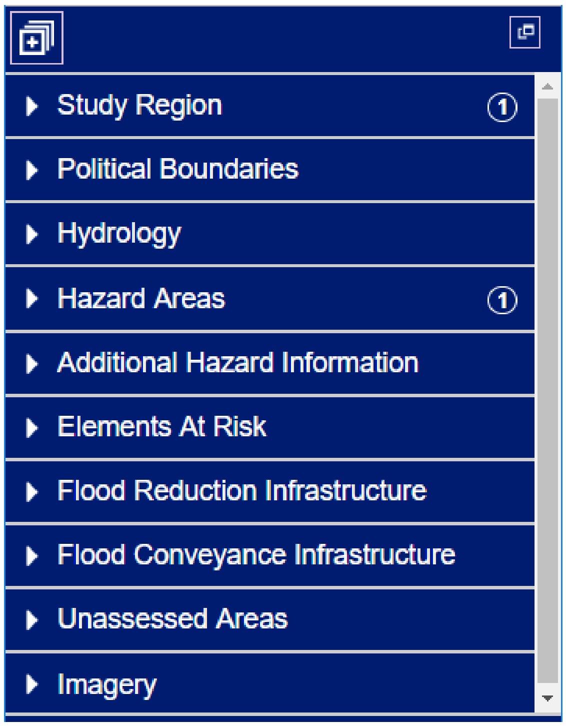

Figure B.3-3. Layers list.

B.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 layer.

B.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 might 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.

B.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 examine a floodplain cross-section 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. Note that 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.

B.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).

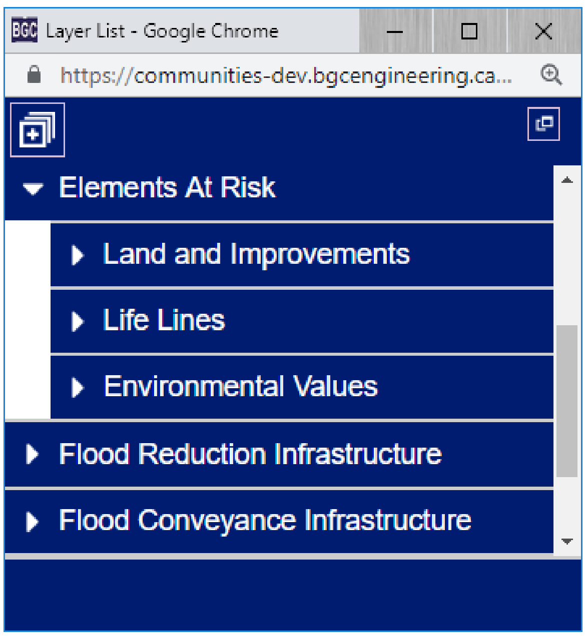

Figure B.4-1. Elements at risk, flood reduction and flood conveyance layers.

B.5. GEOHAZARD INFORMATION

This section summarizes how users can display and access information about geohazard features displayed on the map.

B.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 B.4-1). 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 "ⓘ" opens a sidebar with detailed information about the individual feature, as described in Section B.5.2.

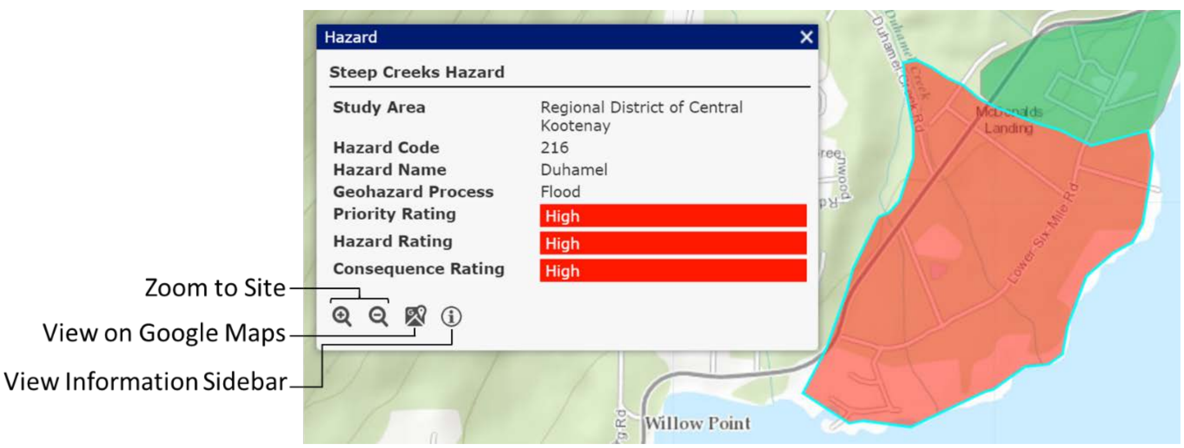

Figure B.5-1. Geohazard feature popup.

B.5.2. Geohazard Information Sidebars

Clicking a geohazard feature and then the "ⓘ" within the popup opens additional information in a sidebar on the left side of the screen (Figure B.4-3). Dropdown menus allow the user to view as much detail as required.

[2] Landslide-dam hazard information is provided for the Thompson River Watershed only.

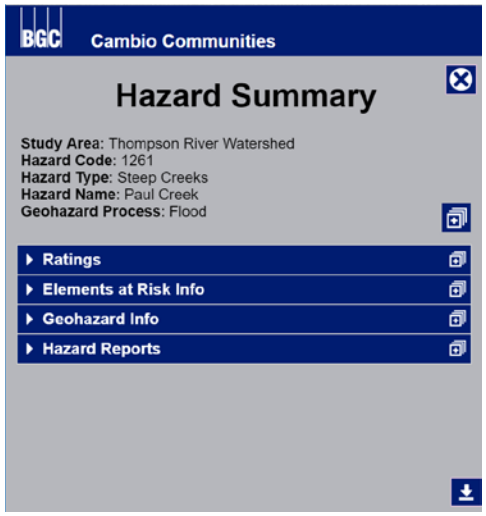

Figure B.5-2. Additional information sidebar.

Table B-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 B-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).

B.6. ADDITIONAL GEOHAZARD INFORMATION

B.6.1. Additional Geohazard Layers

Figure B.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.

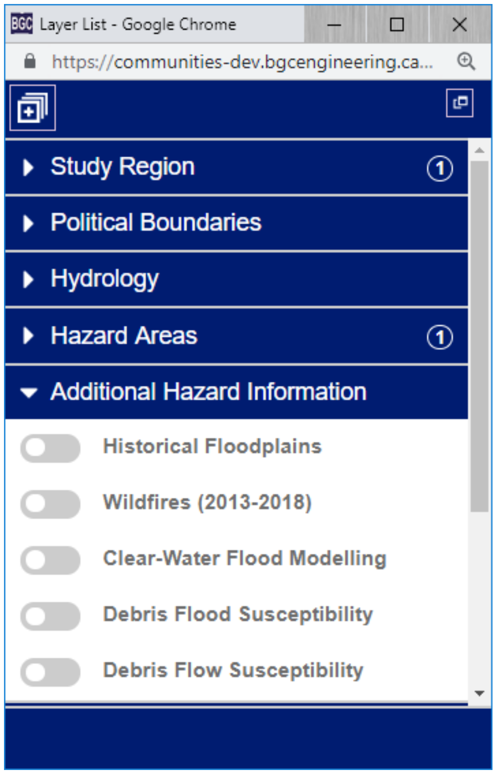

Figure B.6-1. Layers currently available under Additional Geohazard Information.

B.6.2. Imagery

The imagery dropdown provides access to high resolution imagery where available (i.e. Lidar hillshade topography).

B.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 B.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.

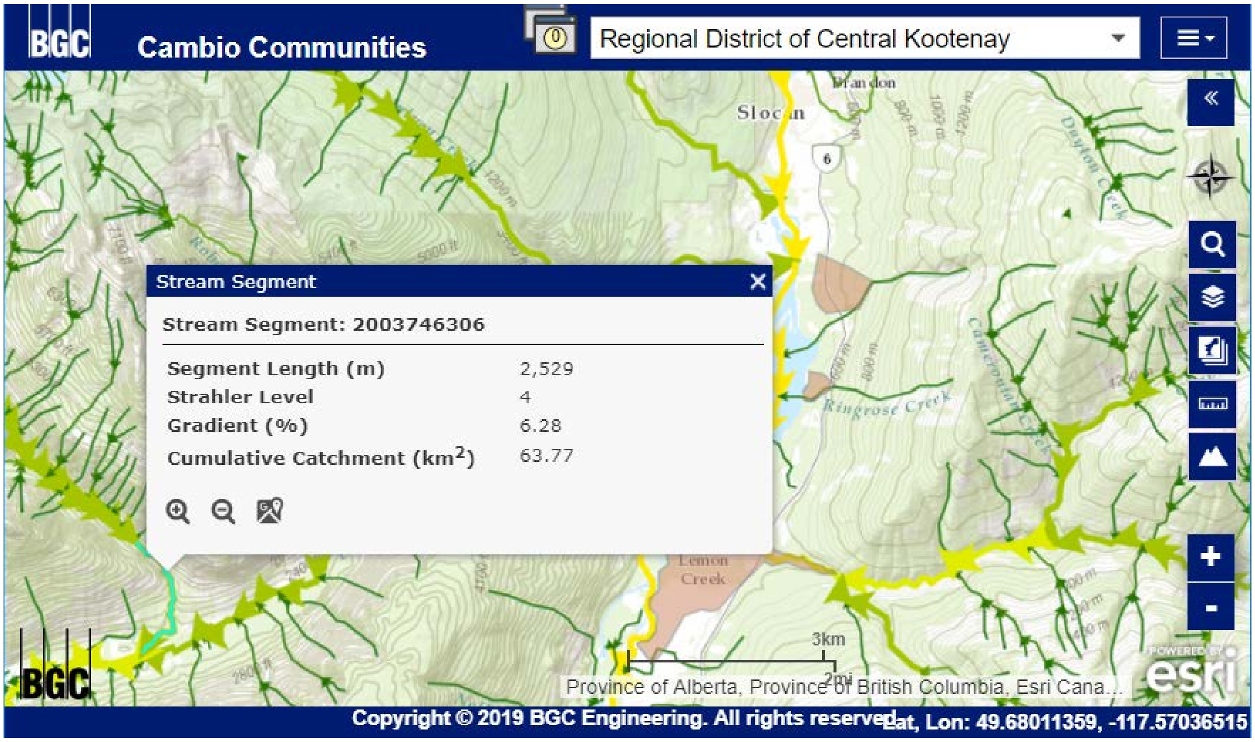

Figure B.6-2. Interactive Stream Network. The popup shows information for the stream segment highlighted in green.

B.7. UNASSESSED AREAS

"Unassessed Areas" in the layer list contains layers not assessed under the current scope of work, but that were flagged as areas of consideration for future assessment. Included are the following layers, which are noted in the Recommendations Section of the main document.

- Unassessed Non-Standard Flood and Erosion Areas (NSFEA)
- Improved Unassessed Steep Creek Parcels.

B.8. 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)
- Inclusion of other types of geohazards (i.e., landslides and snow avalanches).

[3] i.e., information-refresh each time flow monitoring data is updated and provided by third parties.

BGC welcomes feedback on Cambio Communities. Please do not hesitate to contact the undersigned of this report with comments or questions.

APPENDIX C
EVENT HISTORY

Table C-1. Geohazard event history summary for the RDCK.

Year	Month	Type of hazard	Location	Source	Report (if applicable)	Description of Event
1808	June	Flood	Kootenay Lake area	Nisbet (1994)	Septer (2007)	David Thompson found his campsite under water and found that his route south was flooded, which included the Kootenay River. The Columbia River was still flooded in mid-June.
1867	May-June	Flood	Pend O'reille River		Septer (2007)	According to a local First Nations resident, the Pend 'Oreille River reached some 9 m above the high-water mark of the 1894 flood. BGC notes that this flood elevation is potentially exaggerated.
1894	June 3,4,5	Flood	Kootenay Lake	Affleck (1994)	Septer (2007)	Kootenay lake rose to unprecedented heights, causing waters to surge backwards into the Kootenay Flats. High water interfered with mining operations in all sections of the southern Kootenay. The Nelson Hydraulic Company was unable to begin sluicing.
		Thunderstorm	Balfour		Septer (2007)	Water was up to the 2nd story of the hotel and in some parts the water was 2 m deep in the streets.
		Flooding/ Tornado	Kaslo/Kootenay Lake/Nelson		Septer (2007)	Kootenay Lake had risen more than 8 m above the low water mark, causing every business and house to be inundated. The water had been rising an inch an hour when a cloudburst struck, causing a tornado. Much of Kaslo was damaged by the storm. The same storm passed through Nelson.
		Flood	Five-Mile		Septer (2007)	3 men drowned due to possible log jam breach on a tributary to Trout Lake
		Flood	Revelstoke to Nelson		Septer (2007)	The Columbia River was higher than ever before, flooding ranch buildings from Revelstoke to Nakusp. Bank erosion of up to 6 m was noted near Revelstoke.
		Flood	Salmo		Nellestijn & Ells (2008)	Record snow accumulation of more than 6 m caused significant flooding during the freshet.
		Debris flow	Nelson		Septer (2007)	Debris flows caused the railway and freight sheds at Nelson to be shut off. They could only be reached by boat during the closure.
1900	March 9-11	Landslide	Kaslo area		Septer (2007)	A landslide at Sandon demolished 6 homes. An unpublished data source indicated the rockslides caused 4 deaths.
1913	January 17	Avalanche	Slocan Valley		Septer (2007)	Man killed in fatal avalanche as he was hiding in a "shelter shack"
1916	March 26	Debris flow	Creston		Septer (2007)	Steady rain caused a debris flow 12.8 km east of Creston. This halted transportation in the region for 24 hours.
	June 18	Flood	Central Kootenay, Lemon Creek		Septer (2007)	A large area was flooded in the south of Central Kootenay. The Nelson-Slocan Lake line was washed out and the Slocan-Kaslo line had numerous washouts.
	June 20-21	Flood	Nelson		Septer (2007)	At Nelson the water rose more than 0.5 m in 24 hours. Flooded streams took out bridges and other structures.
1920s	Unknown	Debris flow	Hamill Creek		Klohn-Crippen (February 29, 1996)	In the 1920s, an avalanche/debris flow in Hamill Creek caused the creek to change its course from flowing into Kootenay Lake to its present discharge into Duncan River.
1933	June 13-16	Flood	Kootenay Area, Nelson		Septer (2007)	Unprecedented heat wave caused rapid snowmelt in the mountains resulting in widespread flooding. Communications in Nelson and south of Nelson were cut off.
			Salmo		Septer (2007)	Sheep Creek near Salmo was running high.
			Upper Arrows Lake		Septer (2007)	The lake rose at a rate of 2.5 cm an hour.
			Slocan		Septer (2007)	The Slocan River was "at its highest in years" and had flooded the highway in many places
	December 17-30	"Slide"	Kootenay Lake		Septer (2007)	A "slide" took out 5 communication poles (BGC notes that a "slide" may indicate an avalanche or a landslide).
		Avalanche	Blake, 48 km E of Nelson		Septer (2007)	An avalanche blocked CPR's Kootenay Division. The blockage was approximately 300 m long and 15-22.5 m wide.
		"Slide"			Septer (2007)	Numerous other "slides" occurred within this time period, cutting off Slocan and washing out the rail line west of Nelson at Jerome (BGC notes that a "slide" may indicate an avalanche or a landslide).
1934	April	Flood	New Denver		Septer (2007)	Early spring flooding occurred.
		Debris flow	Three Forks		Septer (2007)	A debris flow near Three Forks swept away 3 rail bridges and a highway bridge and washed out approximately 3.2 km of the road.

Year	Month	Type of hazard	Location	Source	Report (if applicable)	Description of Event
1938	May 31	Flood/dyke breach	Creston		Septer (2007)	Floodwaters burst through the dykes at the south end of Creston reclamation district. More than 3,000 acres of wheat fields were flooded.
	June 3	Dyke breach	Creston		Septer (2007)	On June 3, another dyke gave way, flooding an additional 1,700 ha.
	June 7	Dyke breach	Creston		Septer (2007)	The dyke along Kootenay Lake at the north end of Creston Dyking area broke, flooding another 3,000 ha.
	Unknown	Debris flow	Cooper Creek		Klohn-Crippen (February 29, 1996)	Debris and sediment from Cooper Creek blocked the Duncan River for a short time.
1943	March 28-April 3	Debris flow	Nelson-Kaslo Area		Septer (2007)	Public work crews cleared two debris flows from the highway. CN railway crews had to blast a huge boulder off the track to Nelson.
1948	May 17-18	Debris flow	Revelstoke district		Septer (2007)	Rain in the Revelstoke district brought down debris flows and caused a derailment at Twin Butte. Just as the railway was cleared after the initial slides, more mud came down.
	May 25	Flood	Kaslo		Septer (2007)	Kootenay Lake rose to more than 8 m above the low water level and destroyed more than 70 dwellings and businesses in Kaslo.
	June 8	Flood	Creston		Septer (2007)	The dykes broke at Creston, inundating 6,500 ha of land.
	June 9	Flood	Northeastern RDCK		Septer (2007)	The Columbia and Kootenay rivers reached record levels. On June 9, the Columbia River at Revelstoke reached a maximum discharge of more than 5,000 m^3/s.
	June 11	Flood			Septer (2007)	Torrential rains caused the Columbia River to rise 0.3 m in 24 hrs.
		Flood	Salmo		Nellestijn & Ells (2008)	Flooding caused extensive damage along the Columbia River from Trail to Oregon. The flooding was presumed to have caused damage to channel morphology and hydrology of the Salmo River Watershed.
1954	May	Flood	Nelson, Cottonwood Creek	BC Archives		Cottonwood Creek threatened homes and caused erosion of back yards along the creek. A temporary shear dyke was constructed to protect homes. The creek avulsed from its course and flowed across a road off the main highway.
1955	March	Flood	Sandon, Carpenter Creek	Sandon Museum (2011)		Heavy rains on a melting snowpack caused high flows that destroyed the undersized flume through Sandon. As the flume broke up it caused blockages which washed out adjacent building foundations, roadways and railways. The flooding and washouts caused most residents to abandon the already declining town and CPR never repaired the railway line between New Denver and Sandon.
1956	June	Flood	Cottonwood Creek, Procter Creek.	BC Archives		Heavy rains followed three weeks of unseasonably warm weather. A severe thunderstorm and heavy rain caused Cottonwood Creek to flood the CPR tracks and yard. Procter Creek experienced a flash flood late May and in June, and washed away a portion of the CPR lines in Procter.
		Flood	Kootenay Lake	BC Archives		Kootenay Lake levels rose above the previously historic 1948 flood levels.
1968	June	Flood/Debris flood	Nelson	BC Archives		Six-Mile Creek flooded in Nelson and avulsed over onto properties, depositing mud and “slime”. The A.I. Collinson School in Nelson was closed when floods damaged the water main supply. Flooding at Coffee Creek and Enterprise Creek caused traffic to travel single lane across the bridges.
1972	May	Flood	Duhamel Creek, Procter.	BC Archives		Duhamel Creek washed out the Six-Mile bridge. The Harrop Bridge was closed to traffic near Procter.
	June	Flood	Salmo	BC Archives		Flooding occurred due to above average snow pack. The Salmo River recorded its second highest daily maximum flow at 351 m^3/s.
1980	April – May	Flood/ Debris flow	Garrity Creek, Cedar Creek, Anderson Creek, Cottonwood Creek	BC Archives		A blocked culvert caused a rock and debris flow to occur in Garrity Creek (Beasley) that damaged a property and washed out the CPR line. Cedar Creek in Winlaw washed out Highway 6. Highway crews fixed a washout on Deer Creek, along the Sproule Creek Road. Anderson Creek in Nelson blocked its lower culvert, causing the creek to back up and run down 8th Street and Elwyn Street. Cottonwood Creek flooded and threatened homes along its banks.
1990	November 25	Flood	Riondel	BC Archives		Road washouts caused by flooding at Cornbeef Creek. Floodwaters were as deep as 7.5 m.

Year	Month	Type of hazard	Location	Source	Report (if applicable)	Description of Event
	May 5	Debris Flow	Cory Creek	FLNRO	VanDine (June 1990)	High rainfall with snowmelt caused a debris flow that deposited across Highway 6 and hit a house.
		Debris Flow	Van Tuyl Creek			High rainfall with snowmelt caused a debris flow that deposited across Highway 6.
1995	January 20	Rockfall	Mile 111 (near Procter)	BC Archives	Transportation Safety Board of Canada (1995)	Rockfall caused a train derailment and subsequent loss of life as a train went into Kootenay Lake
	March 8-11	Flood	Castlegar, Schofield Creek, Merry Creek		Urban Systems (2000)	The CPR railway and Highway 22 were washed out by Schofield Creek after three days of rain falling on snow. Merry Creek overflowed its banks and flowed across Columbia Avenue, the Safeway parking lot, and CPR tracks.
1996	June 11	Debris Flow	Porcupine Creek	MoE	MoE (June 28, 1996)	A landslide from a tributary stream slid into Porcupine Creek and became a debris flow, depositing debris down to the fan.
1997	March 24	Flood/Debris flow	Creston	Timothy Friesen		2 days of heavy rain melted an above average snowpack on (Goat) Arrow Mountain in the Creston Valley area, causing roads to be washed out and several debris flows. One home was impacted by a debris flow.
	June	Flood	Kitchener, Russell Creek		Septer (2007)	On May 31 and June 1, heavy rain and snow melt caused flooding on Russell Creek. The creek jumped its bank downstream of the Kitchener Improvement District intake. Water and debris flowed overland hitting the deflection berm causing erosion to the setback dyke. The high water also caused erosion to several sections of bank works on the outside bends of the creek.
1999	May	Flood, debris flood	Yakh, Moyie River, Hawkins Creek		Septer (2007)	Hot weather over the May long weekend caused a quick rise of rivers and streams in the East Kootenays. The Moyie River flooded three campsites in the provincial campground near Yakh. Around May 24-25, Hawkins Creek broke loose, sending a torrent of logs, mud and debris into Moyie River, which also threatened the Yakh townsite.
	November 11 and 12	Flood/Avulsion	Mobbs Creek	MoE, FLNRO	MoE & FLNRO (2000)	High intensity rainfall (estimated at 1 in 80-year return period) caused a rapid breach of a snow avalanche dam. This caused Mobbs Creek to avulse.
		Flood	Woodbury Creek			High intensity rainfall (estimated at 1 in 80-year return period) caused channel aggradation and flooding on the fan.
		Debris Flood	Coffee Creek	FLNRO	FLNRO (2000)	Extreme rainfall on snow triggered landslides in the Coffee Creek watershed and a debris flood event, which flooded the fan and reached Kootenay Lake.
2004	Unknown	Flood	Castlegar		Urban Systems (2000)	Rain-on-frozen ground combined with a debris-clogged culvert caused runoff to flow from Trowelex Road over an embankment and across Highway 22.
	August 10	Debris flow	Kuskanook	FLNRO	Jordan & Turner (2008)	In 2003 a fire burned 49 km^2 of land near Kuskanook. In 2004, a rainstorm caused the initiation of 2 debris flows down Kuskanook Creek that destroyed 2 homes and damaged others. Highway 3A was closed in 2 locations as a result of the debris flow.
2006	May	Flood	RDCK	Environment Canada (2006)		Rapid snowmelt caused officials to issue a flood watch for most of the southern Interior, including the Kootenay region.
2011	May to June	Flood	RDCK	Ministry of Forests, Lands, and Natural Resource Operations		Delayed snowmelt led to snow packs being approximately 150 to 400% of normal in the Kootenay region (when compared to previous years). Due to this delayed snowmelt, there was an increased risk of flood conditions.
2012	March 29	Rockslide	Atbara		Nesteroff, (2012)	A rock slide approximately 6 km east of Atbara struck a work train. The train was dislodged and slid down the bank and into the lake.
	June	Debris Flow	Kaslo, Kemp Creek	Kaslo & Area D Emergency Preparedness	"Rise in" (2012)	Kemp Creek above Kaslo had a debris flow after excessive amounts of rain.
		Flood	Creston, Kootenay Lake		"Rise in" (2012)	High water levels caused by record precipitation in June on Kootenay River and Kootenay Lake caused flooding. Water control measures were used to equalize the pressure on the dykes.

Year	Month	Type of hazard	Location	Source	Report (if applicable)	Description of Event
	July 12	Landslide	Johnsons Landing	Kaslo & Area D Emergency Preparedness	FLNRO (2013, April 26)	The Johnsons Landing landslide occurred in the late morning of July 12, 2012. Its approximate volume was 300,000 m^3 and deposited over an approximately 10 ha area. The initial event, which comprised most of the volume, was a rapid debris avalanche which descended the channel of Gar Creek, a steep narrow valley. The avalanche rode up over a low ridge at a sharp bend in the creek channel and spread out over a terrace which was occupied by forest, cultivated land and houses. Three houses in this ridge area were destroyed, two of which were occupied at the time, and two other houses were damaged. There were four fatalities. A small part of the debris was saturated with water, and it continued flowing down the narrow creek channel as a debris flow, destroying the public road crossing and damaging a house on the fan. About 24 hours later, a second debris flow occurred. This event was formed from loose landslide debris in the channel which had been deposited in the creek and became sufficiently saturated and began to flow. This debris flow was larger than the previous debris flow and covered most of the fan and destroyed one of the previously compromised houses.
2013	May 23	Flood	Salmo and Slocan Rivers	Kaslo & Area D Emergency Preparedness		Salmo and Slocan Rivers and Duhamel Creek flowed at higher than normal levels and reached a 5-year peak.
	June	Flood	RDCK			Stream flow advisories were issued across much of the Kootenays.
	June 20	Flood	Hamill Creek		"Kootenay homes" (2013)	Homes north of Argenta flooded because of high flows on Hamill Creek. One home was completely washed away while another had severe foundation erosion. A bridge leading to five homes was washed out at both approaches and power lines adjacent to the creek were out.
		Debris Flood	Fletcher Creek	FLNRO	FLNRO (2013)	High stream flows caused bank sediment to be entrained. Debris was deposited at a point of low gradient and a low bank. Part of the creek avulsed and deposited sediment along a roadway. A home was flooded, and a small access bridge was also affected.
		Debris flow/ Flood/	Kaslo, New Denver, Sandon, Campbell Creek, Crawford Creek, Silverton Creek, Schroeder Creek		"Kootenay homes" (2013), "Highway north" (2013)	Heavy rain in the West Kootenay's affected many creeks. Debris flows around Kaslo on Highway 31A closed sections of the highway. Schroeder Creek overtopped its banks and flooded part of Highway 31A as well. A berm at Crawford Creek on the East Shore of Kootenay Lake was affected. A dyke on Silverton Creek in the Slocan Valley partially failed. It was addressed with rip-rap and equipment. A landslide occurred at Campbell Creek near Kaslo but there was no damage to cabins in the area. A section of the Mirror Lake water system was hit by debris. Sandon has experienced some flooding, affecting the access road to the townsite.
2015	February	Flood	Slocan Valley and Shoreacres-Goose Creek Road		RDCK (2015)	Flooding closed Slocan Valley Road and Shoreacres-Goose Creek Road. Homes in the area were also on evacuation alert.
	February 9	Mud Flow	Slocan Park	RDCK	Boyer (2015)	High rainfall caused a hydro line access road to fail and become a debris flow. The flow was channelized through a gully and spread over the property at 3032 Upper Slocan Park Road and entered the basement of the house. A post event investigation revealed that a culvert had blocked during the heavy rainfall re-directing flow to the road section that had failed.
2017	January	Flood	Creston/Goat River		"Excavator to remove" (2017)	Localized flooding occurred in Creston, BC due to an ice jam. Excavators were brought in to remove the ice jam.
	May 30	Flood	Slocan		"RDCK extends" (2017)	The rising flows of the Slocan River caused the regional district to issue an Evacuation Alert.
2018	April 18	Debris flow	Brilliant Dam		Kline (April 18, 2018)	A debris flow closed Highway 3A just north of the Brilliant Dam.
	April 25	Debris flow	Enterprise Creek		YRB Kootenay Ltd (April 25, 2018)	A debris flow occurred at Enterprise Creek north of Slocan that blocked Highway 6.
	April 29	Debris flow	6-Mile		RDCK (2018)	Sixteen homes in the 6 Mile area were under evacuation alert after a debris flow occurred off the "Middle Road" near Heddle Road.
	May 1	Washout	Nakusp		YRB Kootenay Ltd (May 1, 2018)	Highway 23 north of Nakusp was washed out.

Year	Month	Type of hazard	Location	Source	Report (if applicable)	Description of Event
	May	Flood	Salmo, Ymir		“Evacuation alert” (2018)	Flooding threats on the Salmo River, Erie Creek, Little Slocan River, Slocan River, caused the RDCK to issue evacuation alerts to residences along waterways.
	May 9	Flood	Needles		W Kootenay District (May 9, 2018).	Flooding approximately 33 km west of Needles undermined Highway 6 and caused the road to be closed.
	May 18	Landslide	Kootenay Pass		Smart (May 21, 2018)	A landslide near the Kootenay Pass swept a car off Highway 3 and down an embankment.

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APPENDIX D
EXPOSURE ASSESSMENT

D.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 D-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 D.2 to D.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 D-1 was compiled in collaboration with RDCK for risk prioritization purposes and is not 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).

Table D-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
		10-100 vehicles/day (Class 6)
		100-500 vehicles/day (Class)

Element at Risk Type	Description	Category
		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 Infrastructure	
	Drainage Infrastructure	
Environmental Values	Active Agricultural Area	Presence of any type
	Fisheries	
	Species and Ecosystems at risk	

D.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 D-2 lists uncertainties associated with the use of BCA and cadastral data to assess the exposure of buildings development to geohazards.

Table D-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

D.3. POPULATION

Population data was obtained from the 2016 Canada Census (2016) at a dissemination block[1] 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, 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.

[1] 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).

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.

D.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 RDCK. Facility locations are shown on the web map, classified according to the categories shown in Table D-3.

Table D-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.

D.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 D-4 provides a more detailed breakdown of the utility classes shown in Table D-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. RDCK also provided the alignment of a fibre optic line extending across the District, which was included in the communications infrastructure shown on the web map.

Table D-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

Id	Classified Type (BGC)	Description (ICI Society, 2018)	Position
38	Water Infrastructure	Water Distribution	Subsurface

D.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 D-5 summarizes uncertainties associated with the data. In addition to the uncertainties listed in Table D-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 D-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.

D.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.

D.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 water birds, migratory water birds, 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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APPENDIX E
CLEAR-WATER FLOOD HAZARD ASSESSMENT METHODS

E.1. INTRODUCTION

E.1.1. Objective

This appendix describes the approach used by BGC to identify and characterize clear-water flood geohazards within the Regional District of the Central Kootenay (RDCK). The results form the basis to assign hazard and consequence ratings to prioritize clear-water flood-prone areas in proximity to developed areas within the study area.

This appendix is organized as follows:

- Section E.1 provides background information and an overview of the methodological approach.
- Section E.2 describes methods and data sources used to identify and characterize areas.
- Sections E.3 describes methods used to assign priority ratings.

Appendix F describes the approach used by BGC to identify and characterize steep creek geohazards within the RDCK. Appendix D 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.

E.1.2. Context

The most frequent damaging floods in the RDCK, such as the fatal landslide at Johnsons's Landing, have involved steep creek processes (debris flows or debris floods). However, damaging clear-water floods have also occurred in the RDCK. Areas most susceptible to flood-related losses include settled valley bottoms such as along the Kootenay and Slocan Rivers, and areas where lifeline infrastructure traverse floodplains. The recent flood threats in 2018 and flooding in 2012 (Figure E-1), in addition to the fatal landslide at Johnson's Landing, have brought the issue of geohazard risk to the forefront at the community, regional government and provincial government levels. Johnson's Landing was just one example of many small, rural communities that exist in areas subject to flood or landslide hazards within the RDCK. While extensive efforts have been made to compile hazard information, gaps exist that challenge the RDCK to make land development decisions in hazard areas. The hydro-climatic effects of projected climate change are an added complication to this effort.

Figure E-1. Flooding at Lakeside Park in Nelson in 2012 (Nelson Star, May 16, 2018).

Although flooding can happen at any time of the year, the most severe clear-water flooding in the RDCK typically 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 RDCK, 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. Steep creek processes were evaluated separately and are discussed in Appendix F.

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 E-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).

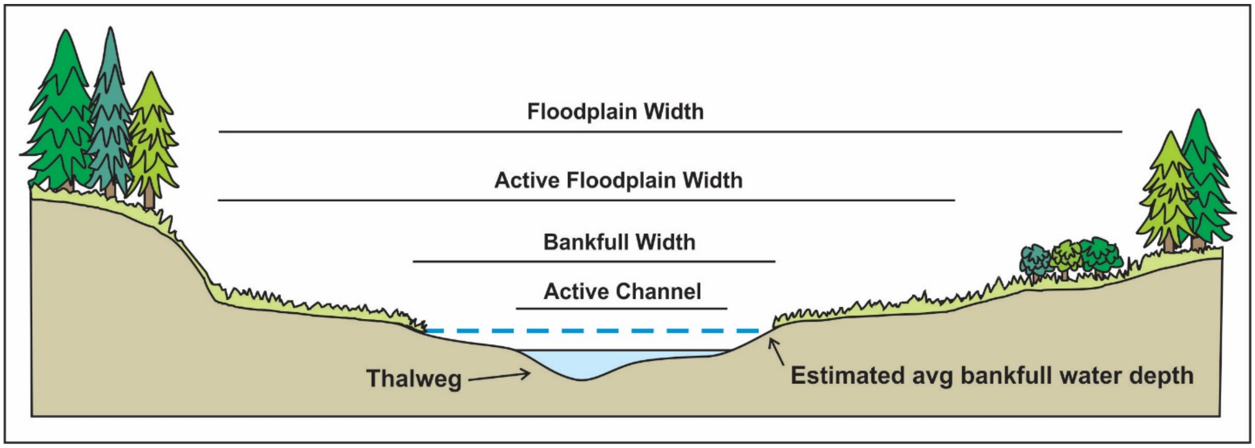

Figure E-2. Conceptual channel cross-section in a typical river valley.

In BC, the 200-year return period flood is used to define floodplain areas, with the exception of the Fraser River, where the flood of record is used (which approximately corresponds to a 500-year return period). 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 wide-spread 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 RDCK.

E.1.3. Terminology

Appendix A provides definitions for key terminology in addition to an overview of flood-related RDCK bylaws.

E.1.4. Approach Overview

Historical clear-water flood events that have occurred within the RDCK are generally due to riverine or lake 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; dam operations; or, landslide, glacial, moraine or beaver dam outbreak floods.

The focus of the clear-water flood hazard assessment for the RDCK 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. The Columbia and Kootenay Rivers have a long history of flow regulation. The impact of these dams on flooding have only been loosely considered in this study, as described further in Section E.2.8.

Historical floodplain maps have been developed for select areas of the RDCK based on the designated flood as represented by the 200-year return period event or AEP of 0.5% (MFLNRO, 2016). These floodplain maps form the basis for this prioritization study, supplemented by screening-level hydraulic modelling, frequency analyses for lake levels, proxy metrics for impounded reservoirs, and a prediction of floodplain extents for remaining watercourses and waterbodies.

Table E-1 summarizes the approaches used to identify and characterize clear-water flood hazard areas. Locations of known dams, flood risk reduction infrastructure, and flood conveyance structures were inventoried but not included in the prioritization of hazard areas. Hazard areas generated from the methods shown in Table E-1 that were found to be located on or adjacent to cadastral parcels of interest[1] were identified, and adjacent areas were amalgamated[2] into geohazard areas for prioritization. The resulting geohazard areas for prioritization are shown on the web application accompanying this report. Also shown on the web application are all mapped stream segments and their associated geohazard process type, as well as historical mapped floodplains and flood depth results from the screening-level hydraulic models.

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1 Cadastral parcels of interest were defined as those parcels identified in the BC Assessment dataset for 2018 as having a gross general improvement value greater than $0, and a land use code not equal to 428 (Managed Forest (Improved)).

2 Amalgamation was based on the concept of “consultation zones”, which define a geographic area considered for geohazard safety assessment (Geotechnical Engineering Office 1998; Porter et al, 2009). Geographic areas were selected on the basis of hazard type and characteristics, jurisdiction/community continuity, future detailed study funding considerations and study efficiencies.

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

Approach	Area of RDCK 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 floodplain mapping	All mapped watercourses and waterbodies prone to clear-water flooding where existing information was available.	Identification of floodplain extents from publicly available historical mapping sources and estimates of flood depths across the floodplain.
Screening-level hydraulic modelling	Select unregulated watercourses prone to clear-water flooding, not previously mapped. Generally areas with a higher concentration of elements at risk[1], a Strahler stream order[2] of 4 or greater, and sufficient topographic relief to be captured in the low-resolution topography.	Identification of flood inundation extents and depths based on a digital elevation model with an approximate 18 m x 18 m grid size.
Lake level prediction	All lakes with active gauge stations or previous lake level modelling.	Lake levels or elevations predicted for the 200-year return period event (AEP of 0.5%) used to generate flood inundation extents and depths.
Proxy metrics for impounded reservoirs	Major reservoirs.	Identification of potential inundation extents and depths resulting from extreme water levels.
Floodplain extent predication for watercourses and waterbodies.	All remaining watercourses and waterbodies with a Strahler stream order[2] of 4 or greater, and prone to clear-water flooding, but not associated with an alluvial fan.	Identification of low-lying areas adjacent to streams using a topographic elevation offset applied to mapped centrelines. The unregulated stream discharge was used as a proxy for flood hazard intensity.
	All remaining watercourses and waterbodies with a Strahler stream order[2] of 3 or less, and prone to clear-water flooding, but not associated with an alluvial fan	Identification of low-lying areas adjacent to streams using a 30 m horizontal buffer applied to mapped centrelines. The unregulated stream discharge was used as a proxy for flood hazard intensity.

Note:

1. Elements at Risk considered in this study are described in the main report document (Exposure Assessment)
2. **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 E.2.1.

The accuracy of clear-water flood identification approaches listed in Table E-1 was strongly influenced by the resolution of available digital elevation models (DEM). While the RDCK has now acquired high resolution LiDAR topography across much of the developed areas of the District, these data were not processed and available in time to be used in this current study. Topographic data in most clear-water flood areas assessed was limited to the approximately 25 m resolution Canadian Digital Elevation Model (CDEM). Figure E-3 shows the extent of LiDAR available at the time of study. Use of the available LiDAR was limited given that coverage did not extend to entire areas of interest (e.g. mapping the right bank only) and that the varying datums did not permit the LiDAR to be readily integrated into CDEM data. Analysis limitations associated with CDEM resolution are discussed in sections below.

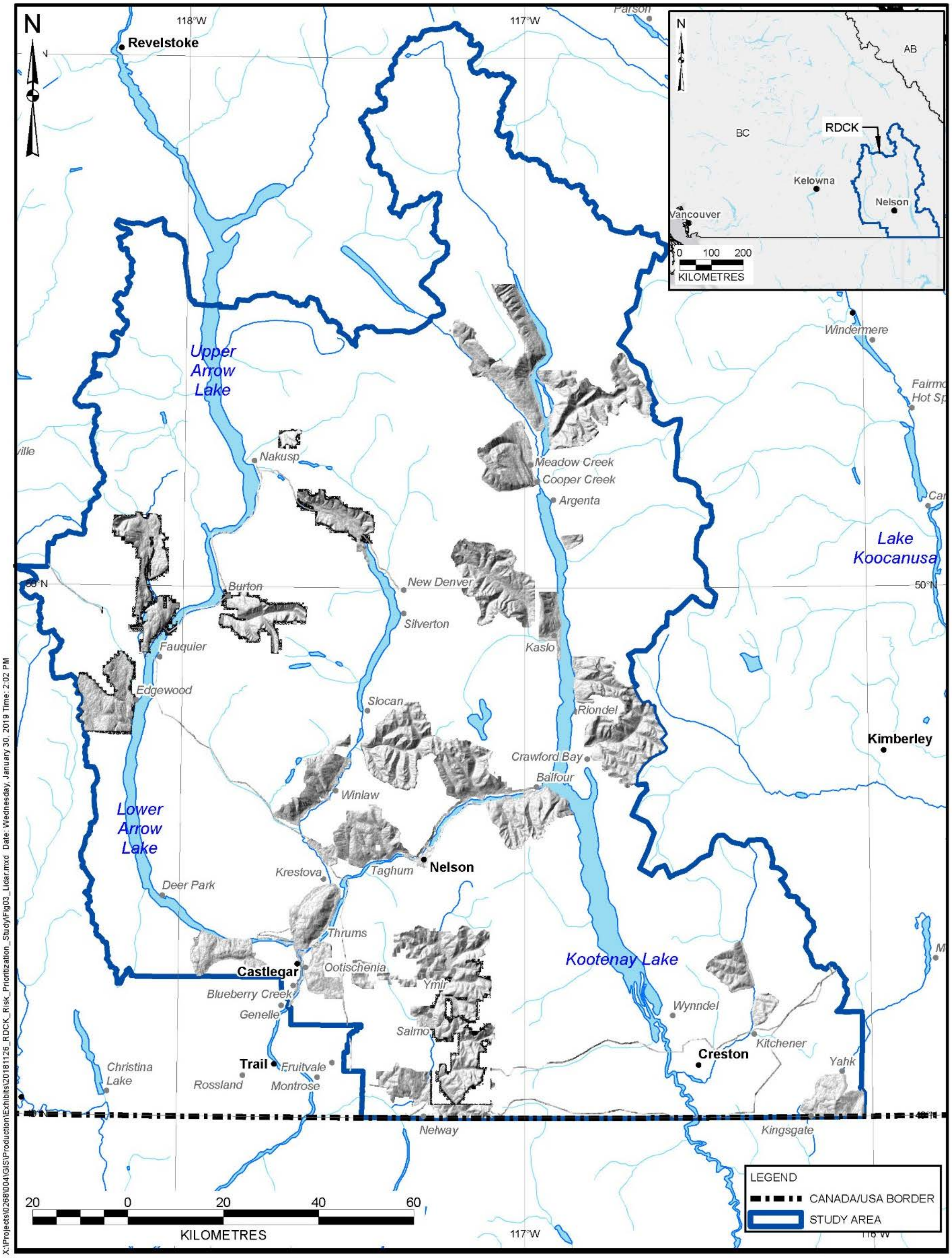

Figure E-3. LiDAR availability (shown as grey hillshades) at the time of this study.

E.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 E-1.

E.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., Duncan River), while Strahler order 3 and lower streams are typically smaller, headwater streams (e.g., Redfish Creek). An illustration of Strahler stream order classification is shown in Figure E-4 and described conceptually for the RDCK in Table E-2. Strahler stream order was used to determine the method applied to predict the potential floodplain extents and hazard intensity for watercourses within the study area as described in Section E.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).

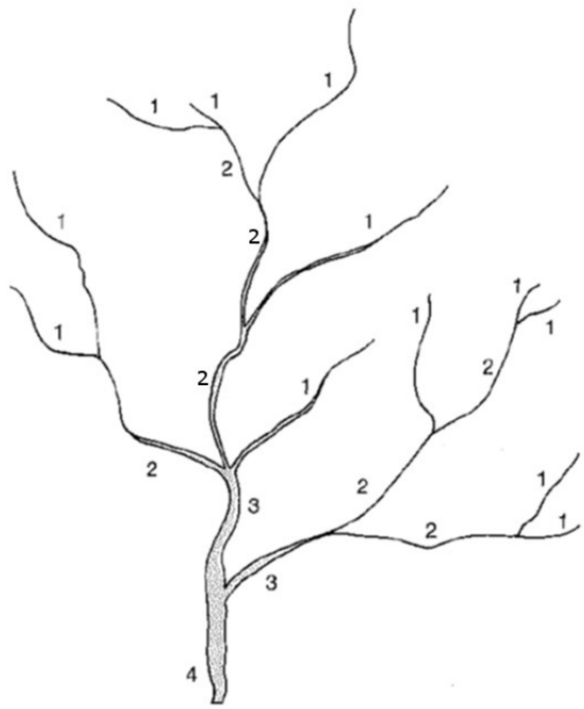

Figure E-4. Illustration showing Strahler stream order (Montgomery, 1990).

Table E-2. Strahler order summary for the RDCK stream network.

Strahler Order	Description	% of all Stream Segments in the RDCK	Example Watercourses
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 many are unnamed. Catchment areas typically less than 50 km^2	85%	Apex Creek, Redfish Creek, Smoky Creek
4 – 6	Medium stream or river. Generally, less steep and lower flow velocity than headwater streams.	14%	Goat River, Moyie River, Kaslo River, Crawford Creek
7+	Large river. Larger volumes of runoff and potentially debris conveyed from smaller waterways. Typically, flow is regulated by hydroelectric dams. Catchment areas typically greater than 3,000 km^2.	1%	Columbia River, Kootenay River, Salmo River

RNT also contains hydrometric data collected from Water Survey of Canada (WSC) gauging 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 E.2.2.

E.2.2. Flood Frequency Analysis (FFA)

In RNT, flood quantiles are either pro-rated from a nearby single gauge or estimated by regional FFA from multiple gauges, depending on the location relative to available WSC gauge stations. A total of 358 WSC gauges stations are located within the RDCK (DataBC, 2017). Of these gauges, 31 are active stations and 327 are discontinued. Of the 31 active stations, 18 are used by WSC for real-time monitoring (Figure E-5). Of the discontinued stations, the starting years and ending years of stations show that there has been a trend of fairly continuous adding and simultaneous discontinuing of gauging stations in the RDCK between 1910 and 1990, with many being operational for only a few years (Figure E-6). A large number of gauges started in the 1920s and 1930s have been discontinued, and many gauges became obsolete following construction of dams in the 1960s.

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 RDCK. 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 in watercourses with flow controlled by dams.
- Attenuation from the many lakes, wetlands and marshes in the RDCK 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, nor landslide dams, 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 the current study.

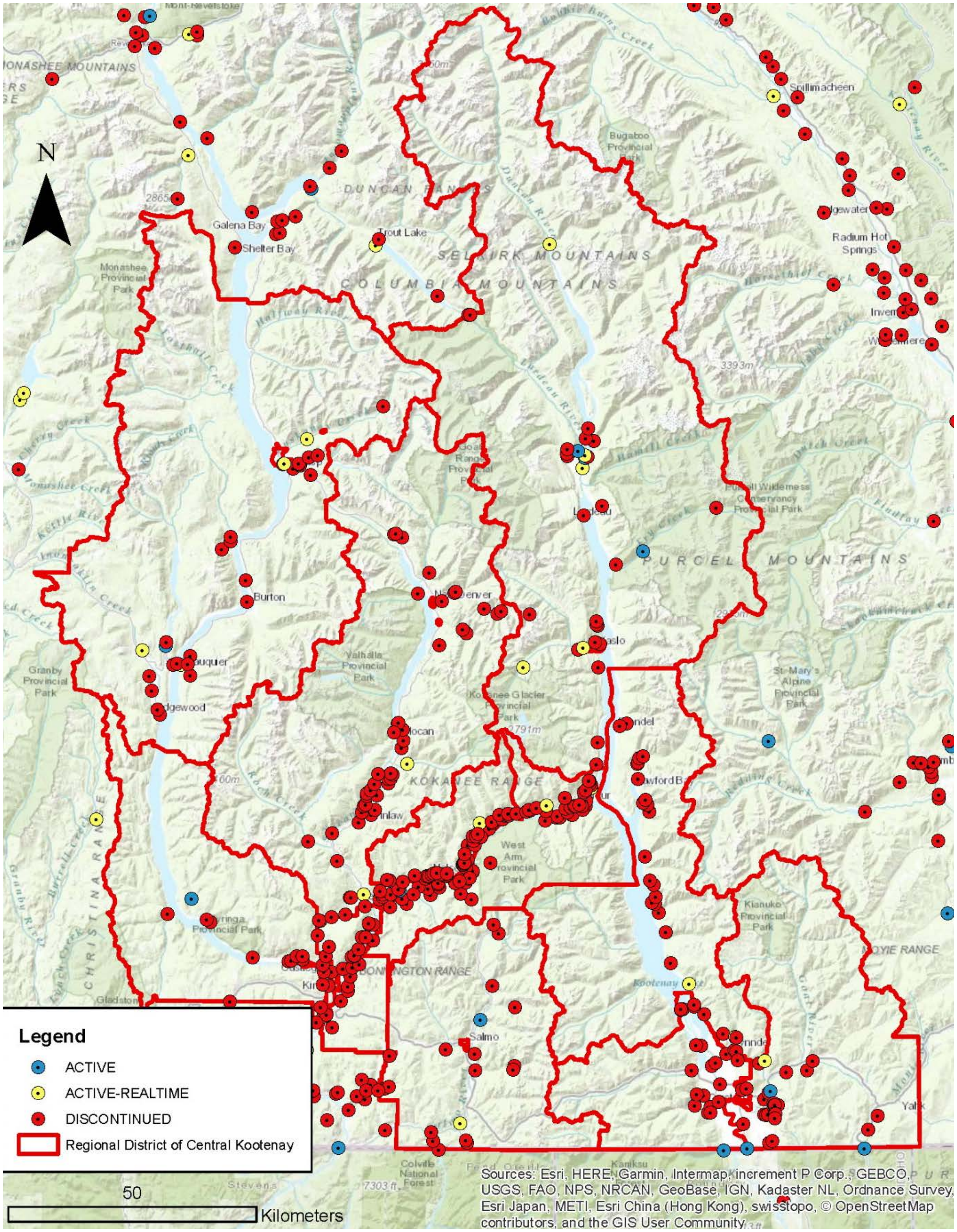

Figure E-5. WSC active, active-real time, and discontinued gauges within the RDCK.

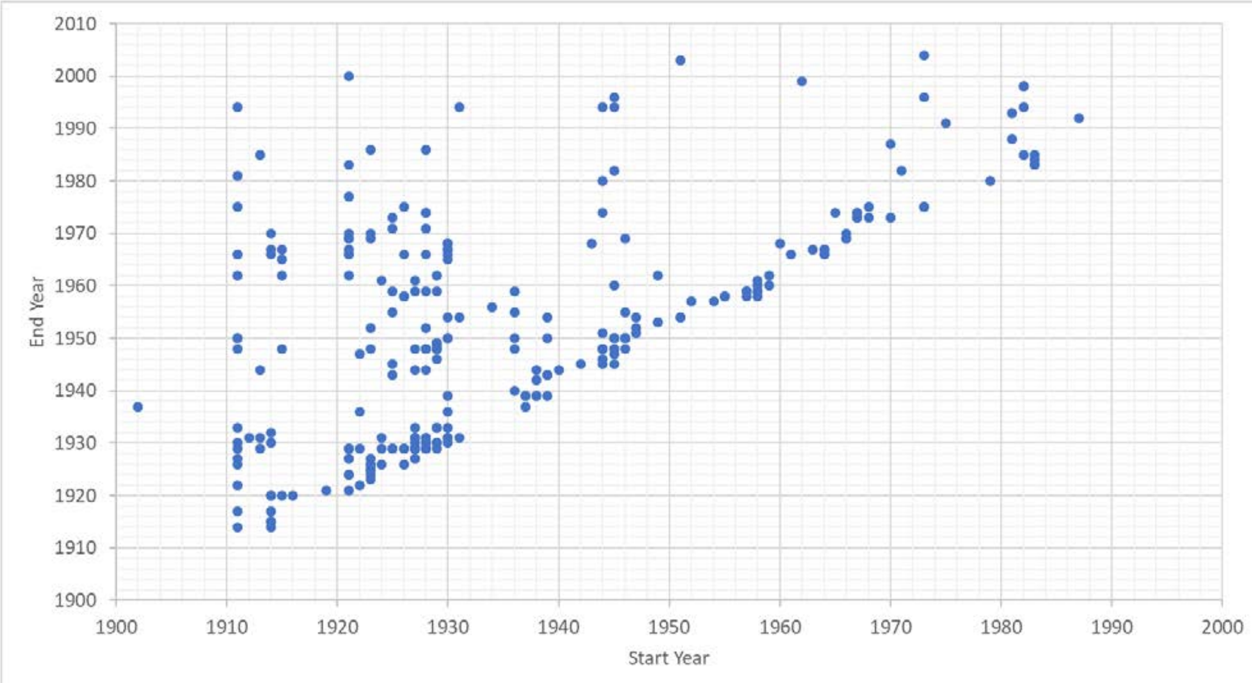

Figure E-6. WSC discontinued gauges within the RDCK plotted by record year.

E.2.3. Geohazard Process Type

Every mapped stream segment in the RDCK, from small tributary creeks to large rivers, was assigned a predicted process type (flood, debris-flood or debris flow) based on a statistical analysis of Melton Ratio[3] and watershed length[4]. 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 E-3. The web map displays every stream segment in the RDCK and its associated predicted geohazard process type (clear-water flood, debris flood or debris flow).

Table E-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

3 Melton ratio is watershed relief divided by the square root of watershed area (Melton, 1957).
4 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.

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 RDCK 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[5] 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 E-7. 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.

[5] 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).

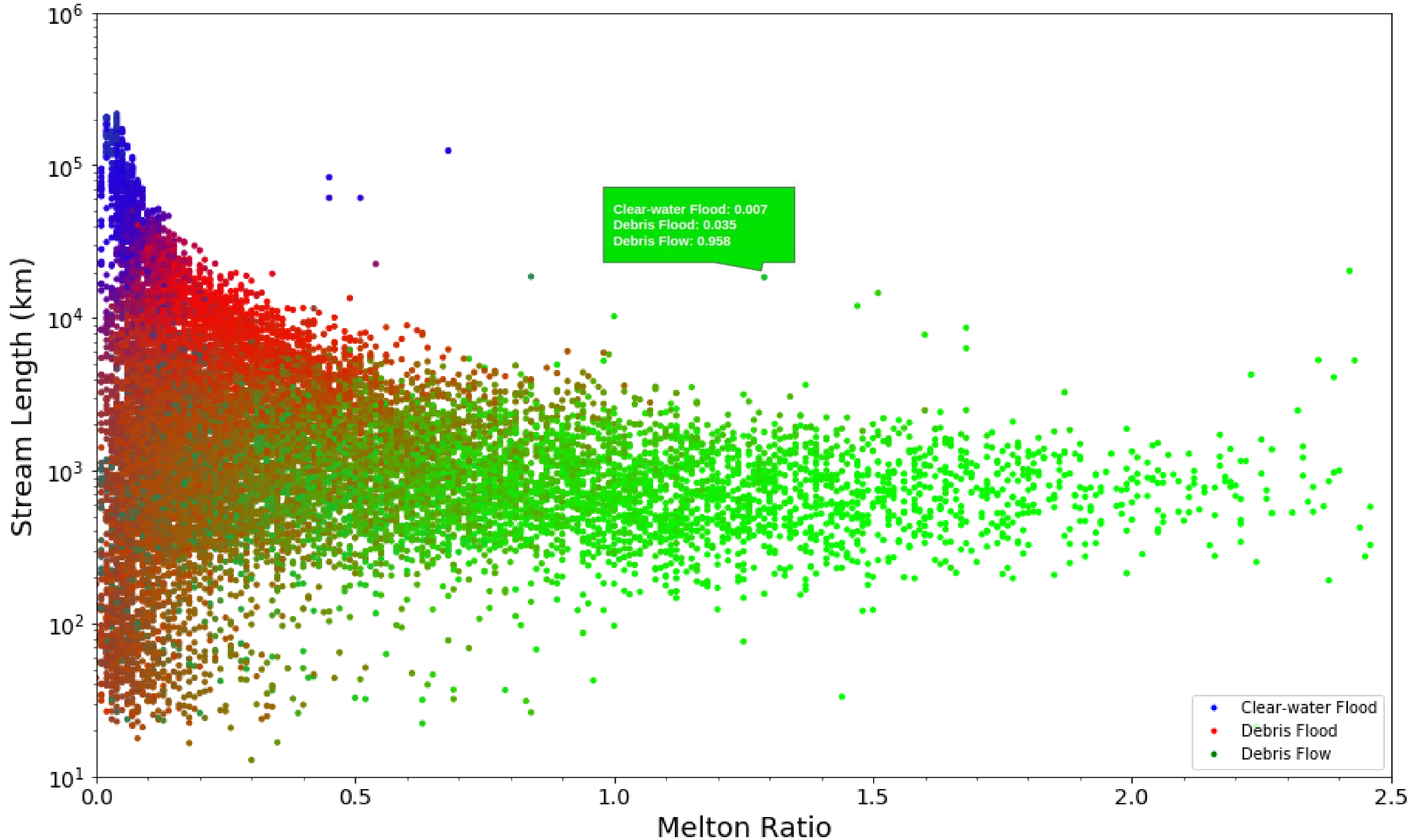

Figure E-7. Example of geohazard process-types identified for a subset of stream segments in a mountainous region based on stream length (km) and Melton Ratio.

E.2.4. Alluvial Fan Inventory

A fan inventory was developed for the RDCK as part of the steep creek geohazard identification process (refer to Appendix F). The boundaries of alluvial fans were used to define fan geohazard areas prioritized in this study. A total of 71 out of the 329 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.

E.2.5. Historical Floodplain Mapping

E.2.5.1. Background

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.

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 E-4 and shown on Figure E-8. 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 (200-year return period event) and include a freeboard allowance[6]. 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.

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[6] Freeboard is a depth allowance that is commonly applied on top of modelled flood depths. There is no consistent definition, either within Canada or around the world, for freeboard. Globally, the variables accounted for within freeboard can be extremely diverse. Overall, freeboard is used to account for two distinct factors:

1. Uncertainties in the calculation of a base flood elevation, and
2. To compensate for quantifiable physical effects (e.g., local wave conditions or dike settlement).

Freeboard in BC is commonly applied as defined in the BC Dike Design and Construction manual: a fixed amount of 0.6 m (2 feet) where mean daily flow records are used to develop the design discharge or 0.3 m (1 foot) for instantaneous flow records. Appendix A provides a background summary on what freeboard is generally, and discusses how it is incorporated into floodplain mapping and RDCK policy.

Historical floodplain mapping within the RDCK is more than 20 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 in many cases
- Reflect changes to flow regulation schedules for dams located upstream of mapped flood areas, which results in changes to the design flood
- 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).

In addition:

- Flow velocities and flood depths (as opposed to flood elevations) were not provided as part of the mapping program
- The reported flood elevations include a freeboard allowance; however, the amount of freeboard assumed varies and is not stated on the maps themselves. There are inconsistent documentation standards for the methodologies that were used to generate the different maps.

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 E-4. Summary of historical floodplain mapping within the RDCK.

Site No.(1)	Floodplain Name	Approximate Floodplain Area (km2)	Approximate Floodplain Length (km)	Map Year	Dam Regulation?	Regulated dike exists in the mapped area(2)?	Comments
1	Salmo River (including Erie Cr)	19.2	28	1991	No	Yes, both rivers	During the 2018 freshet, despite the Village of Salmo having historical mapping, BGC completed emergency hydraulic modelling for RDCK to provide flood depths, velocities and inundation extents for the forecasted freshet peaks to assist in emergency operations and sandbagging efforts.
2	Slocan River	20.9	48	1989 / 1990	No	No	At Goose Creek near the confluence with the Slocan River, MFLNRORD personnel identified an avulsion hazard (Dwain Boyer, personal communication, July 27, 2018). At this site is a water supply to a 60+ home settlement.
3	Kootenay River (to US Border)	167.1	32	1981, 1984	Yes	Yes	No analysis documentation is available for previous floodplain mapping. BGC (2014) determined that the peak flow due to dam regulation is well below the dike crest. Although the floodplain mapping did not include the dikes in the evaluation, the floodplain is still potentially subject to flood hazards such as dike breaches.
4	Goat River (at Creston)	4.3	6.5	1981, 1984	No (3)	Yes	No analysis documentation is available for previous floodplain mapping.
5	Kaslo River (at Kaslo)	1.1	1.8	1984	No	Yes	No analysis documentation is available for previous floodplain mapping.
6	Crawford Creek - Alluvial Fan	2.7	2.7	1987	No	Yes	For previous floodplain mapping, limited analysis was conducted and no digitized results. MOE (2009) notes that the Crawford Creek orphan dike “is deteriorating and overgrown with vegetation putting several homes, businesses and the highway at risk of flood damages.”
7	Kuskanax Cr.	7.1	6	1998	No	No	
8	Duncan & Lardeau Rivers	19.7	16	1996	Yes	No	
9	Lemon Creek- Alluvial Fan	2.0	1	1989 / 1990	No	Yes	No analysis was completed at the time. The hazard extents were originally defined by the geomorphic fan extents.
10	Beaver Creek	3.0	20	1989 / 1990	No	No	No analysis was completed at the time. The hazard extents were originally defined by the geomorphic fan extents.

(1) As shown on Figure E-8. (2) Dikes were not included in the original analysis. (3) Although a dam is present, the storage capacity behind the dam is limited.

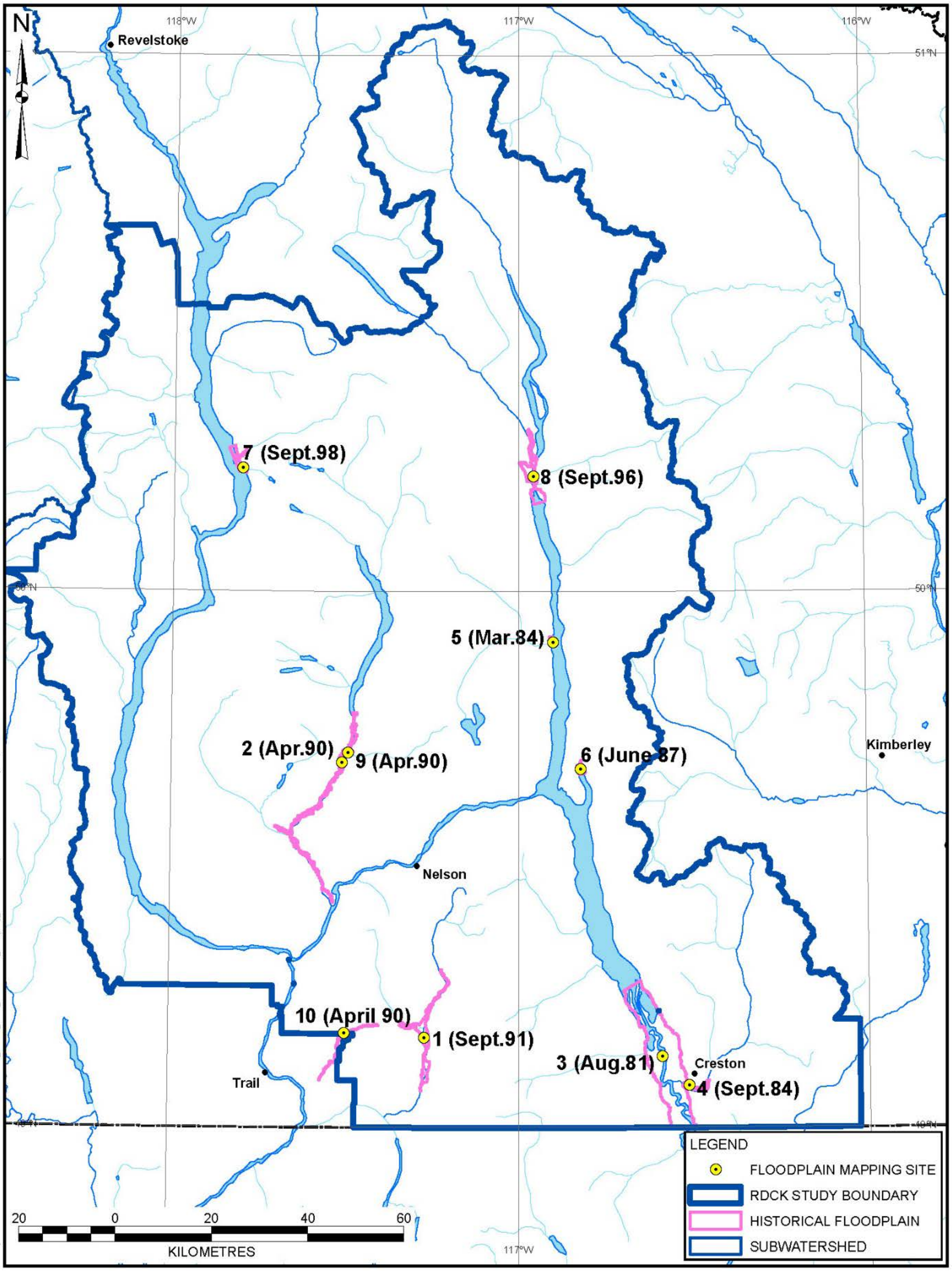


Figure E-8. Historical floodplain mapping in the RDCK.

E.2.5.2. Mapping within the RDCK

Historical floodplain mapping conducted within the RDCK was generally focused on major rivers as summarized in Table E-4. Some of the mapped floodplains include alluvial fans, for which no estimate of flood elevation or extents was mapped, only the geomorphic extent of the fan. For the remaining areas, the digital mapping provides an inundation extent polygon for the 200-year flood (including a freeboard allowance), and 1 m flood elevation contours (Flood Construction Levels, FCLs). The extent and contours were used by BGC to generate a flood surface in ArcGIS.

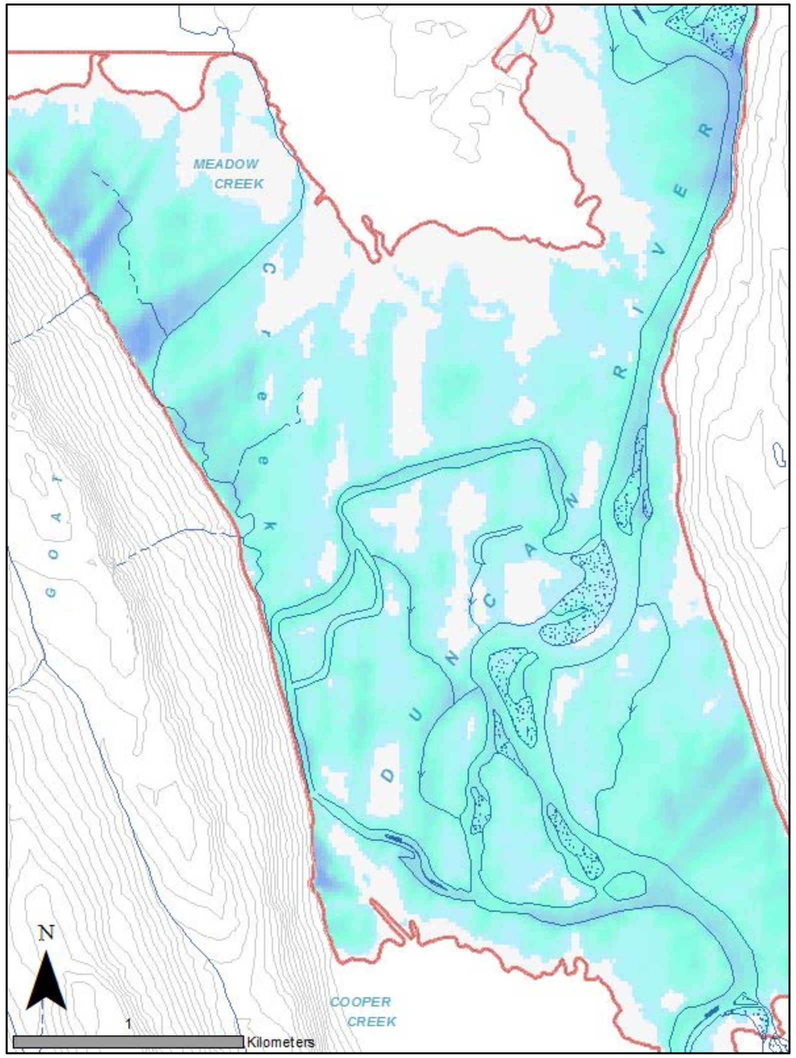
The flood elevation contours could not be directly used to generate the flood surface because:

- Varying vertical datums between different mapping areas and the topographic ground surface produced poor quality flood surfaces.
- The topographic ground surface dataset (CDEM) available for this study was significantly poorer resolution than the detailed surveys undertaken for the floodplain mapping projects.

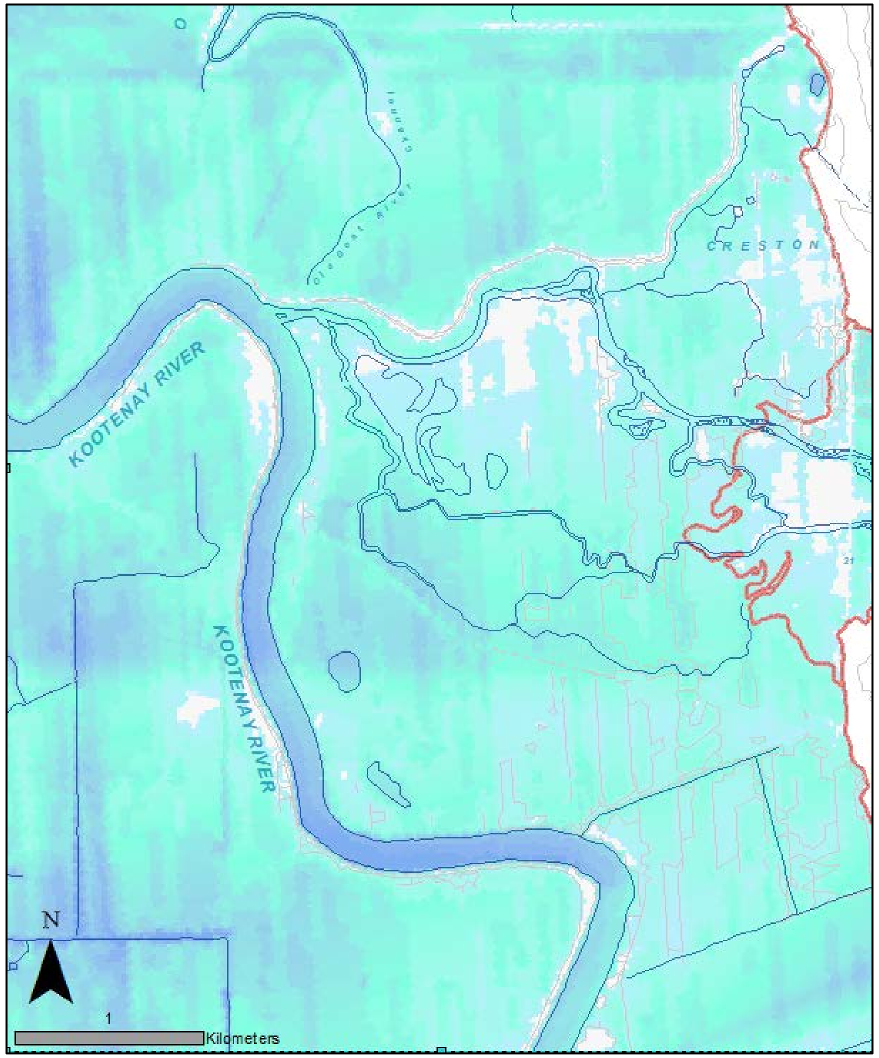
Instead, flood elevation surfaces were generated by BGC by intersecting the mapped flood extent polygons with the DEM and triangulating across the valley. A flood depth grid was then created for the flood polygon at the same resolution as the DEM, and a freeboard of 0.6 m (1.0 m for Duncan/Lardeau) was assumed and subtracted from all surfaces to estimate the 200-year flood depth. This method generally produced reasonable results (Figure E-9, Figure E-10). Some areas, such as Meadow Creek and Upper Slocan River, did not produce reasonable results as the valley wall was steep on one side and shallow on the other, which gave incorrect triangulations because the CDEM resolution was too poor to adequately capture steep wall elevations. As LiDAR and screening level hydraulic modelling results were available for Kaslo, it provides a useful comparison. Figure E-10 compares different methods for developing a flood depth grid for the Kaslo River at Kaslo historical floodplain:

- Inset A shows flood depth results based on historical floodplain mapping inundation extent (less freeboard) and the CDEM topographic dataset.
- Inset B shows flood depth results based on historical floodplain mapping inundation extent (less freeboard) and the LiDAR topographic dataset.
- Inset C shows flood depth results based on screening-level hydraulic modelling (described in the next section) and the LiDAR topographic dataset

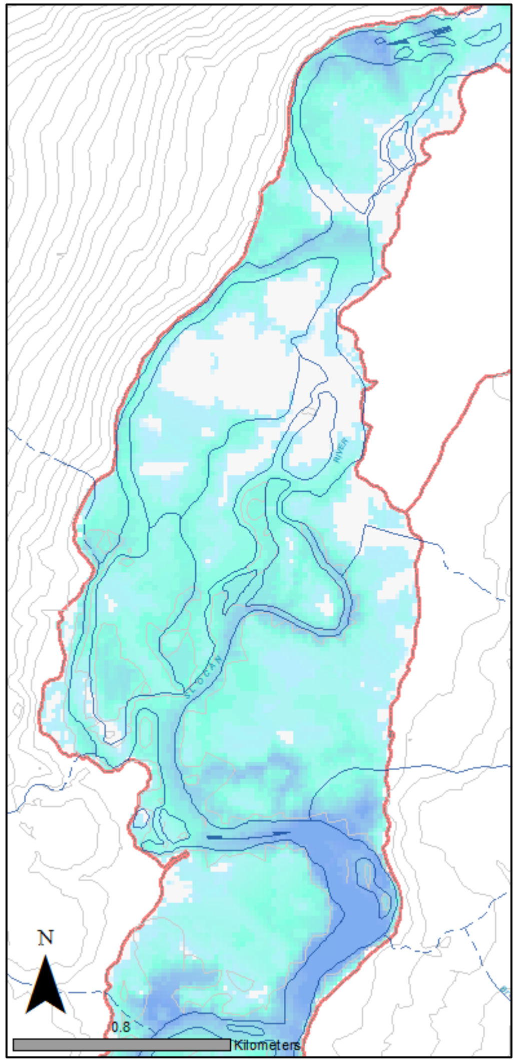
The flood depth grid results based on historical floodplain mapping inundation extent (less freeboard) and the CDEM topographic dataset are coarse in resolution when compared with the channel. The three methods presented each give different results, but at a screening-level, the depth grids generated from the historical floodplain and CDEM topographic dataset provide a useful tool.



Duncan River and Meadow Creek

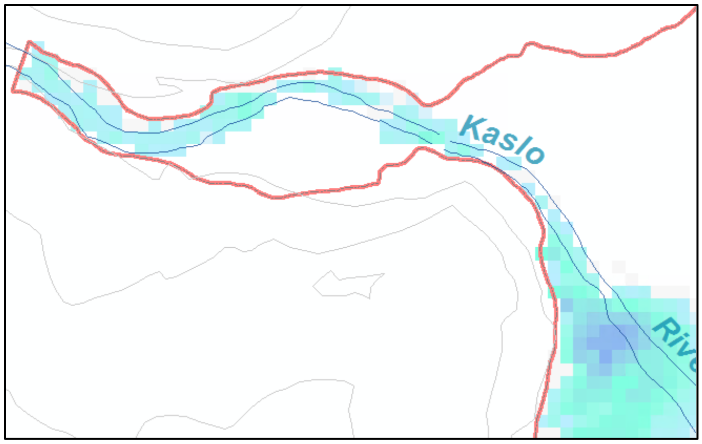


Kootenay River at Creston

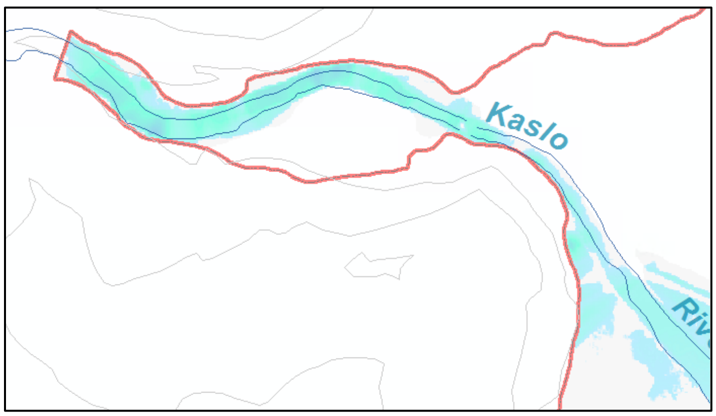


Slocan River at Lemon Creek

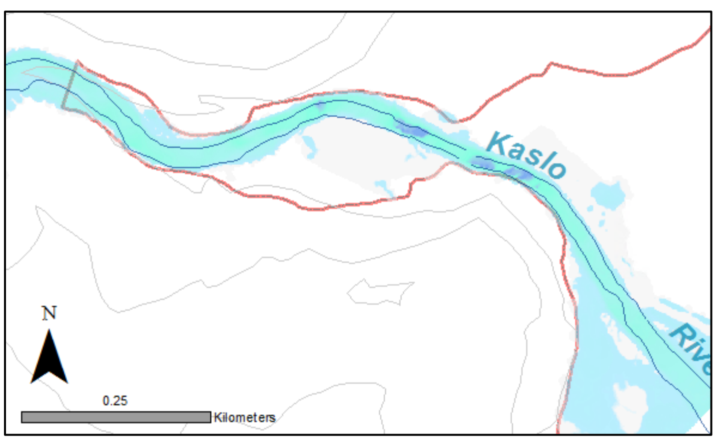
Figure E-9. Flood depth grid results for select historical floodplains (outlined in red). White indicates depths less than 0.1 m, the darker the blue, the deeper the calculated flood depth. Background mapping provided by RDCK, contour interval of 20 m.



(A) Flood depth grid results based on historical floodplain mapping inundation extent (less freeboard) and the CDEM topographic dataset.



(B) Flood depth grid results based on historical floodplain mapping inundation extent (less freeboard) and the LiDAR topographic dataset.



(C) Flood depth grid results based on LiDAR and screening-level hydraulic modeling.

Figure E-10. Comparison of flood depth grid results for Kaslo River at Kaslo historical floodplain (outlined in red), based on 3 different datasets. White indicates depths less than 0.1 m, the darker the blue, the deeper the calculated flood depth. Background mapping provided by RDCK, contour interval of 20 m.

E.2.6. Screening-Level Hydraulic Modelling

Screening-level, two dimensional, hydraulic models were developed for select unregulated watercourses prone to clear-water flooding, where the floodplains had not previously been mapped. Table E-5 provides a summary of where screening-level hydraulic models were developed. Generally, the sites selected represent areas with a higher concentration of elements at risk[7], a Strahler stream order of 4 or greater, and sufficient topographic relief to be captured in the low-resolution topography.

Table E-5. Summary of locations where screening-level hydraulic models were developed.

Watercourse Name	Communities	Modelled Stream Length (km)	Upstream Watershed Area (km2)
Bonanaza Creek	Hills	8	130
Burton Creek, Snow Creek, Caribou Creek	Burton	12	500
Crawford Creek	Crawford Bay	14	200
Goat River upstream of dam, Arrow Creek	Arrow Creek, McConnel	30	1200
Goose Creek	Krestova	8	100
Inonoaklin Creek	Edgewood	20	400
Kaslo River at Kaslo	Kaslo	4	500
Moyie River, Hawkins Creek	Yahk, Curzon, Glenlily	23	1500
Norris Creek	Pass Creek, Gibson Creek, Raspberry	12	200

Screening-level modelling uses the best-available topography along with simplified or automated methodologies to provide estimates of inundation extent, and maximum flood depths and flow velocities across the floodplains. The level of detail of modelling is comparable to “Automated Engineering” as defined by the U.S. Federal Emergency Management Agency (FEMA 2016). These analyses are not exhaustive and do not replace detailed floodplain mapping (as would be completed under NDMP funding Stream 2) but were used to identify and prioritize areas subject to clear-water flood risk. The screening level modelling also serves as a basis for more detailed mapping in the future, given it is more efficient to refine the models than prepare detailed flood maps from scratch.

Some of the simplifications used for the screening-level hydraulic modelling include:

- Elevation model uses topographic data only and therefore does not account for river and lake bathymetry.

[7] Elements at Risk considered in this study are described in the main report document (Exposure Assessment)

- No “break-lines” (i.e., control lines that delineate a break in slope, such as top of bank) were included in the topography, with the exception of the mapped river centerlines which were used to refine the mesh in the channel and thereby improve computational stability.
- Bridges, culverts, and dike infrastructure were not modelled, except to the extent where embankments are captured by the topography and the model resolution. Bridge decks were excluded from the topography.
- Topography of the built environment (e.g., buildings) was not considered.

For all sites, with the exception of Kaslo, the best available topographic data was the Canadian Digital Elevation Model (CDEM). 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 RDCK, this corresponds to approximately 25 m grid cell resolution (Government of Canada, 2016), which is a significant limitation on the accuracy of the hydraulic modelling results. LiDAR was available for the Kaslo River at Kaslo and was used for this analysis.

The software package used was TELEMAC-2D, a public domain hydraulic modeling program. The TELEMAC-2D package was developed initially by the National Hydraulics and Environment Laboratory (Laboratoire National d’Hydraulique et Environnement - LNHE) of the Research and Development Directorate of the French Electricity Board (EDF-R&D) and is now managed by a consortium of other consultants and research institutes. TELEMAC-2D provides a number of unique characteristics:

- Open source – no license fees/restrictions means the software is readily available. Users are also able to modify the code if needed to suit their specific requirements.
- Parallelized – the model is fully parallelized, which means it can be run on multi-core machines and/or clustered machines significantly reducing runtimes.
- Robust – the solvers are robust for both steady and unsteady flow problems and include shock-capturing capabilities (e.g., for steep creeks).
- Command Line Interface (CLI) – TELEMAC-2D uses a CLI which allows for easy scripting and automation of the model and allows it to be used on remote connections (e.g., via ssh).
- Flexible mesh – TELEMAC-2D uses a flexible mesh allowing the mesh to be designed to conform to the geometric shape of the river and features on the floodplain. It also allows the node density to be adjusted based on the anticipated flow gradients (e.g., high in the channel and lower in the floodplains).

BGC developed pre-processing tools to extract both the relevant spatial and hydrological data to pre-process each model. Had LiDAR been available in time for this project, more sites would have been modelled and BGC would have utilized cloud computing to run the models along with specialized scripting to automate the data extraction, model post-processing, and to setup and run models on the cloud servers.

Inputs to the model included:

- Inflow hydrographs – constant discharge values were used in the model, and coincidence of peak flows from tributaries was assumed. The development of discharge values for use in the models is described in Section E.2.2.
- Starting water levels for lakes – the water elevation at the time of the survey or as mapped, was assumed.
- Terrain model – CDEM was used.
- Mesh structure – triangular using Blue Kenue from the Canadian Hydraulic Centre (CHC).
- Flow Resistance – a uniform manning's n value of 0.04 was selected.

Some additional uncertainties and limitations of the models include:

- Models were not calibrated. Select models were validated and the validated parameters were applied to all models.
- The models assume a static topography and do not account for erosion or sediment deposition that could occur during a high flow event, nor do the models account for emergency measures, such as sandbagging.
- Debris floods, debris flows and landslides impacts to flood hydraulics were not considered; modelling contains only flood inundation.

E.2.7. Lake – Level Frequency Analysis

A frequency analysis approach was also used to estimate the lake elevation associated with the 200-year flood event for two lakes within the RDCK including:

1. Slocan Lake.
2. Kootenay Lake.

E.2.7.1. Slocan Lake

Slocan Lake is not regulated by dams. Water Survey of Canada (WSC) maintained a water level gauge (08NJ137) on the lake at Slocan City between 1916 and 1969 (31-year record). As part of the floodplain mapping for the Slocan River, NHC (1989) reviewed Slocan Lake level frequency analyses previously completed by MOE. NHC also estimated wind-generated wave heights for the lake at Silverton (they determined that this location had the most severe wave climate on the lake). As no new gauge records were available since the NHC analysis in 1989, BGC used the values reported in NHC (1989).

For the purposes of this assessment, a 1-year wave height in combination with the 200-year return period lake level was selected as the joint frequency of occurrence that would be equivalent to the 200-year value. The reported results (NHC 1989) were as follows:

- 200-year lake level (538.36 m) + 1-year wave height (0.72 m) = 539.1 m

For comparison, RDCKs Floodplain Management Bylaw lists a flood construction level (FCL) of 539.2 m for Slocan Lake. NHC (1989) documents the origin of this value as coming from a hydrologic analysis by MOE in 1975 of maximum daily lake levels recorded by the WSC gauge. MOE determined a 200-year return period lake level of 538.5 m and recommended a freeboard of 0.70 m. MOE then recommended that the 200-year designated lake level be 539.2 m, which is similar to the value selected by BGC.

A Slocan Lake water elevation of 539.1 m was selected to generate the flood inundation hazard polygon; however, the CDEM reports a lake elevation of 541 m. As the topographic dataset is not of sufficient resolution to map the calculated water levels, a 30 m buffer from the mapped lakeshore was used to delineate the hazard polygon. As a flood depth grid could not be calculated for the hazard polygon, a moderate depth was assumed for the entire polygon (see Section E.3.2.2 and Table E-8 for description)

E.2.7.2. Kootenay Lake

Kootenay Lake is a naturally formed lake whose levels have been regulated since the construction and subsequent modifications of the Corra Linn Dam in the 1930s at the lake's outlet near Nelson. Depending on how the Corra Linn Dam is operated, the hydraulic control for the lake outlet can either be the dam itself or a natural constriction known as the Grohman Narrows, located approximately 10 km upstream of the dam. Flows into Kootenay Lake have been regulated since construction of the Duncan Dam in 1967 and the Libby Dam in 1975. The USACE (2005) developed a water elevation-frequency relationship for Kootenay Lake that accounted for modified operations of the Libby Dam (upstream) and the Corra Linn Dam (downstream), while simplifications were used to estimate the impact of the Duncan Dam on inflow to the lake. USACE (2005) calculated a 200-year lake level of 535.2 m.

By comparison, RDCKs Floodplain Management Bylaw lists a flood construction level (FCL) of 536.5 m for Kootenay Lake. This value was reportedly derived (Klohn-Crippen, 1996) from two studies: one from Environment Canada in 1975 which estimated the Kootenay Lake flood of 1894 (the flood of record, and prior to any dam construction) to have a return period inflow of approximately 200-years; and another from the US Army Corps of Engineers that modelled the 1894 inflow with Columbia River Treaty Flood Control dams which calculated a flood elevation of 535.7 m (1757.5 ft). Klohn-Crippen (1996) reports that the BC Ministry of Environment, Lands and Parks added a freeboard of 0.7 m (same as for Slocan Lake), and in 1975 adopted a 200-year Kootenay Lake FCL of 536.4 m as part of the flood damage reduction program of the time.

A Kootenay Lake water elevation of 535.2 m was selected to generate the flood inundation hazard polygon. This elevation was extended through the Kootenay West Arm (Queen's Bay to Corra Linn Dam) despite this portion of the lake behaving as a river (and therefore a sloped water surface profile) under certain conditions. A flood depth grid was created for the shoreline based on the CDEM dataset which reported a lake elevation of 533 m.

BGC understands that BC Hydro intends to conduct stochastic analysis of flows along the Columbia River system. Additionally, ongoing Columbia River treaty negotiations could result in significant changes to dam operations. It is recommended that these future analyses be incorporated into the current study when they become available, and that the assessment be subsequently updated.

E.2.8. Dams and Reservoirs

Most major valley bottom rivers and lakes in the RDCK are regulated by dams directly or indirectly (i.e., upstream). Commonly, they are regulated by multiple dams, whose owners (BC Hydro, Fortis, USACE) coordinate their activities to some degree with each other and with downstream dam owners, and have water level / discharge commitments (biological, dam safety, Columbia River Treaty, International Joint Commission, Kootenay Lake Order etc.). The first dams were constructed in the 1920s, while most dams were constructed in the late 1960s through late 1970s. Dams in the region include:

- Duncan Dam (Duncan River, BC Hydro)
- Libby Dam (Kootenay River upstream of the RDCK in Montana, USACE)
- Corra Linn Dam (Kootenay River, Fortis)
- Upper and Lower Bonnington Dams, South Slocan Dam Complex (Kootenay River, Fortis)
- Brilliant Dam Complex (Kootenay River, Columbia Power Corporation and Columbia Basin Trust)
- Goat River Dam (Goat River, Cascade Pacific Power Corporation)
- Whatshan Dam (Whatshan River, BC Hydro)
- Seven Mile Dam (Pend d'Oreille River, BC Hydro) The dam is not located in the RDCK, but the reservoir crosses into the RDCK
- Keenleyside Dam (Arrow Lakes / Columbia River, BC Hydro)
- Mica Dam and Revelstoke Dam (Columbia River upstream of the RDCK, BC Hydro)
- Several small provincially-regulated facilities located on small tributary creeks.

Those dams located within the RDCK are shown on Figure E-11. The web map displays all the inventoried dams in BC that are regulated under the *Water Sustainability Act* (SBC, 2014).

The impacts on flood hydrology downstream of the dam are typically a decrease in the peak freshet discharge and an increase in winter discharges, when compared with pre-dam hydrology. Within the reservoir area, high water levels can persist longer than before dam construction.

Evaluating the impact of regulation on flows and reservoir water levels was outside the scope of this study. Therefore, for this study, hazard areas were delineated as follows:

- Lake – level frequency analysis by others (See Section E.2.7.2) was used for Kootenay Lake
- Historical floodplain mapping (see Section E.2.5) was used for: Duncan River downstream of Duncan Dam; and Kootenay River (Creston Valley)
- Floodplain Extent Prediction (See Section E.2.9) was used for all remaining rivers and reservoirs regulated by dams, with no specific accounting for flow regulation, with the exception of: Duncan, Arrow, Whatshan and Seven Mile Reservoirs, where dam licensing elevations were used, as described below.

Table E-6 summarizes the various dam licensing elevations for four of the major reservoirs in the RDCK. The FCL stated in the RDCK bylaw 2080 is also shown for comparison.

Table E-6. Inundation indicators for impounded reservoirs.

Reservoir	Dam Crest		Maximum Licensed Water Elevation		Dam Safeline(5)		FCL Bylaw 2080 (2009)(6)
	Elevation	Source	Elevation	Source	Elevation	Source	
Duncan	581.5	BC Hydro 2007	577.3 m or 1894 ft	BC Hydro 2017	n/a		581.2
Arrow Lakes	444.7 m	MFLNRO (2017a) Dam Inventory	440.7 m or 1446 ft	BC Hydro 2017	440.7 m (1)	RDCK Bylaw 2080	443.5 (1)
Whatshan	640.1 m (2)	MFLNRO (2017a) Dam Inventory	unknown (3)		n/a		652.3
Seven Mile Reservoir	unknown		527.3 m (1730 ft)	(4)	n/a		3.0 metres above natural boundary

(1) FCL = 440.7 m + 2.8 m allowance. The terms impact line and safeline/safe line/safe-line appear to be used interchangeably; however, as described in Note 5, they may not be. The RDCK bylaw 2080 identifies the safeline as 440.7 m (and defines a setback from that elevation), but as this value is the same as the maximum licensed water elevation, the safeline is unlikely to be equivalent to an "impact line" as defined by BC Hydro.
(2) Main Dam. Elevation appears to be incorrect, as the water license indicates normal operating water elevation range is 634.4 to 641.3 m ("local datum")
(3) The elevation is "as per the Operation, Maintenance and Surveillance Manual" (BC Comptroller of Water Rights. Final Water License 120711, 120712 (2005))
(4) https://www.bchydro.com/community/recreation_areas/pend_d_oreille_recreation_area.html#history
(5) In 1978, a consultant compiled a report for Arrow Lakes and a 'safeline' was defined prior to completion of the reservoir. The concept of "impact line" at BC Hydro came much later. In 1993 an internal group of BC Hydro engineers got together to create the concept of impact lines – there are five: 1) flooding impact line; 2) erosion impact line; 3) stability impact line; 4) ground water impact line; 5) landslide generated wave impact line. The most inland impact line is selected to make this the 'overall impact line'. Some private properties may have individual covenants specifying a safeline. Development restrictions are posed on the area internal to a safe line or impact line. No habitation is permitted on the downhill side, and any other structure on the downhill side of the line must be approved by BC Hydro. (personal communication, M. Chadwick, Stakeholder Engagement Advisor, BC Hydro. January 18, 2018).
(6) GSC Datum

The dam crest elevation was selected to define the hazard polygon for each reservoir. Inundation depths for the polygon were established by subtracting the DEM surface from the dam crest elevation. As the crest elevation was unknown for Seven Mile, the maximum licensed water elevation was used to define the hazard instead. For Whatshan Reservoir, the dam crest elevation is listed as 640.1 m; however, the CDEM reports a lake elevation of 643 m. Hazard polygons were compared for an elevation of 643 m and 652.3 m (Bylaw FCL), and neither elevation appeared to intersect buildings visible in imagery on cadastral parcels of interest. Therefore, the polygon for elevation 643 m was used to define the hazard polygon.

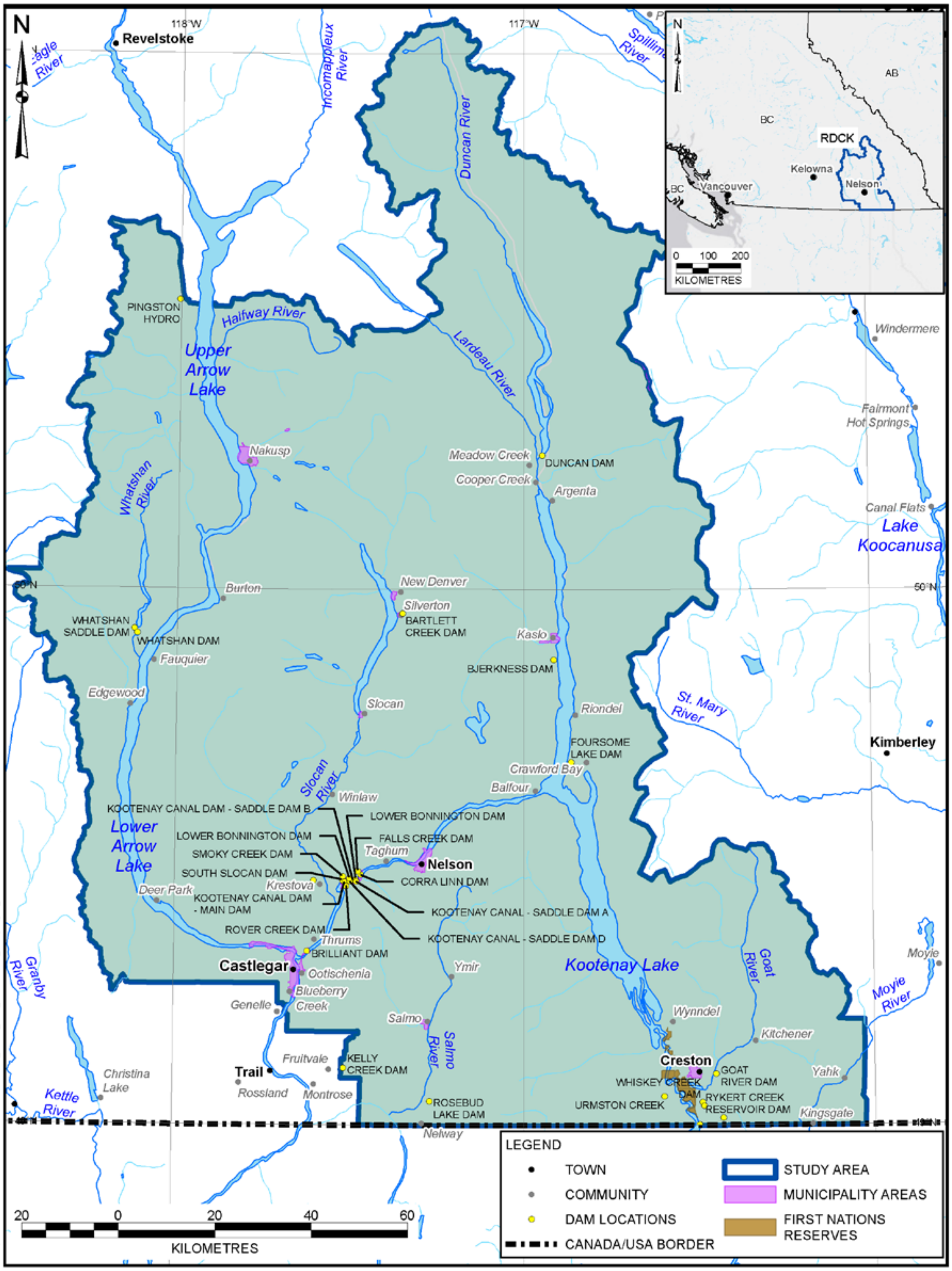


Figure E-11. Dams in the RDCK.

E.2.9. 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 and screening-level hydraulic modelling was not practical (for reasons such as poor topographic data, unknown flow regulation impacts, small areas containing few elements at risk). 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.

E.2.9.1. 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 RDCK to represent potential flood inundation extents for the remaining watercourses and lakes not included in the other approaches. The vertical offset approach was 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 E.2.1 and intersected with the RNT stream network to identify the geographical location of the watercourses. A 20 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 E-12).

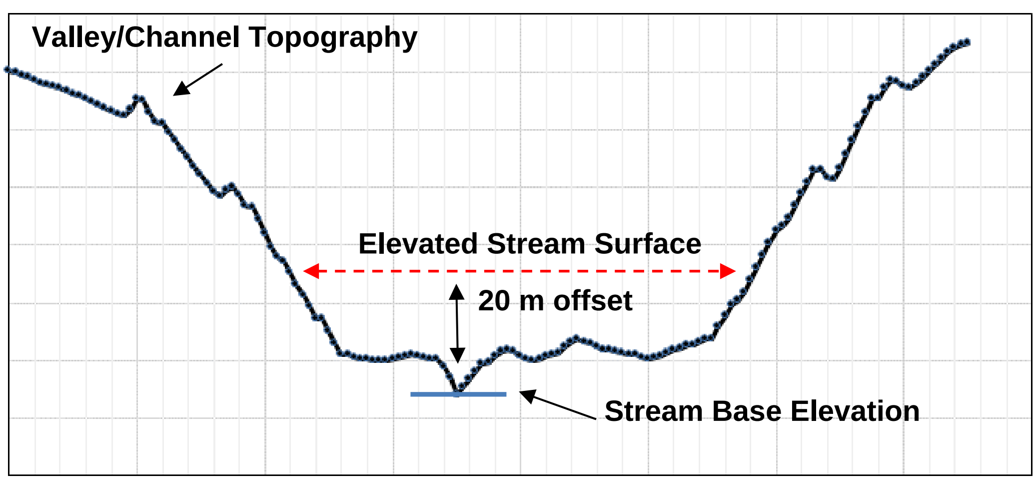
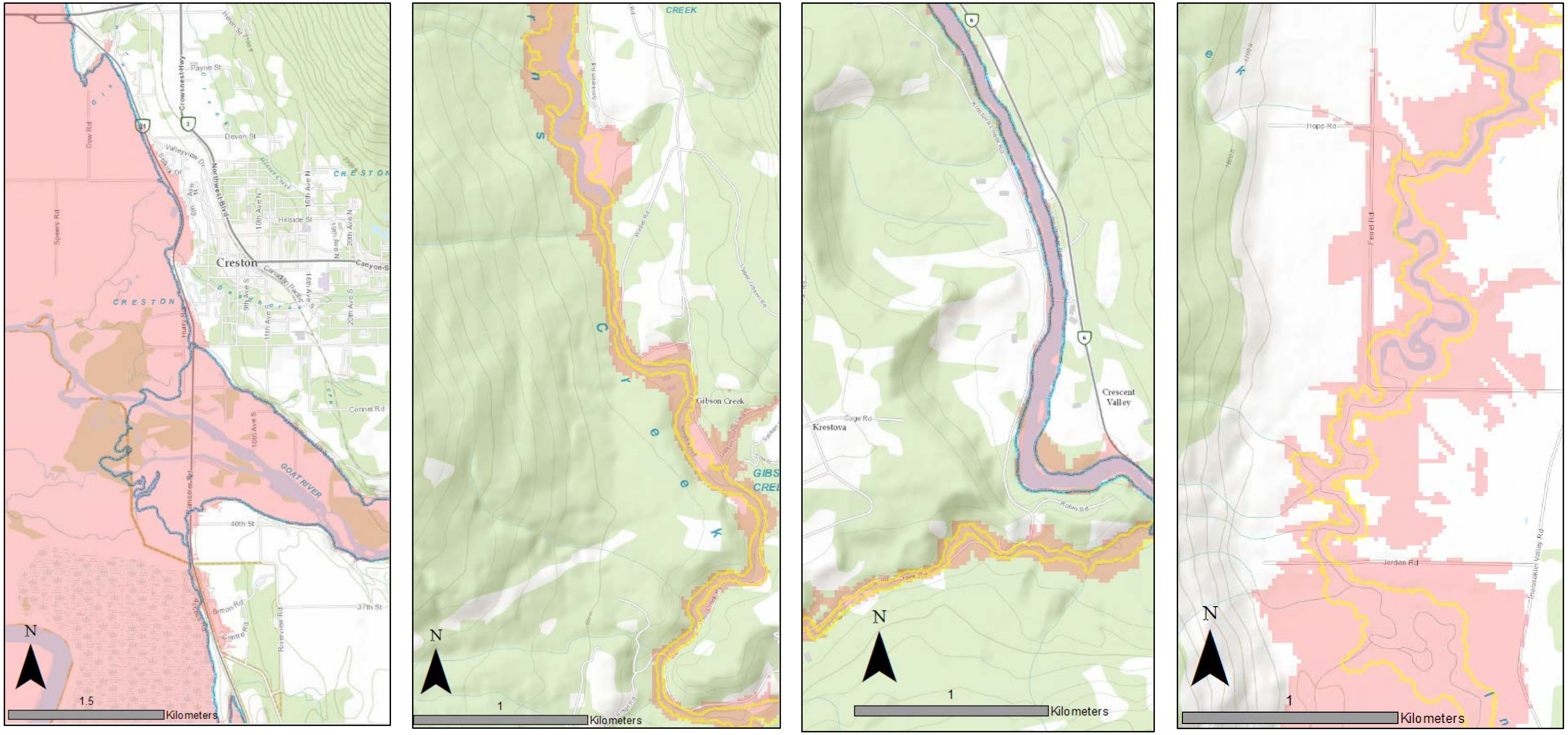


Figure E-12. Vertical topographic offset modelling conceptual sketch.

In the absence of existing floodplain mapping, this surface represents a “high-water level” estimate used to define topographic low-lying areas adjacent to watercourses that are potentially subject to flood inundation. A 20 m vertical offset and Strahler 4 or higher classification was selected given the resolution of the topographic dataset, in addition to comparing the resulting automated floodplain extents with previous, detailed studies as shown on Figure E-13.

Figure E-13 shows that generally the 20 m offset provides a conservative estimate of the 0.5% AEP (200-year return period) inundation extents and is intended to capture the widest extent of areas that should be considered in more detailed floodplain mapping. It is very likely that detailed floodplain mapping will reduce the hazard area from the extents generated by the 20 m offset and CDEM dataset. The vertical offset model provides a better estimate for confined floodplains and large rivers in wide floodplains. This reinforces that the quality of the results relies on the resolution of the DEM data to capture topographic features that influence the extent of the floodplains, which are better represented in the wider floodplains or very confined channels.

The vertical offset results were used as a proxy for the ‘0.5% AEP” flood extent in the absence of other information. However, they should not be considered a specific representation of a flood return period and do not replace hydraulic modelling or detailed floodplain mapping.



Kootenay River and Goat River at Creston. **Norris Creek** **Goose Creek at Slocan River** **Inonnoaklin River**

Figure E-13. Example comparisons of BGC vertical offset modelling results (20 m offset shaded in pink) against historical floodplain mapping (outlined in blue) and hazard extents developed from screening level hydraulic model results (outlined in yellow).

E.2.9.2. 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 RDCK. 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, RDCK Floodplain Bylaw). 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 (as shown in Figure E-14), whereas the 30 m horizontal buffer used by BGC results in a 60 m wide hazard zone centered around the mapped stream centerline because the stream network 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 E-15.

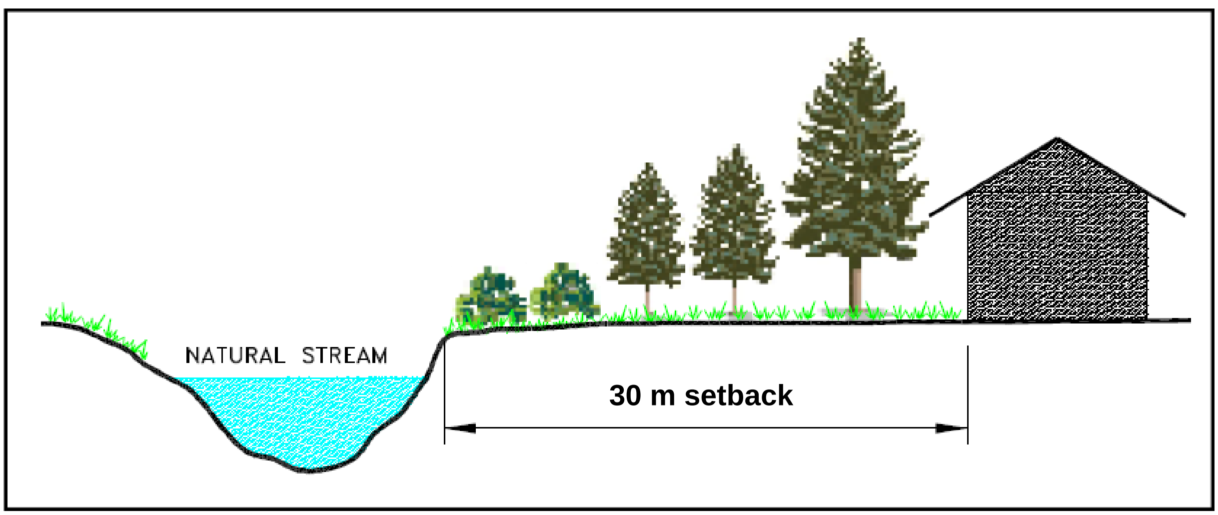


Figure E-14. A 30 m setback distance for natural streams applied to the top of bank. The horizontal buffer used by BGC was measured from the mapped stream centerline and does not represent the distance from the top of the bank of the watercourse.

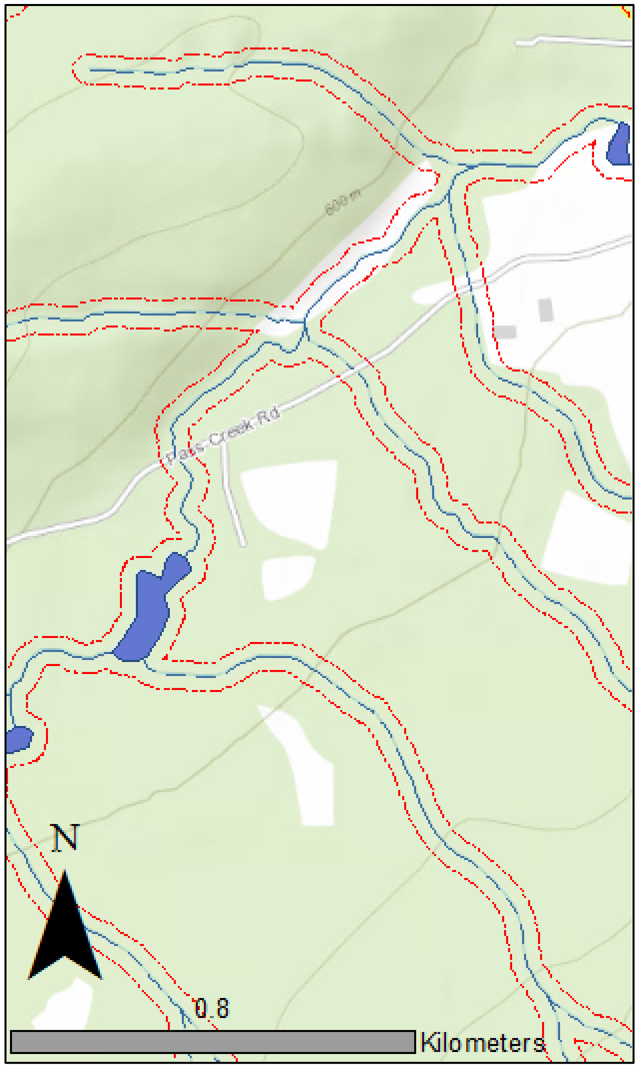


Figure E-15. Example of 30 m horizontal topographic buffer results (red outline) for Strahler order 3 or lower stream segments and lakes (shown in blue) in the RDCK to identify potential low-lying areas.

E.2.10. 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 an "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".

In the RDCK, the most extensive dike systems are found in the Creston Valley where approximately 93 km are found on the Kootenay River and a further 3.7 km are found on the Goat River (BGC, 2014a). In 2014, BGC completed a Floodplain Management Plan for the Lower Kootenay Band, one of 7 diking authorities in the valley. The study determined that:

- The present-day 200-year return period flows are approximately equivalent to the 2-year return period flows prior to construction of the upstream Libby Dam.
- The 200-year flood levels are well below dike crest levels and therefore the sources of flooding behind the dikes (for an event less than the 200-year) would be the result of a dike failure (rather than overtopping) or from internal drainage.
- That because the floodplain slopes away from the main Kootenay River channel, a breach during the 2-year return period flow could result in wide spread flooding. However, the diking districts do not share a common dike (except for one), and so the impacts of a breach would be limited to a single diking district.

In the RDCK, there are also a number of regulated dikes located on alluvial fans such as Duhamel Creek, Kokanee Creek and Eagle Creek, many of which are classified by the Province as Orphan works. The Province (MOE, 2009) recognizes that Orphan works:

> *"were typically built during or shortly after major historical flood and/or debris flow events. Most were built without engineering design and many are on private property. They are termed 'orphan works' because they are not being maintained by an owner or a diking authority. Most of the structures have deteriorated over time, are overgrown with vegetation and do not have access for machinery."*

The web map displays the inventoried flood protection works in the RDCK. 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.

E.2.11. 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 RDCK. Because no single dataset exists for watercourse crossings in the RDCK, 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) that is owned and/or maintained by MoTI.

- 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. Some municipalities in the RDCK maintain digital databases for their infrastructure, but where available, the information was found to be of limited detail.

E.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.

E.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 clear-water flood sites across the RDCK, which corresponds to a representative AEP of 0.5% or a “low” geohazard likelihood as summarized in Table E-7.

Table E-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).

E.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:

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

This section describes how these two factors were determined.

E.3.2.1. Hazard Exposure Rating (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.

Within this study, cadastral parcels with a BC Assessment improvement value greater than zero dollars[8] ("parcels of interest") were used to identify hazard areas and assign both hazard exposure and hazard intensity (E.3.2.2) ratings. These parcels also correspond to those containing people, critical facilities, or businesses. The remaining categories of elements at risk (lifelines and environmental values) were assessed on a presence/absence basis across the entire hazard area and are present within all of the hazard areas mapped. However, remote areas containing lifelines or environmental values, but no other development, were not considered in geohazard area delineation.

E.3.2.2. Hazard Intensity Rating

Parameters were developed for classifying clear-water hazard polygons into one of five hazard intensity categories: very low; low; moderate; high; and, very high. The parameters selected were peak flood depth above the ground surface for portions of hazard areas where this information was available, and flood event peak discharge (see Section E.2.2) as a proxy for flood depth where it was not available (such as sites where floodplain extent prediction techniques were used). Relative flood severity (as estimated by flood depth or discharge) parameter breakpoints used in this study for each category are shown in Table E-8. The thresholds shown for depth reflect typical residential first-floor elevations (FEMA 2017), while the 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 (e.g., FEMA, May 2016). As well, the flood depths do not account for the occurrence of flood protection structures that could potentially alter the extent of flood inundation.

[8] Parcels with the land use code 428 (Managed Forest – Improved) were also excluded.

Table E-8. Hazard intensity rating categories and relative flood intensity criteria.

Relative Hazard Intensity Parameters[1]		Hazard Intensity Rating
If Flood Depth is Available:	If Flood Depth is Not Available:	
Average Peak Flood Depth above Ground Surface (m)	Q_{200} discharge (m^3/s)	
< 0.1	< 1	Very Low
0.1 – 0.3[2]	1 – 6	Low
0.3 - 1.5[2]	6 – 200	Moderate
1.5 – 3	200 – 1000	High
> 3	> 1000	Very High

(1) It should be noted that 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 where it was not available. 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

(2) 0.3 m and 1.5 m correspond to the default assumed first-floor elevation of a concrete slab foundation residential building, and a residential building with a sub-grade basement, respectively (FEMA 2017). These thresholds assume a step-increase in flood damages once flood depths exceed first-floor elevation, but do not replace the use of stage-damage curves as would be required for detailed flood scenario and consequence modelling.

In order to assign a single hazard intensity rating to each hazard area, each cadastral parcel of interest within the hazard area (i.e., cadastral parcel with non-zero improvement value) was assigned a rating based on either the average peak flood depth across the parcel or the discharge associated with the stream segment which intersects the parcel[9]. Ratings for each of the parcels within the hazard area were averaged, weighted by parcel area located within the hazard area. The resulting average hazard intensity rating was then applied to the entire hazard polygon.

The other categories of elements at risk (lifelines and environmental values) did not factor into the hazard intensity rating or the delineation of hazard polygons.

[9] If more than one stream segment intersects the parcel, then the one with the higher discharge was selected. If no stream intersects the parcel, then the discharge of the nearest stream segment was selected.

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APPENDIX F
HAZARD ASSESSMENT METHODS – STEEP CREEKS

F.1. INTRODUCTION

F.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 F.1 provides background information and key terminology.
- Section F.2 describes methods and criteria used to identify steep creek geohazard areas.
- Sections F.3 and F.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.

F.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 F-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 and Onda, 2004).

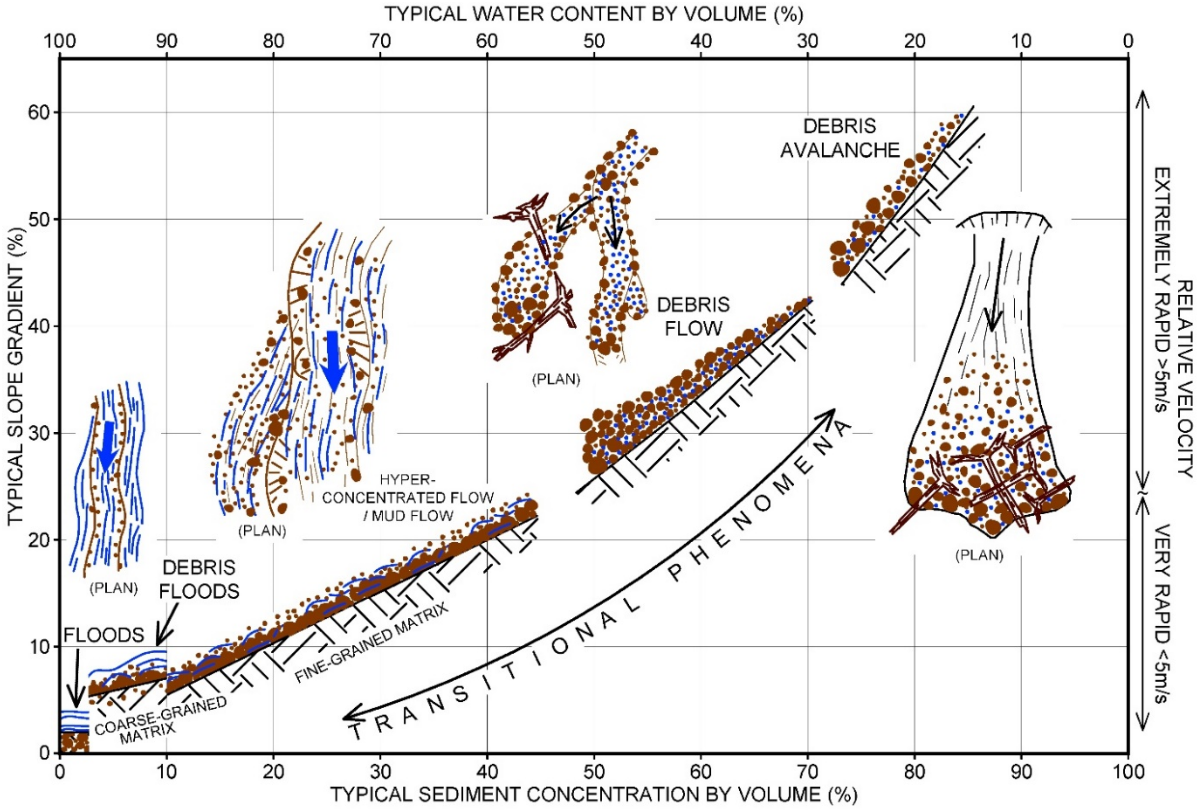

Figure F-1. Hydrogeomorphic process classification by sediment concentration, slope velocity and planform appearance.

F.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 F-2 provides a typical example of a steep creek in the RDCK.

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 F-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.

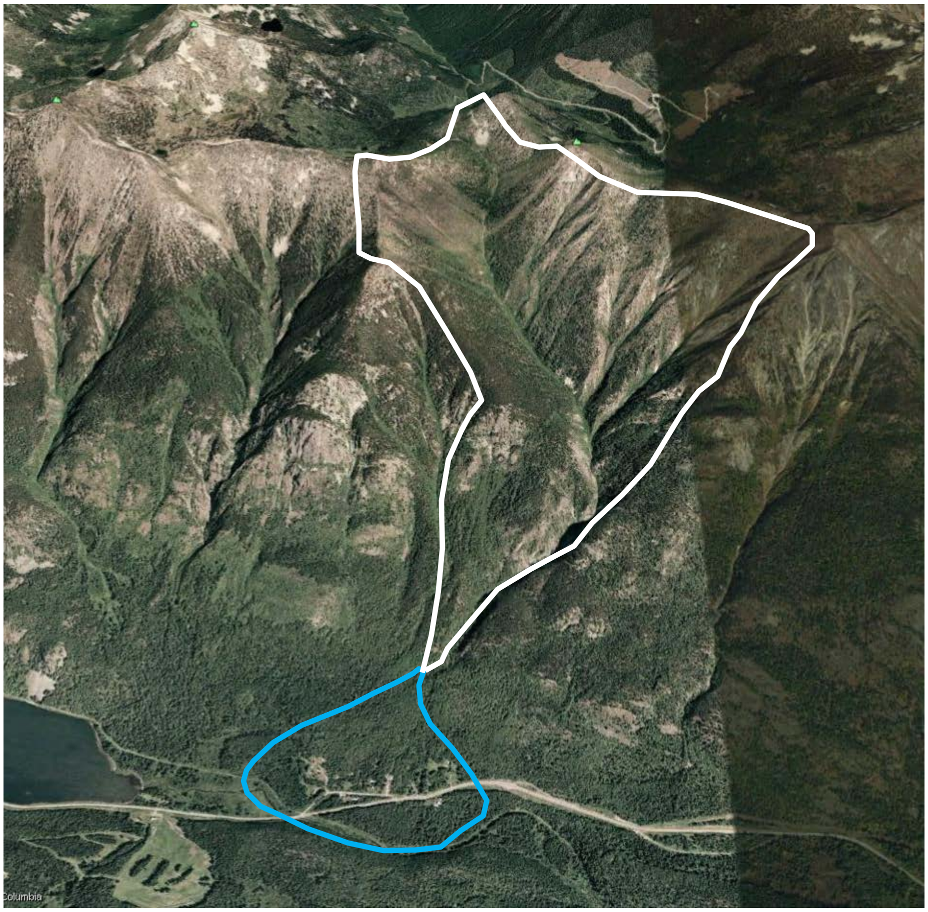

Figure F-2. A Google Earth image of a typical steep creek watershed (Charlie's Creek) located near Nakusp in the RDCK. The approximate watershed and fan boundary are outlined in white and blue, respectively.

Figure F-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 F-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 catastropically. 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.

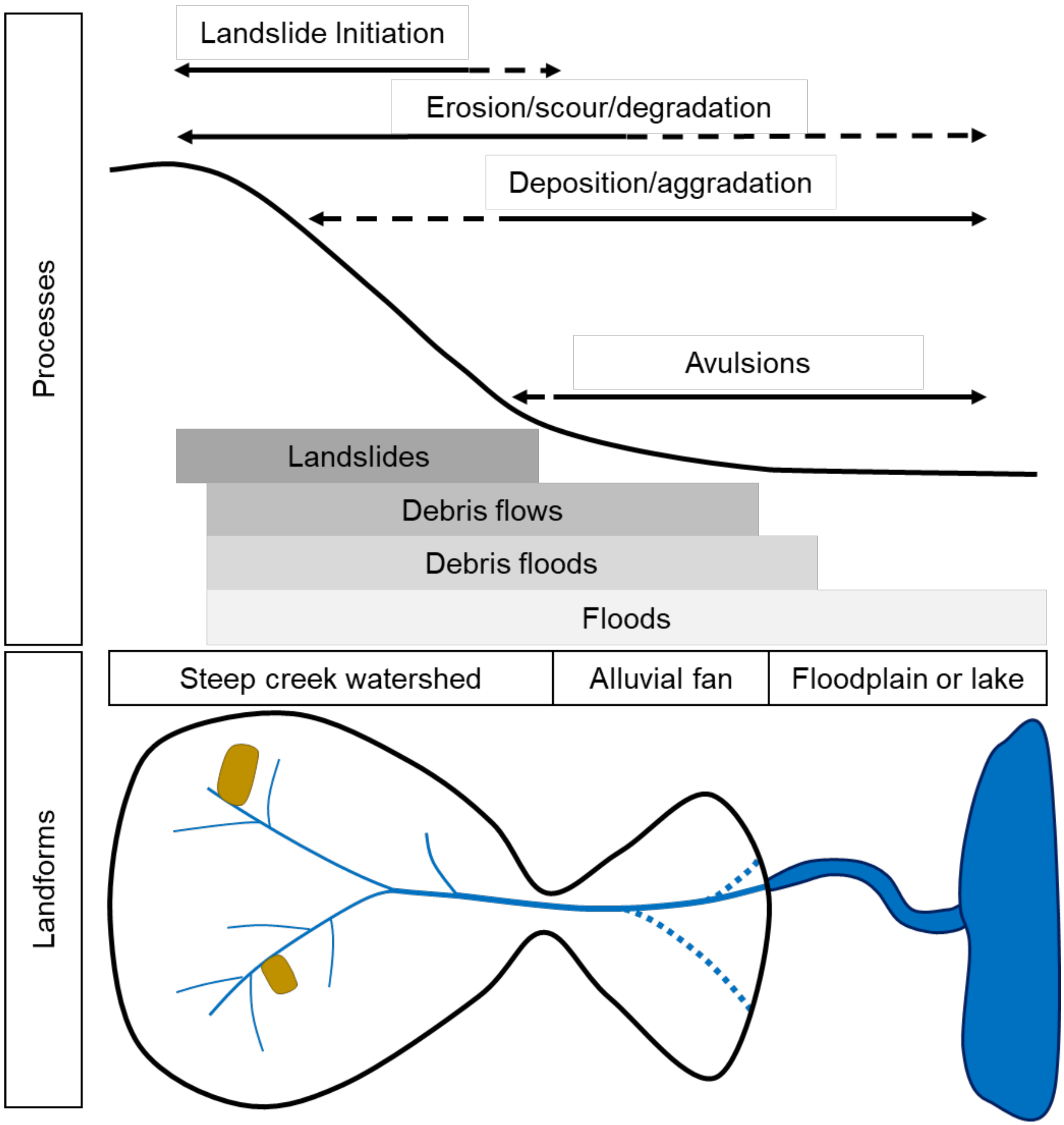

Figure F-4. Schematic diagram of a steep creek watershed system that shows the principal zones of distinctive processes and sediment behaviour. The alluvial fan is thought of as the long-term storage landform with a time scale of thousands to tens of thousands of years. Sketch developed by BGC from concepts 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). 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.

F.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).

F.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 and 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

[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).

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).

F.2. STEEP CREEK GEOHAZARD IDENTIFICATION

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

F.2.1. Fan Inventory

Fan[3] extents were manually delineated in an ESRI ArcGIS Online web map based on hillshade images built from lidar Digital Elevation Models (DEM) and review of previous fan mapping (e.g. MWLAP, 2004; Klohn Crippen, July 7, 2004). 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 the ESRI web map 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 330 fans were mapped. The web map provided with this report links to geotechnical reports for a given fan, where existing.

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 F-5). 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 RDCK, this corresponds to approximately 25 m grid cell resolution (Government of Canada, 2016).

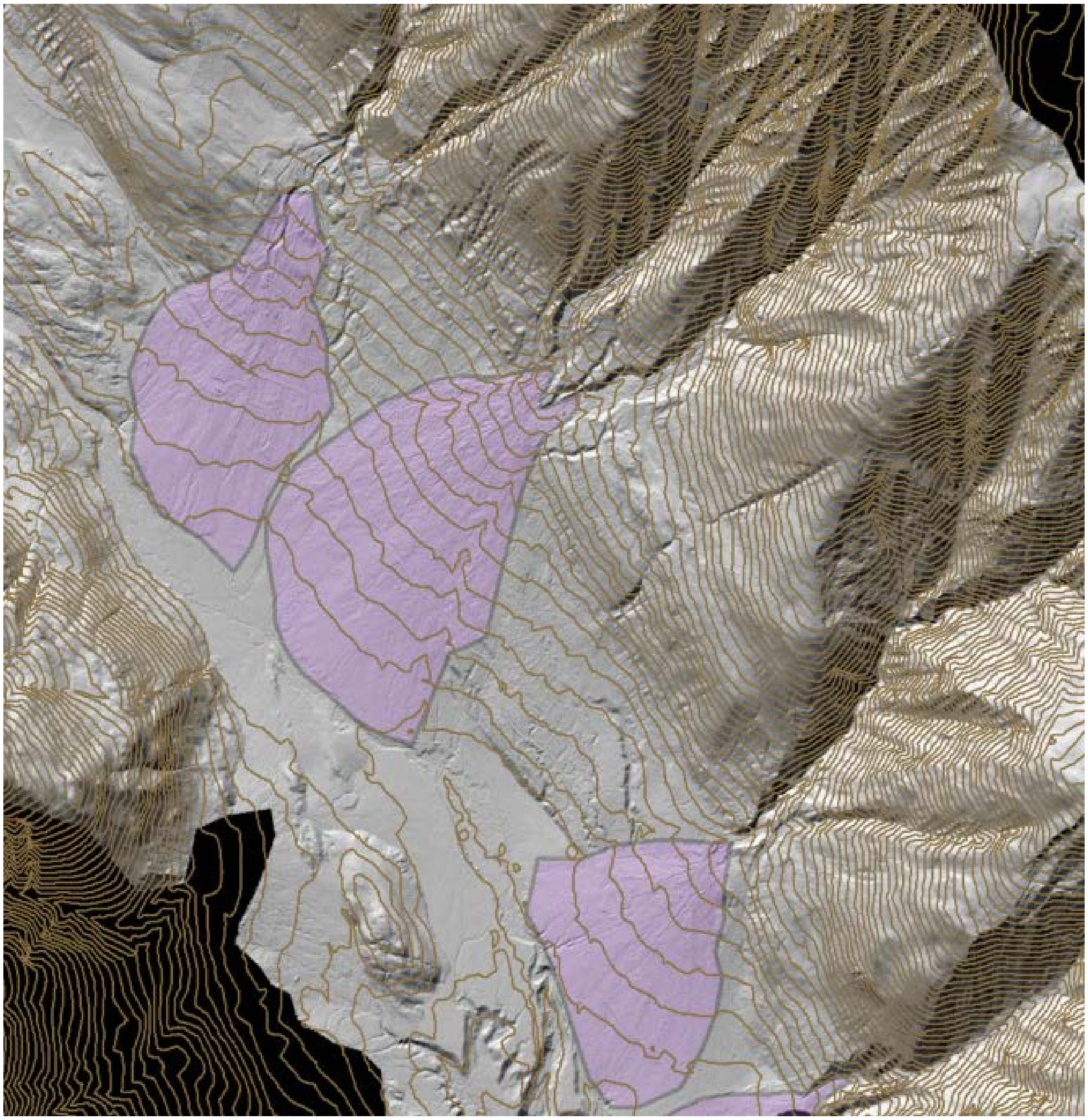

Figure F-5. Example of lidar hillshade showing from left to right, Unnamed Creek, Owl Creek and Cadden Creek fans.

F.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.

F.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.

F.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 length6 for each segment of each creek. These t errain 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 F-6 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 F-1 lists class

[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.

boundaries used to define process types on each segment of each creek within the RDCK. The results are shown on the web map as a layer coloring each stream by predicted process type.

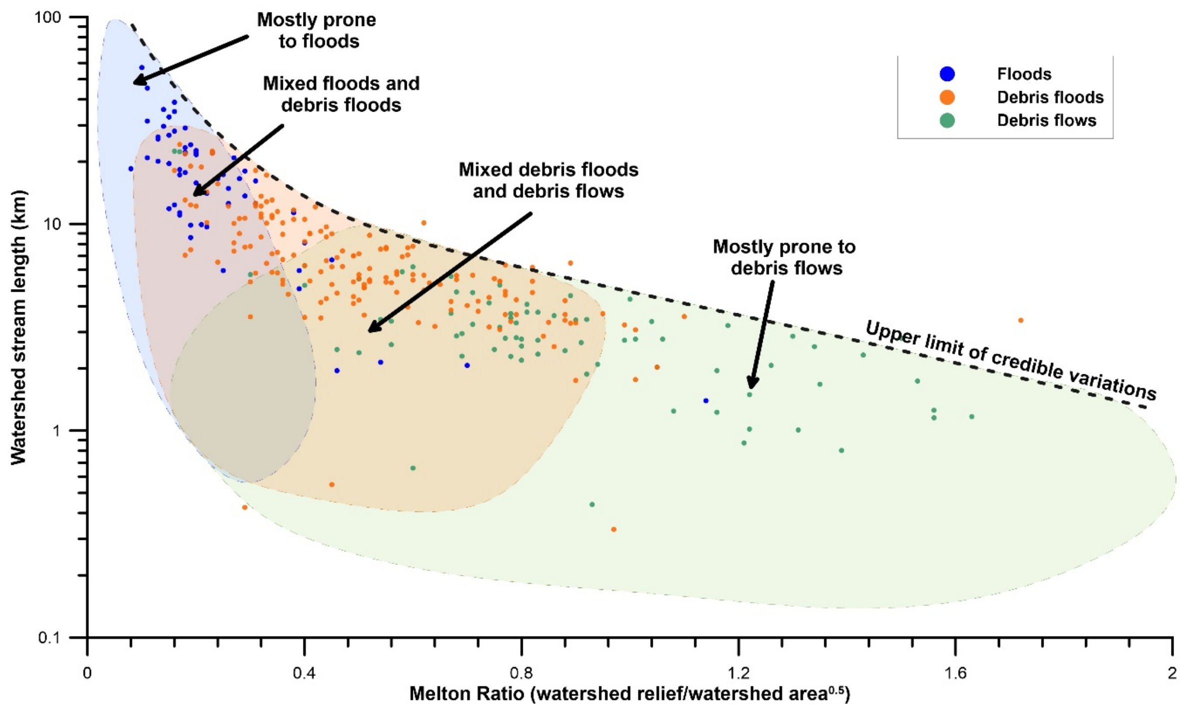

Figure F-6. Steep creek processes in the RDCK as a function of Melton Ratio and stream length. Process boundaries are derived from this study and additional fans in Alberta and BC (Holm et el., 2016, Lau, 2017).

Table F-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).

F.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 F.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 F.3.2)?

This section describes methods to estimate both factors and combine them to arrive at a geohazard rating. Appendix D 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.

F.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 F-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 F-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 F-7 and Figure F-8. 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 F-3 lists the fan and basin characteristics used to assign hazard frequency categories.

Figure F-7. Example of evidence for recent landslide activity within the basin of Fry Creek Fan No. 101.

Figure F-8. Example of bright tones on an alluvial fan caused by exposed sediment and vegetation removal caused by the August 2004 debris flows on Fan No. 63, Kookonook Creek (Jordan, 2004).

Table F-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 AAR²; 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 AAR²; 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 (AAR²); 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 (AAR²); 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 (AAR²); 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/a¹		n/a¹		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/a¹		n/a¹		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 AAR² 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.

Of the 329 steep creek fans that were inventoried, 18 are at the outlet of watersheds subject to wildfires in the past 5 years. These watersheds are indicated on Cambio Communities and activity within these basins was implicitly considered in hazard likelihood estimates according to Table F-3. However, detailed post-wildfire geohazard assessment was outside the scope of work, and the likelihood of geohazards is subject to change following future wildfires.

F.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 (Section F.3.2.1) and steep creek susceptibility modelling for all streams identified as being subject to steep creek hazards[8] (Section F.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.

F.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.

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

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 F-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 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 F-9). These features are readily detectable on lidar hillshades; interpretations are less certain for areas without lidar coverage.

Figure F-9. Example of evidence for higher avulsion potential on Fan No. 101 on Fry Creek.

Table F-4. Avulsion potential criteria.

			Channel Confinement[1]				
			Very High	**High**	**Moderate**	**Low**	**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.

F.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 F.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 F.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 F.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 Kootenay 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

[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

a 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 RDCK (Holm et al., 2018). As such, the Canmore-area creeks provided a good starting point to calibrate the model.
- BGC then applied the calibrated model to creeks adjacent to Kootenay Lake east of Nelson and west of Balfour, and compared the results to terrain analyses.
- Finally, BGC applied the model to map debris flow and debris flood susceptibility on all creeks in the stream network, within the RDCK. The results were further compared to terrain analyses and a database of past road closures (BC MoTI, 2018).

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

Selection	FLOW-R Parameter	Value
Directions algorithm	Holmgren (1994) modified	dh = 2 exponent = 1
Inertial algorithm	weights	Gamma (2000)
Friction loss function	travel angle	5°
Energy limitation	velocity	< 15 m/s

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

Selection	FLOW-R Parameter	Value
Directions algorithm	Holmgren (1994) modified	dh = 2 exponent = 1
Inertial algorithm	weights	Cosinus
Friction loss function	travel angle	4°
Energy limitation	velocity	< 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 F-10). Within each affected area, the summed susceptibility values follow a negative exponential distribution (Figure F-11). 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 F-11). 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.
- Susceptibility mapping does not replicate special cases such as the Johnsons Landing debris flow, where the main channel is characterized by a sharp change in direction and debris flows may overtop the channel (Nicol et al., 2013).

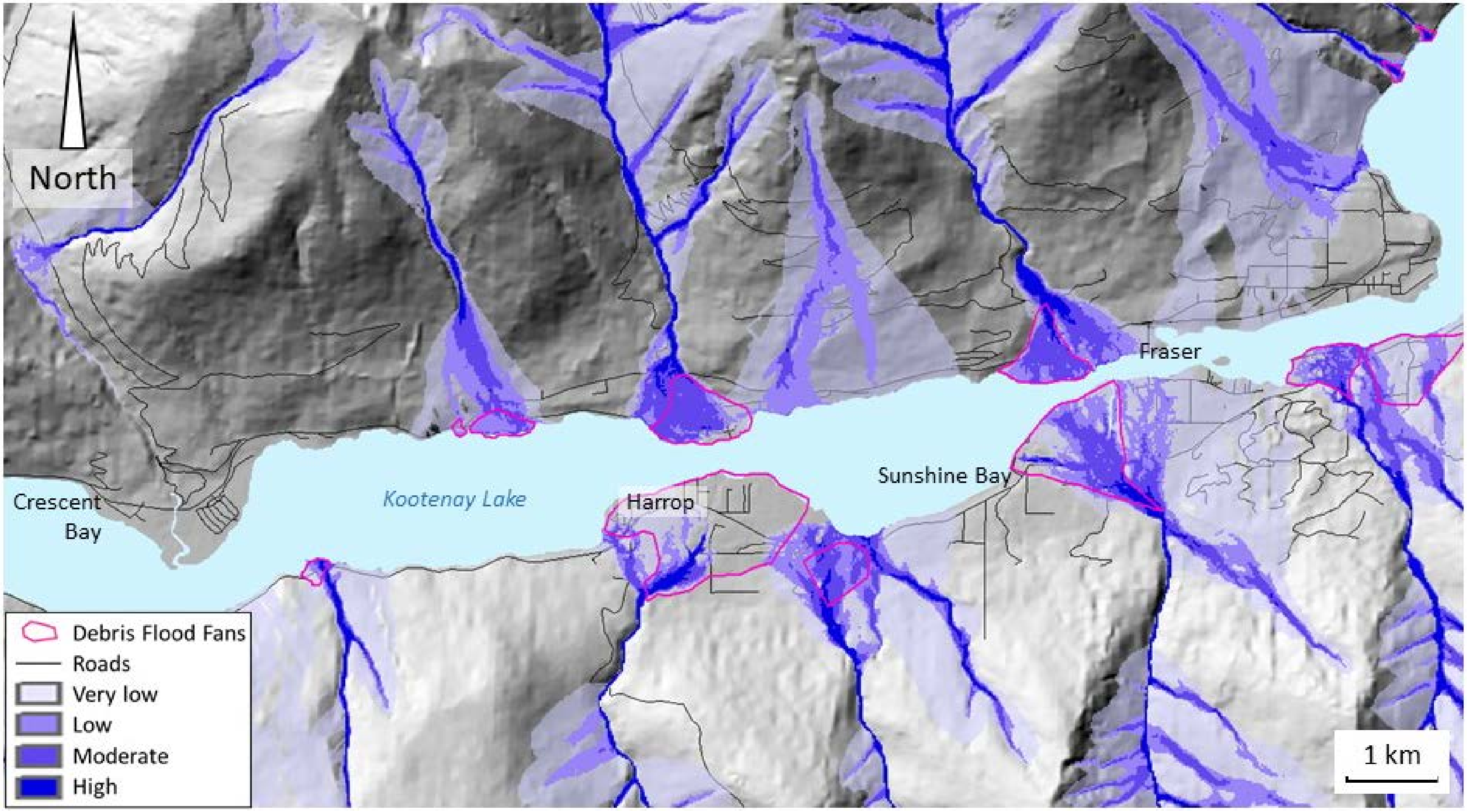

Figure F-10. Debris flood susceptibility map for a section of the study area showing the spatial distribution of the four different susceptibility classes. Note that this is a susceptibility map, and as such an individual debris flood event will very unlikely occupy the same area as shown in this figure.

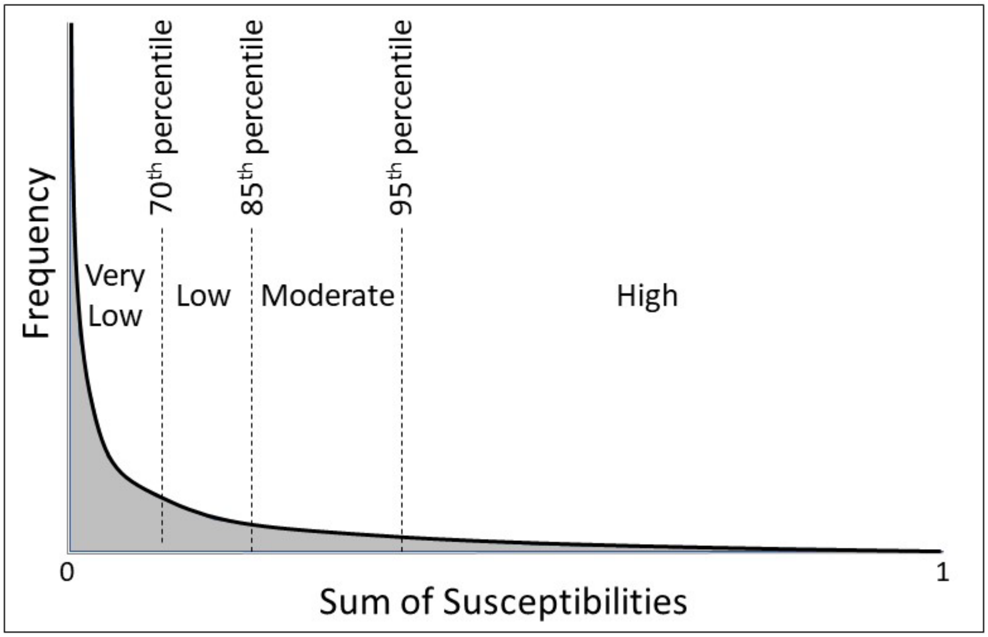

Figure F-11. Illustration of the negative exponential distribution of summed susceptibilities and the percentiles used to define zones of very low, low, moderate and high susceptibility.

F.3.2.3. Landslide Dam Outbreak Floods

Some watersheds are prone to landslide dam outbreak floods (LDOFs), which could have the potential to trigger major flooding, debris floods or debris flows. Table F-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 F.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 F-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 F-12 shows an example of a potential landslide dam location in Harrop Creek basin. Note that actual landslide dams are not visible at the resolution of Figure F-12; the interpretation is based on the combination of characteristics noted above. However, these basins are identified on the web application and in results for consideration in future more detailed assessment.

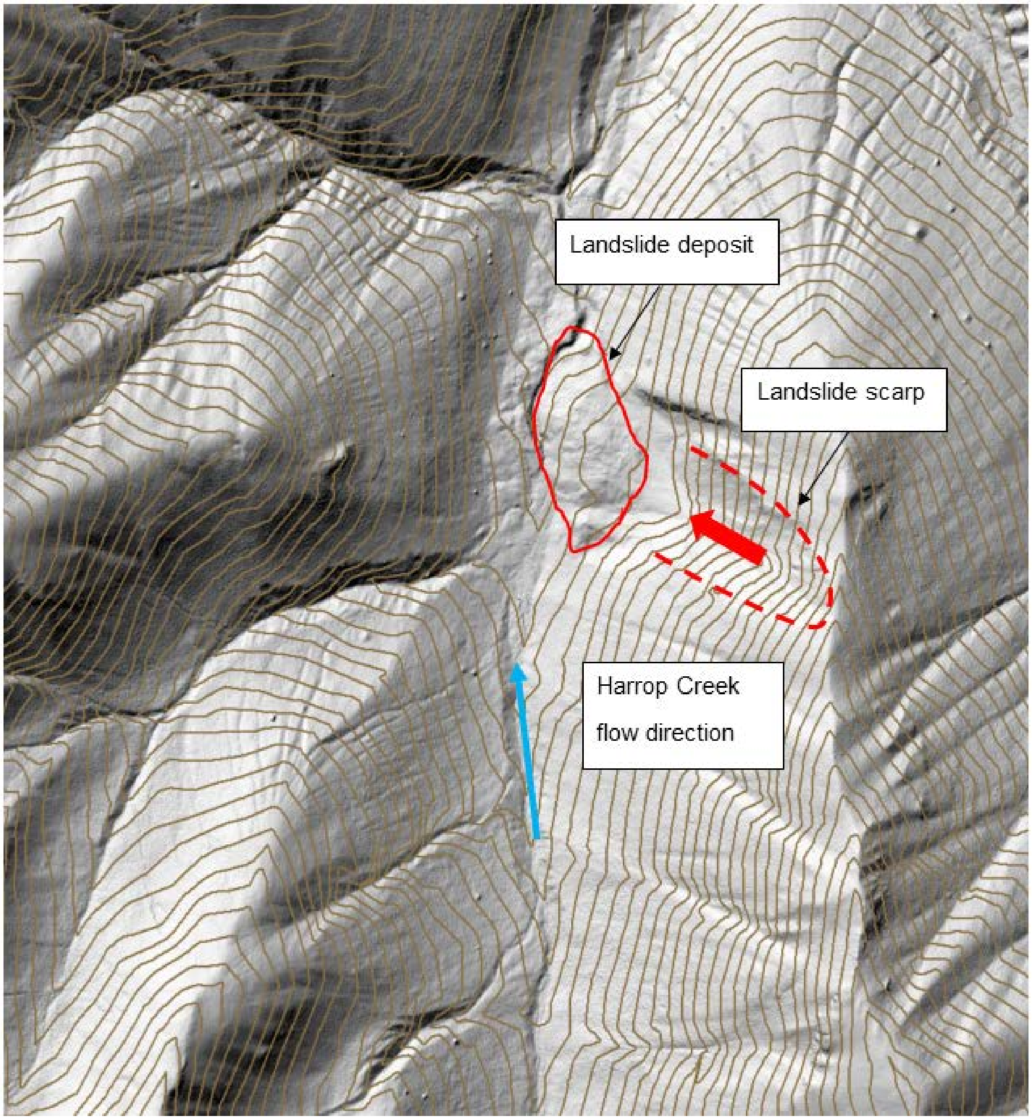

Figure F-12. Example of evidence for landslide dam outbreak flood potential in Harrop Creek basin.

F.3.2.4. Impact Likelihood Rating

Table F-8 provides impact likelihood criteria, which are based on both susceptibility modelling and terrain interpretation. 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 F.3.2.3. For clearwater floods, impact likelihood was estimated based on avulsion potential (Table F-4) and adjustments for evidence of past avulsion and possibility of landslide dam outbreak events.

Table F-8. Summary of criteria used for impact likelihood rating.

Impact Likelihood Rating	Criteria*
Very Low	Fan area is rated Very Low susceptibility; no evidence of past avulsion
Low	Less than 40% of fan area is rated Moderate or High susceptibility; poor evidence of past avulsion
Moderate	Less than 40% of fan area is rated Moderate or High susceptibility, and moderate evidence of past avulsion; OR 40 to 70% of fan area is rated Moderate or High susceptibility, and poor evidence of past avulsion
High	More than 70% of fan area is rated High susceptibility; OR 40 to 70% of fan area is rated Moderate or High susceptibility, and moderate evidence of past avulsion
Very High	More than 70% of fan area is rated High susceptibility, and moderate to strong evidence of past avulsion; OR 40 to 70% 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".

F.3.3. Geohazard Rating

Table F-9 presents a qualitative geohazard rating assigned to each area. It combines the hazard likelihood (Table F-3) and impact likelihood ratings (Table F-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 F-9. 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

F.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 RDCK, and in the context of the current prioritization study, BGC used peak discharge as a proxy for flow intensity.

F.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 F-13 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).

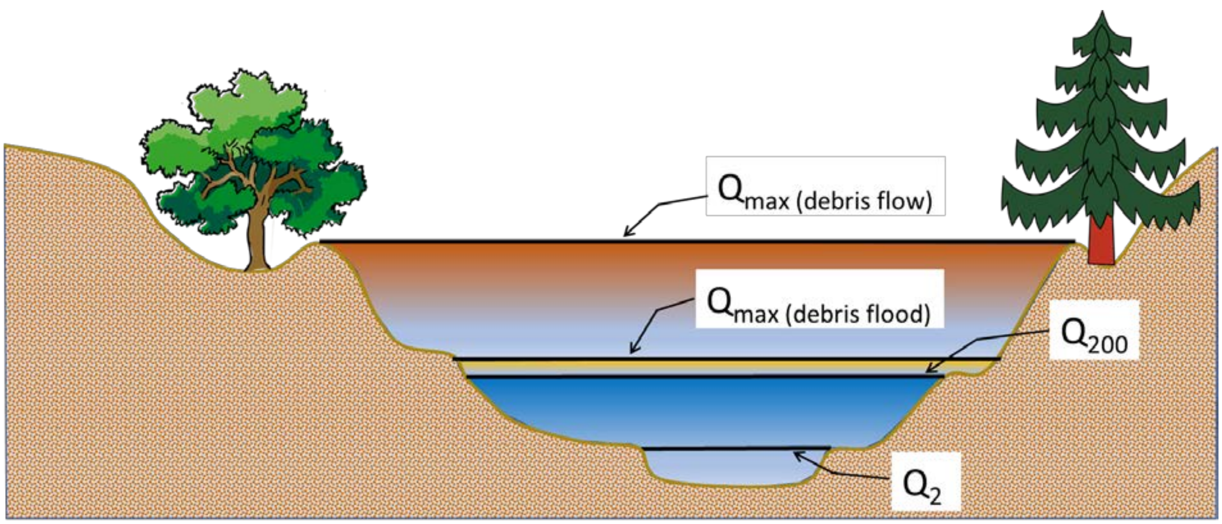

Figure F-13. Steep creek flood profile showing peak flow levels for different events.

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 E) 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 then plotted collectively versus return period. A logarithmic best-fit curve was then fit to the data, Figure F-14 show 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.

[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.

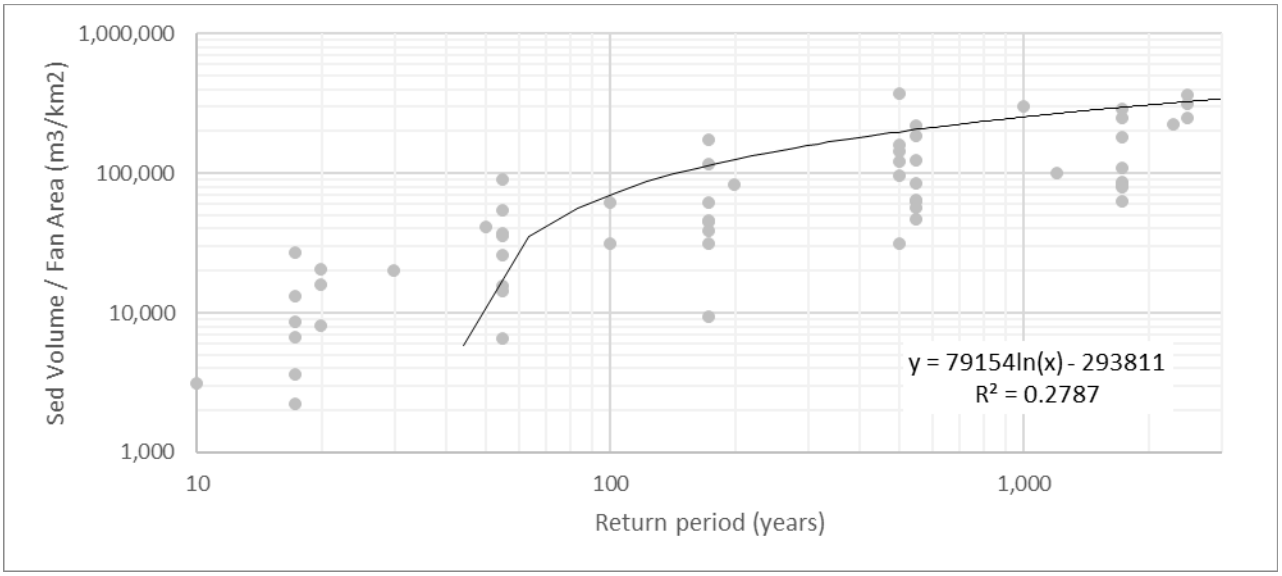

Figure F-14. F-M curve for debris flows in southwestern British Columbia and Bow Valley, Alberta, using data from sixteen study creeks. Curves are truncated at the 40-year return period (Jakob et al., 2016).

The regional F-M relationship (Equation F-1, derived from Figure F-14) was developed by BGC from the detailed study[12] of sixteen creeks in southwestern BC, as follows:

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

BGC predicted sediment volumes (V_s) for each study fan with area (A_f) of the RDCK 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.

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. F-2]

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

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

[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.

F.4.2. Hazard Intensity Rating

Peak discharge estimates obtained based on the methods described in Section F.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 F-10). 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 RDCK 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 F-10. 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 G
CLIMATE CHANGE

G.1. INTRODUCTION

Climate change is expected to impact flood hazards both directly and indirectly through complex feedback mechanisms. This makes it challenging 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 RDCK 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 RDCK.

The results of the climate change sensitivity analysis were not incorporated into the prioritization, but 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 RDCK, as part of future studies.

A number of temperature, precipitation, and hydrologic climate change impact studies have been completed for the Kootenay region, including the following reports from the Pacific Climate Impacts Consortium (PCIC) out of the University of Victoria:

- (2012). Plan2Adapt. https://www.pacificclimate.org/analysis-tools/plan2adapt. [Accessed August 17, 2018]
- (2013). Climate Summary For: Kootenay/Boundary Region: Part of a Series on the Resource Regions of British Columbia [online]. Available from https://www.pacificclimate.org/sites/default/files/publications/Climate_Summary-Kootenay-Boundary.pdf [accessed January 30, 2018]. University of Victoria.
- (2011a). Change on BC Water Resources: Summary Report for the Campbell, Columbia and Peace River Watersheds. July.
- (2011b). Hydrologic Impacts of Climate Change in the Peace, Campbell and Columbia Watersheds: Hydrologic Modelling Project Final Report (Part III).

And from the Columbia Basin Trust (CBT):

- (2017). Water Monitoring and Climate Change in the Upper Columbia Basin - Summary of Current Status and Opportunities. January.

Projected changes in average climate variables across the RDCK are presented in Table G-1 and show that there is likely to be:

[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 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.

Average annual maximum hourly precipitation intensity (i.e. 2-year return period 1 hour rainfall or snowfall peak intensity) for both December/January/February (DJF) and June/July/August (JJA) periods are generally projected to increase in the RDCK relative to the period January 2001 to September 2013, assuming an RCP 8.5 scenario and a 95-year ensemble monthly mean climate change signal from 19 Coupled Model Intercomparison Project Phase 5 (CMIP5) models (Prein et al., 2017). The 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[2].

Table G-1. Plan2Adapt. Projected changes in average climate variables in the RDCK (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	+1.9 ºC	+1.2 ºC to +2.8 ºC
Precipitation(2)	%	Annual	+5 %	-3 % to +10 %
		Summer	-8 %	-20 % to -2 %
		Winter	+7 %	-3 % to +17 %
Snowfall	%	Winter	-9 %	-16 % to +3 %
		Spring	-52 %	-72 % to -8 %

Notes:
(1) Source: Pacific Climate Impacts Consortium 2012. 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.

[2] There are large uncertainties with this values as frequency changes are sensitive to changes in weather patterns, which were assumed to stay constant in the study's simulations.

G.2. RELATIVE CLIMATE CHANGE SENSITIVITY – REGIONAL EVALUATION

Climate change sensitivity was defined and evaluated differently for clear-water and steep creek flood hazards.

G.2.1. 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 RDCK can be sub-divided into five (5) 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 RDCK.
- 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 (e.g., catchment areas, watershed shape, etc.) 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 (G.2.1.1), streamflow regimes and the influence of snowmelt (G.2.1.2), results (G.2.1.3), and uncertainties (G.2.1.4).

G.2.1.1. Regional Variations in Snowpack

The RDCK can be sub-divided into five (5) hydrologic regions, and each region has a relatively different, typical snowpack depth (Figure G-1, Table G-2).

Table G-2. Hydrologic regions of the Columbia Basin located in the RDCK and their existing relative snowpack depth (CBT, 2017).

Region	Existing Relative Snowpack Depth
St Mary-Moyie	Low to moderate snowpack
Kettle-Inonoaklin	Moderate to low snowpack
Lower Columbia-Kootenay	Moderate snowpack at higher elevations
Mid Columbia-Kootenay	Moderate to deep snowpack
Northwest Columbia-Kootenay	Deep snowpack

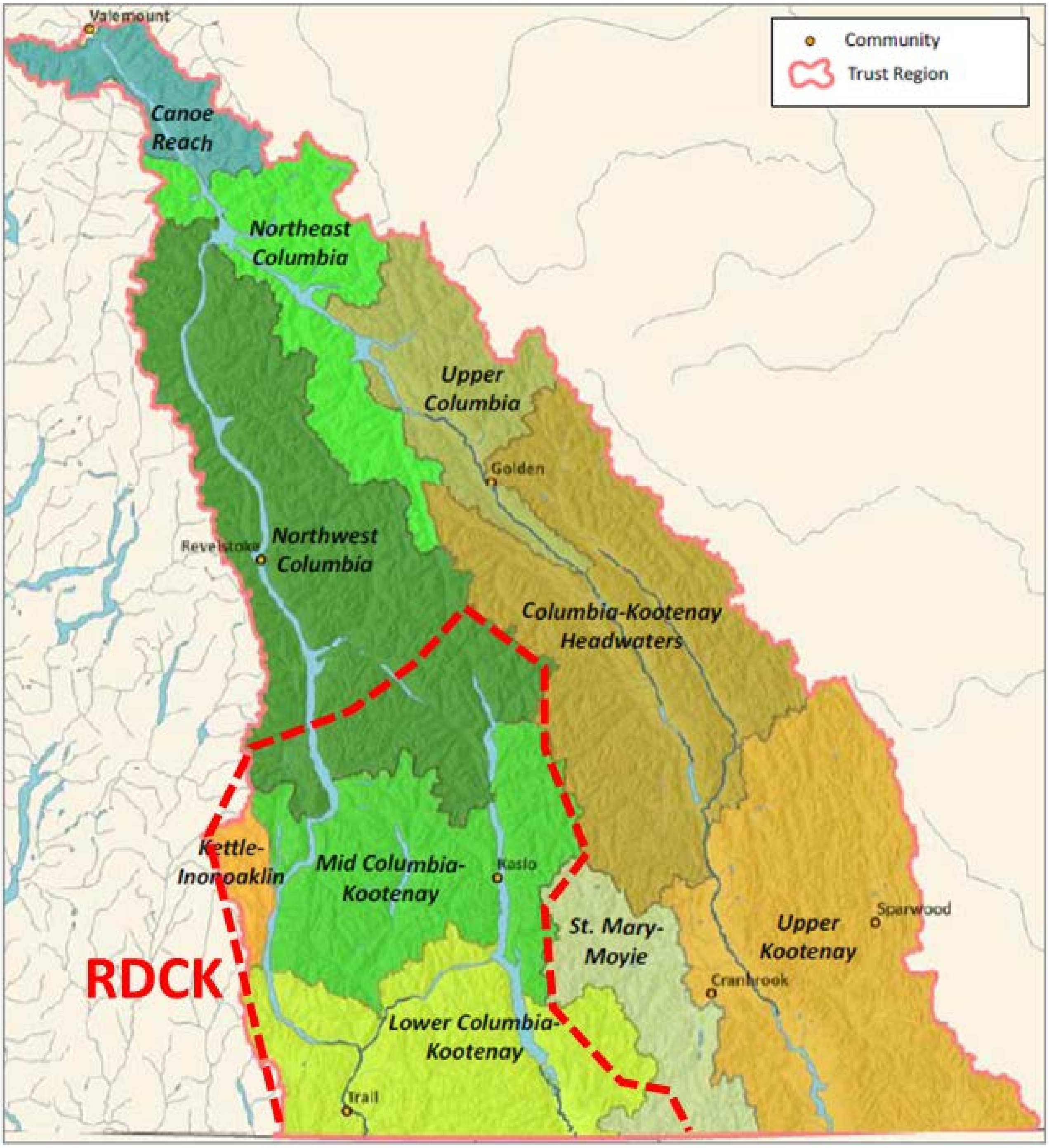

Figure G-1. Hydrologic regions of the Columbia Basin as indicated by patterns of climate and surface runoff. The RDCK contains 5 of these regions (CBT, 2017)

G.2.1.2. 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).

Example annual hydrographs are shown in Figure G-2. Snowmelt-driven and -dominant regimes have their maximum annual flow occur with the spring freshet.

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 would likely shift to a different season[3].

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 is dependent on the snowpack depth as well as spring temperature and rainfall patterns. The timing of the freshet is also dependent on these example factors:

- 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 the snowpack depth) is typically the dominant factor impacting timing sensitivity (PCIC 2011). Where climate change is projected to result in a reduced snowpack, streamflow regimes would be expected to shift (Figure G-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).

[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).

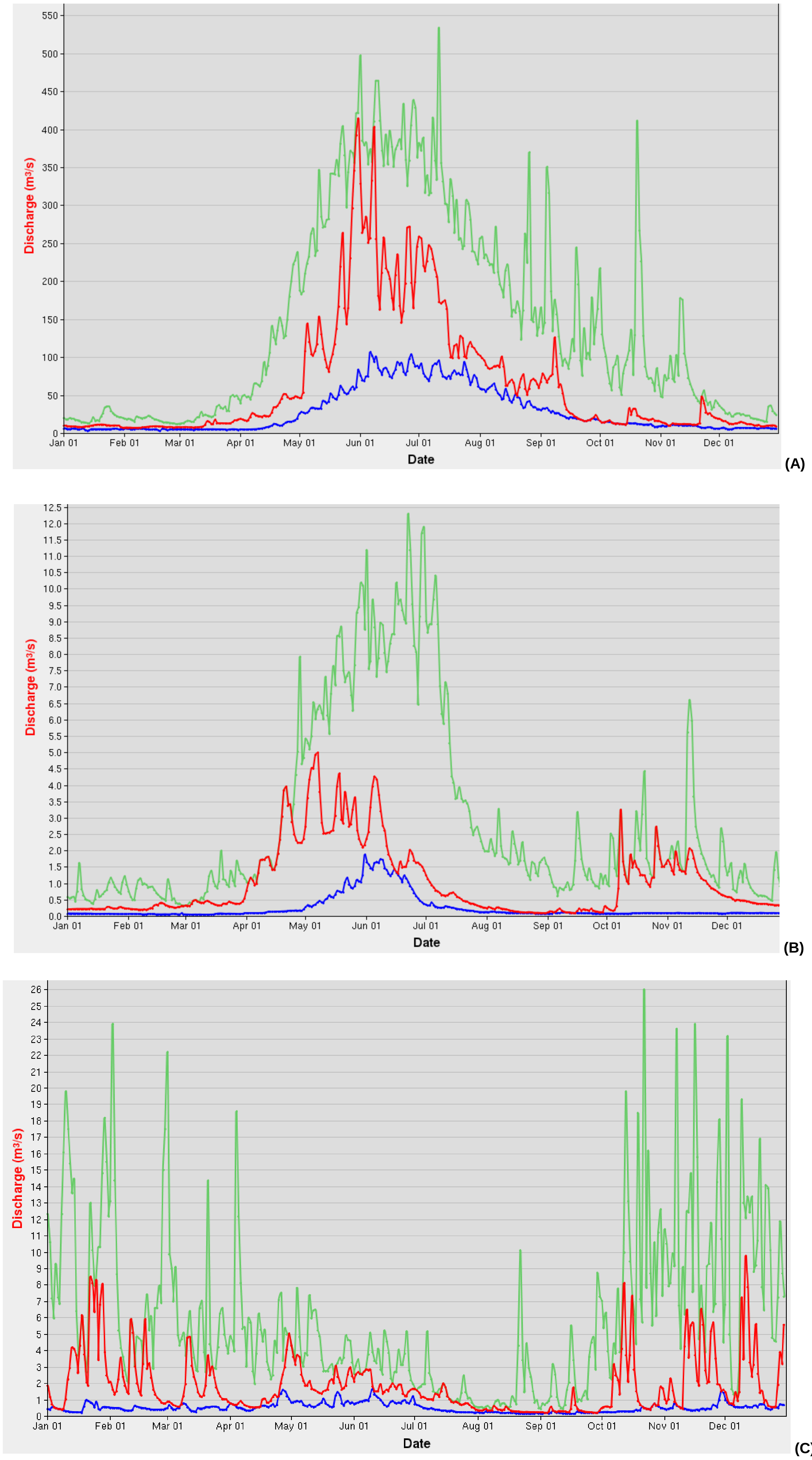

Figure G-2. Example streamflow regimes from Water Survey of Canada gauge records. Green line indicates gauge record daily maximum. Blue line indicates gauge record daily minimum. Red line indicates record for a single year. (A) Glacial-Supported Nival. Gauge: Duncan River above B.B. Creek. (B) Nival-Dominant Hybrid. Gauge: Moyie River at Eastport. (C) Pluvial-Dominant Hybrid. Gauge: Russel Creek near mouth (near Creston).

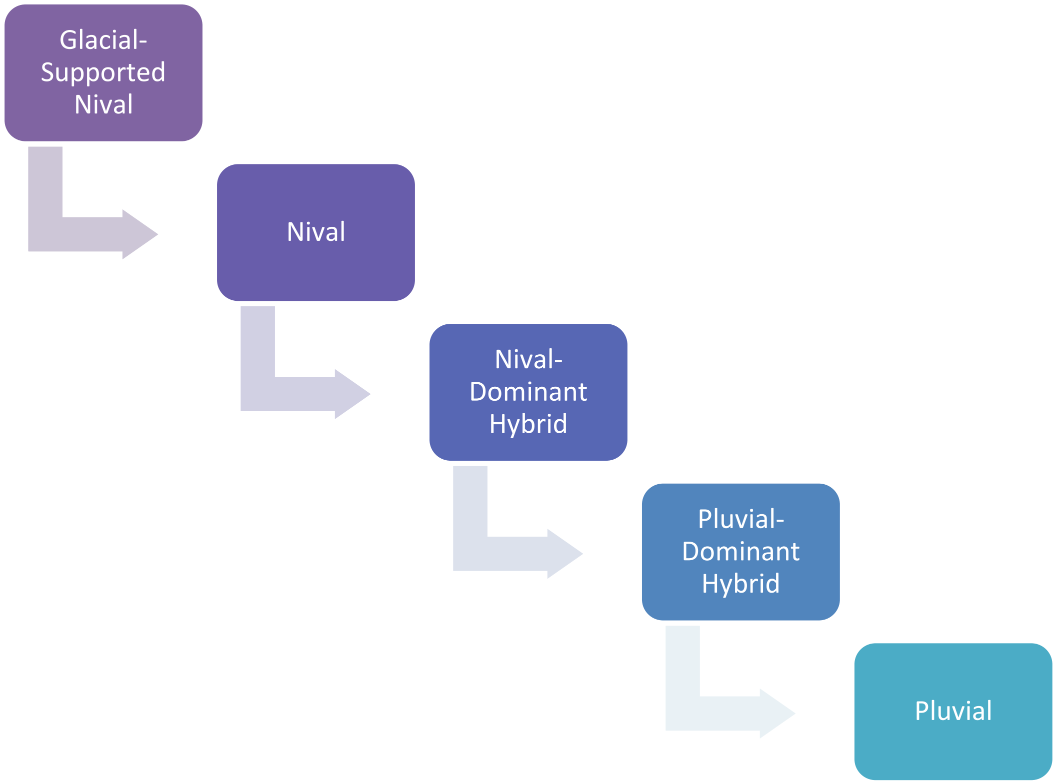

Figure G-3. Climate change is anticipated to shift streamflow regimes, reducing the influence of glacial/snow-melt.

As of the date of this report, no systematic regime classification has been undertaken by BGC or others for watercourse segments in the RDCK. Therefore, BGC reviewed select Water Survey of Canada (WSC) hydrometric gauges to classify these example streams and then distinguished between existing snowmelt-driven/-dominant regimes and existing rain-driven/-dominant regimes at hazard sites based on available metrics.

G.2.1.3. Results

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 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. Hazard areas where the streamflow regime is currently rain-driven/-dominant are the least sensitive as they don't have a peak flow associated with a freshet. Within the RDCK, large, multi-hydrologic region watercourses, such as the Columbia and Kootenay Rivers, have regimes that are dependent on the dam operation rules. Dam operations can override climate change effects and were therefore not ranked. The ranking scale[4] is summarized in Figure G-4.

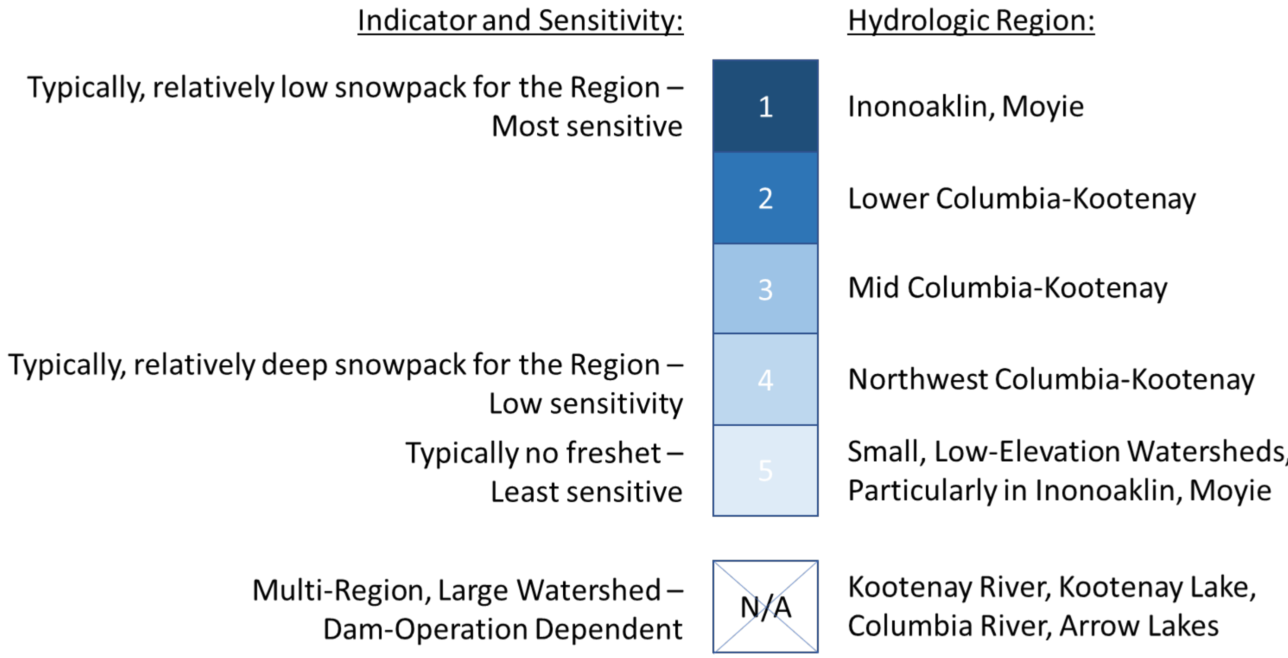

Figure G-4. Clear-water hazard spring freshet timing sensitivity to climate change (relative to similar watercourses within the RDCK). Relative ranking scale.

Clear-water flood hazard areas and hydrologic regions are shown on the web-map as two separate layers. Climate change sensitivity for an individual hazard area can be inferred from the hydrologic region based on Figure G-4. Although some hazard areas do contain watercourses that would rank as 5, they are smaller tributaries to larger watercourses in the hazard area that are dominated by the freshet and therefore ranked by the hydrologic region.

G.2.1.4. Uncertainties

The ranking methodology described above and summarized in Figure G-4: 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 RDCK only. The majority of 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.

[4] There is also a timescale component. If warming continued to the point where snowfall typically did not occur, then all streams would eventually be pluvial regimes with some streams shifting to pluvial sooner than others. The intended timescale for this analysis is much shorter – on the order of decades – and assumes that the shift in freshet timing would be more apparent for some watersheds given their baseline snowpack than others.

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 RDCK, 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 3rd, 4th,...nth) 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, etc.)). All of 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.

G.2.2. 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[5]; 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.

[5] In this context, magnitude is defined as both the total debris and water volume as well as the peak discharge associated with the event.

The sensitivity of these two types of basins to increases in rainfall (assuming intensity and frequency increase) are different (Figure G-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 un-limited 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 both increase the sediment supply and lower the precipitation threshold for steep creek events to occur.

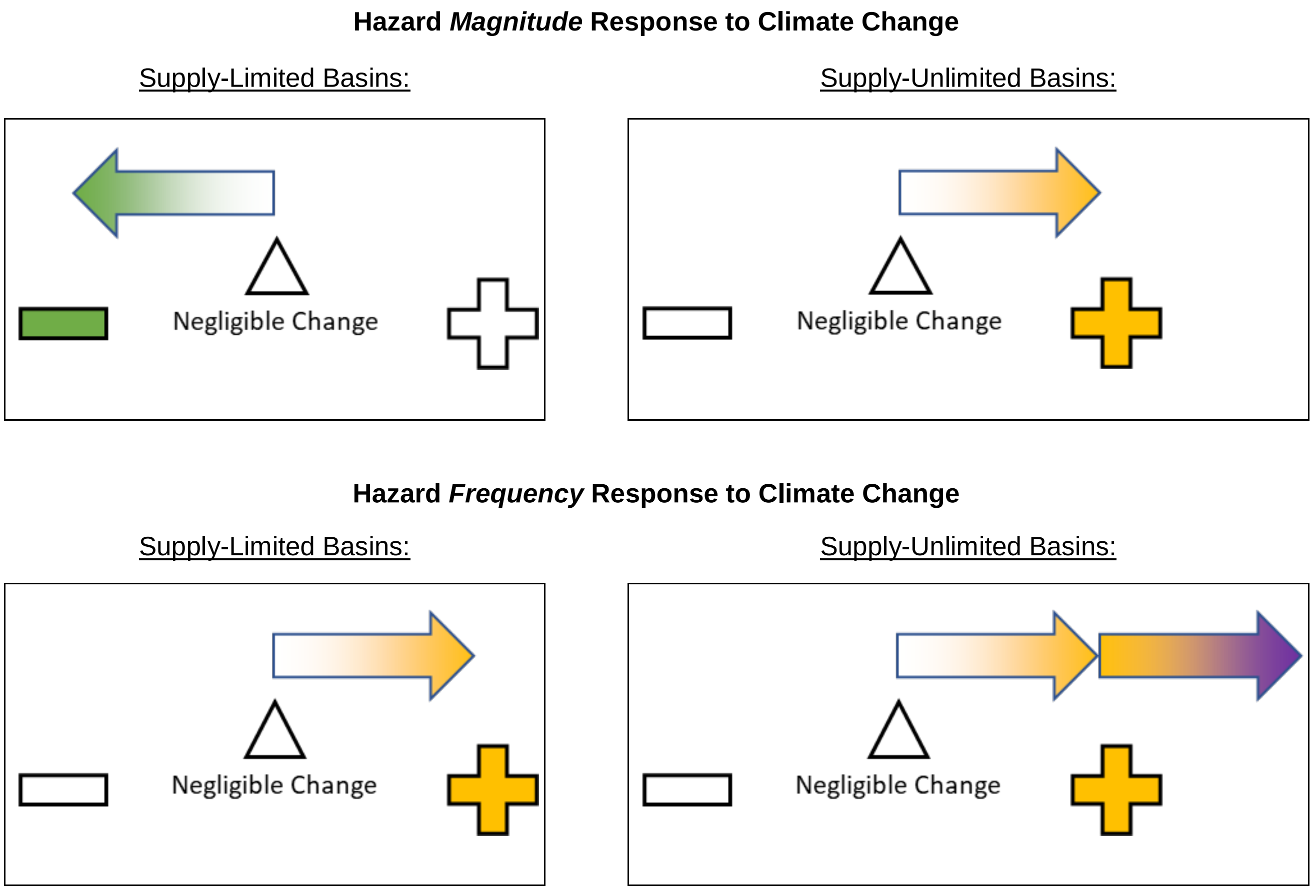

Figure G-5. Steep creek hazard sensitivity to climate change – supply-limited and supply unlimited basins.

G.3. FUTURE POTENTIAL INITIATIVES

At a regional scale, reducing the methodological uncertainty outlined in Section G.2 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 G-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.

Corporate Climate Change 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 Geomorphic Processes Acting in Study Area					
Climate Change has potential to lead to system change by exceedance of geomorphic threshold by target time frame	4	M	H	VH	VH
Climate change is likely to cause substantial change in geomorphic activity by target time	3	L	M	H	VH
Climate change is likely to casue some measureable change in geomorphic activity by target time frame	2	VL	L	M	H
Climate change is unlikely to cause measureable geomorphic change by target time frame	1	VL	VL	L	M
		1	2	3	4
		Pipeline exposure unlikely, rupture very unlikely if unmitigation by target time frame	Pipeline exposure possible, rupture unlikely if unmitigation by target time frame	Pipeline exposure likely, rupture possible if unmitigation by target time frame	Pipeline exposure very likely, rupture likely if unmitigation by target time frame

Figure G-6. Example of a climate change risk assessment matrix developed for pipelines. Source: BGC Engineering (DRAFT).

The following provides an example of a more detailed assessment of a hydrocarbon pipeline that might follow a regional climate change risk prioritization assessment:

The creek is a gravel bed stream with close to vertical, highly erodible banks in gravel overlain by sandy overbank deposits. Climate change analysis suggests an increase of 30% in the magnitude of extreme runoff and a 5-fold increase in the frequency of runoff extremes could occur by 2100 compared to a year 2000 base case. According to BGC's bank erosion calculations, bank erosion rates could double under this scenario, and scour per event could increase by up to 20%. As per Figure G-6, the bank erosion hazard would be classified as "Climate change is likely to cause substantial change in geomorphic activity by target time*". The next step is to determine if the likely change will change the risk profile of the pipeline.*

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 H
RISK ASSESSMENT INFORMATION TEMPLATE (RAIT)

Public Safety Canada Sécurité publique Canada

Ottawa, Canada
K1A 0P8

UNCLASSIFIED

National Disaster Mitigation Program (NDMP)
Risk Assessment Information Template

Risk Event Details			
Start and End Date	Provide the start and end dates of the selected event, based on historical data.	Start Date: 03/05/2018	End Date: 23/05/2018
Severity of the Risk Event	Provide details about the risk, including: • Speed of onset and duration of event; • Level and type of damaged caused; • Insurable and non-insurable losses; and • Other details, as appropriate.	The RDCK is a mountainous region frequently subject to damaging floods that have resulted in property damage, the interruption of key rail and highway transportation corridors, and loss of life. This RAIT focuses on the Salmo River/Erie Creek flood hazard to the Village of Salmo. This site was selected given the recent flood events of May 3-20, 2018, and its representativeness of the wider range of flood concerns within the RDCK described in the proposed work. On May 15, the 10-day forecast showed peak discharges as high as the 100-year return period. Limitations in the historical mapping resulted in emergency response hydraulic modelling to determine potential impacts and to assist emergency response efforts. Both historical floodplain maps and new flood modeling indicated dike overtopping and flooding of most of Salmo at this flow level, and that significant flood damage could also occur at smaller magnitude (more frequent) flows. About $150M of equivalent building value were potentially exposed to flooding, as well as infrastructure and transportation corridors. Fortunately, the weather conditions resulted in flows peaking at the 10-year return period event and major flood damage was avoided.	
Response During the Risk Event	Provide details on how the defined geographic area continued its essential operations while responding to the event.	- RDCK worked with EMBC and local governments to conduct 2018 District-wide flood emergency response, including Salmo - Emergency Operations Centre (EOC) was set up to direct operations. - Over 40 firefighters from fire halls across the RDCK arrived on-site to help fill and place sandbags to protect critical public infrastructure, and were trained in Rapid Barrier System dams. - Engineering/geoscience consultants were retained to help direct sandbag placement. - BGC Engineering completed emergency hydraulic modelling and provided flood inundation maps to support flood response efforts. - On May 15, a village-wide evacuation alert was issued.	
Recovery Method for the Risk Event	Provide details on how the defined geographic area recovered.	May 31, 2018 All regional evacuation alerts and orders were rescinded. Temporary emergency infrastructures (tiger dam, sand bags, signage, road barriers) were removed. Support was provided to communities in the Slocan Valley floodplain and Salmo River floodplain to enable post event meetings.The Village of Salmo, Electoral Area G, and Electoral Area H engaged in a Regional Floodplain Management Bylaw Review with the Columbia Basin Trust.	

Recovery Costs Related to the Risk Event	Provide details on the costs, in dollars, associated with implementing recovery strategies following the event.	• $5000 for heavy machinery to remove sandbags in Salmo • $15,000 for repairs to Salmo Dyke • $2500 RDCK Staff time and resources to required to support re-entry and recovery • $5000 for removal of Tiger Dam.
Recovery Time Related to the Risk Event	Provide details on the recovery time needed to return to normal operations following the event.	Recovery required approximate 2 weeks from the rescinding of Emergency Orders.

National Disaster Mitigation Program
Risk Assessment Information Template

Risk Event Identification and Overview	
Provide a qualitative description of the defined geographic area, including: • Watershed/community/region name(s); • Province/Territory; • Area type (i.e., city, township, watershed, organization, etc.); • Population size; • Population variances (e.g., significant change in population between summer and winter months); • Main economic areas of interest; • Special consideration areas (e.g., historical, cultural and natural resource areas); and an • Estimate of the annual operating budget of the area.	- Watersheds of Erie Creek and Salmo River (1210 km^2 watershed area) - Village of Salmo (located in Regional District of Central Kootenay, BC) - 2016 Census Profile: Population 1141 (excludes summer tourists), 572 private dwellings, 467 pop/square kilometers, 20% of population is under 18, 28% of population is 55 to 69 years old, median age of 51 years. 75% of occupied private dwellings are single-detached houses, 37% of private households are people living alone, 67% of the population aged 15 and over in private households earned less than $40,000 in 2015 (the median was $25,700). - Rural community and historic mining town - Major economic areas of interest: construction and trades; local businesses; significant tourist destination for outdoor recreation. - The annual operating budget for the Village of Salmo is $1.6 Million
Methodolgies, processes and analyses	

Provide the year in which the following processes/analyses were last completed and state the methodology(ies) used: • Hazard identification; • Vulnerability analysis; • Likelihood assessment; • Impact assessment; • Risk assessment; • Resiliency assessment; and/or • Climate change impact and/or adaptation assessment. *Note:* It is recognized that many of the processes/analyses mentioned above may be included within one methodology.	The following processes/analyses were completed in 2017-2018. RDCK retained BGC Engineering Inc. (BGC) to complete a district-wide flood study under NDMP Stream 1, risk assessment. BGC's scope of work was described in a proposal dated September 30, 2016 and was completed under the terms of RDCK Contract No. 04-1365-20-NDMP, dated October 1, 2017. All methodologies listed (hazard identification, vulnerability analysis, likelihood assessment, impact assessment, risk assessment; resiliency assessment, and climate change assessment) were included in the scope of work. This work has been commenced October 2017 and is currently ongoing. Interim results were produced to develop an NDMP Stream 2 scope of work. • Hazard locations were identified using a combination of historical floodplain extents (GeoBC), and screening level two-dimensional hydraulic flood modelling (software:Telemac-2D). • Vulnerability analysis considered buildings (including critical facilities), businesses, agriculture, life lines (linear infrastructure), and environmental values (fisheries and species and ecosystems at risk).
	Alongside the RAIT ratings, the area was assigned the following ratings to support RDCK decision-making: • Geohazard rating. This rating estimates the relative likelihood a flood would occur and reach elements a risk. • Consequence rating. This rating estimates the relative consequences given impact by a flood, based on proxies for the value of elements at risk and their vulnerability to damage or loss. • Priority rating. 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. The Village of Salmo and adjacent rural areas is considered High priority for further flood mapping.

Hazard Mapping

To complete this section:

- Obtain a map of the area that clearly indicates general land uses, neighbourhoods, landmarks, etc. For clarity throughout this exercise, it may be beneficial to omit any non-essential information from the map intended for use. Controlled photographs (e.g. aerial photography) can be used in place of or in addition to existing maps to avoid the cost of producing new maps.
- Place a grid over the maps/photographs of the area and assign row and column identifiers. This will help identify the specific area(s) that may be impacted, as well as additional information on the characteristics within and affecting the area.
- Identify where and how flood hazards may affect the defined geographic area.
- Identify the mapped areas that are most likely to be impacted by the identified flood hazard.

Map(s)/photograph(s) can also be used, where appropriate, to visually represent the information/prioritization being provided as part of this template.

National Disaster Mitigation Program
Risk Assessment Information Template

Hazard identification and prioritization	
List known or likely flood hazards to the defined geographic area in order of proposed priority. For example: (1) dyke breach overland flooding; (2) urban storm surge flooding ; and so on.	(1) dike overtopping, (2) bank overtopping, (3) dike breach, (4) debris impact, (5) scour, (6) river encroachment and bank erosion, (7) slumps and landslides from slopes adjacent to Salmo River and Erie Creek.
Provide a rationale for each prioritization and the key information sources supporting this rationale.	The Village of Salmo, at the confluence of Erie Creek and Salmo River, is considered high priority for flood mapping because there is (1) known history of damaging flood events and high expected likelihood of future flooding, as was demonstrated by the 2018 emergency assessments and flood response; (2) there exists high potential for loss, with approximately $150M in assessed buildings infrastructure in the village plus supporting infrastructure and transportation corridors. (3) the nature of flood hazard is not sufficiently understood for land use planning, bylaw implementation and emergency response. The existing flood maps are inaccurate, imprecise, out of date, and do not consider climate change. This was highlighted in 2018, when the existing historical mapping proved inadequate to inform the Spring 2018 flood response. (4) the condition and effectiveness of local dikes is not well understood.
Risk Event Title	
Identify the name/title of the risk. An example of a risk event name or title is: "A one-in-one hundred year flood following an extreme rain event."	The 2018 flood event was forecast to be a one-in-one hundred year return period flood event triggered by rapid snowmelt/rain-on snow.
Type of Flood Hazard	
Identify the type of flood hazard being described (e.g., riverine flooding, coastal inundation, urban run-off, etc.)	Riverine flooding of Erie Creek and Salmo River

Secondary hazards

Describe any secondary effects resulting from the risk event (e.g., flooding that occurs following a hurricane).	Secondary effects of riverine flooding with the potential to cause damages include debris impact, channel scour, river encroachment and bank erosion, and slumps and landslides from slopes adjacent to Salmo River and Erie Creek.
Primary and secondary organizations for response	
Identify the primary organization(s) with a mandate related to a key element of a natural disaster emergency, and any supporting organization(s) that provide general or specialized assistance in response to a natural disaster emergency.	The Regional District of Central Kootenay (RDCK) is the primary response organization for disasters in 11 Rural Electoral Areas and 8 Municipalities with support from the Ministry of Transportation, the Ministry of Forest Lands and Natural Resources, the Interior Health Authority, Emergency Social Services and Municipal Partners.

Risk Event Description	
Description of risk event, including risk statement and cause(s) of the event	
Provide a baseline description of the risk event, including: • Risk statement; • Context of the risk event; • Nature and scale of the risk event; • Lead-up to the risk event, including underlying cause and trigger/stimulus of the risk event; and • Any factors that could affect future events. *Note:* The description entered here must be plausible in that factual information would support such a risk event.	The Village of Salmo is subject to flood risk from Erie Creek and Salmo River, which border the south and east sides of the village, respectively. High discharge on Erie Creek leads to elevated risk of dike overtopping and/or failure and propagation of flood waters through the central part of the town, and bank overtopping from the Salmo River would result in floodwaters entering the town from the north. On May 15, the 10-day forecast showed peak discharges as high as the 100-year return period. Limitations in the historical mapping resulted in emergency response hydraulic modelling to determine potential impacts and to assist emergency response efforts. Both historical floodplain maps and new flood modeling indicated dike overtopping and flooding of most of Salmo at this flow level, and that significant flood damage could also occur at smaller magnitude (more frequent) flows. About $150M of buildings were potentially exposed to flooding, as well as infrastructure and transportation corridors. Fortunately the weather conditions resulted in flows peaking at the 10-year return period event. Large scale flooding would cut off evacuation routes and impact travel on Highways 3 and 6 (Salmo is at the junction of the two highways). Factors that could affect future damaging events including changing hazard associated with climate change, and the ability of the Village to reduce vulnerability through increased resiliency and improved flood mitigation, supported by better access to flood hazard and risk information.

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Location	
Provide details regarding the area impacted by the risk event such as: • Province(s)/territory(ies); • Region(s) or watershed(s); • Municipality(ies); • Community(ies); and so on.	- Village of Salmo and adjacent rural communities, Regional District of Central Kootenay, BC. - Watersheds of Erie Creek and Salmo River, within the Columbia River Basin. - The Village is located at the junction of the Crowsnest Highway (3) which traverses the south of BC, and Highway 6 which connects Nelson, BC with the USA.
Natural environment considerations	
Document relevant physical or environmental characteristics of the defined geographic area.	The Village of Salmo is located on a floodplain at the confluence of Erie Creek and Salmo River, whose watersheds encompass 1210 square kilometers. The area proposed for flood hazard mapping indlues the Salmo River floodplain (including Erie Creek), encompassing 190 square kilometers, with a total watercourse length of 81 km. Future changes to hydro-climate, watershed hydrology (e.g., due to wildfires, large-scale clear cutting, beetle infestations), river morphology, or development in flood-prone zones will also have bearing on flood hazard and risk.
Meteorological conditions	
Identify the relevant meteorological conditions that may influence the outcome of the risk event.	Relevant meteorological conditions include the following: consistently high spring temperatures and deep saturated snowpack resulting in accelerated, higher volume snowmelt in a shorter period of time; high volume rain event on deep snowpack; a storm event with long duration, and higher intensity rainfall. Some of these variables are projected to change in the future, which in many cases will lead to more and/or higher magnitude hydroclimatic extremes.

Seasonal conditions	
Identify the relevant seasonal changes that may influence the outcome of the risk assessment of a particular risk event.	Hazard: Depth of snowpack, spring temperatures, spring precipitation intensity and duration, fluctuations in lake levels and timing of lake level fluctuations with respect to timing of severe runoff events. Timing and combination of hazard variables Consequences can vary depending on the timing of flood and the impacts to seasonal workers, tourism, fisheries
Nature and vulnerability	
Document key elements related to the affected population, including: • Population density; • Vulnerable populations (identify these on the hazard map from step 7); • Degree of urbanization; • Key local infrastructure in the defined geographic area; • Economic and political considerations; and • Other elements, as deemed pertinent to the defined geographic area.	- 2016 Census Profile for the Village of Salmo (excludes adjacent rural region): Population 1141 (excludes summer tourists), 572 private dwellings, 467 pop/square kilometers, 20% of population is under 18, 28% of population is 55 to 69 years old, median age of 51 years. 75% of occupied private dwellings are single-detached houses, 37% of private households are people living alone, 67% of the population aged 15 and over in private households earned less than $40,000 in 2015 (the median was $25,700). -The majority of the Census profile is located within the flood hazard area and includes residential and commercial buildings/businesses, elementary and secondary schools, government buildings, recreational and cultural facilities, an RCMP station, roads including Highway 3 and 6, electrical infrastructure, petroleum infrastructure, water infrastructure, communications infrastructure, agriculture and environmentally sensitive areas (fish habitat). The area also includes a key transportation corridor to the USA

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Asset inventory	
Identify the asset inventory of the defined geographic area, including: • Critical assets; • Cultural or historical assets; • Commercial assets; and • Other area assets, as applicable to the defined geographic area. Key asset-related information should also be provided, including: • Location on the hazard map (from step 7); • Size; • Structure replacement cost; • Content value; • Displacement costs; • Importance rating and rationale; • Vulnerability rating and reason; and • Average daily cost to operate. A total estimated value of physical assets in the area should also be provided.	Critical assets: residential and commercial buildings, elementary and secondary schools, care services, an RCMP station; roads including Highway 3 and 6; electrical infrastructure, petroleum infrastructure, water infrastructure, communications infrastructure; and environmentally sensitive areas (fish habitat). The area also includes a key transportation corridor to the USA. Size: population 1140 Structure cost: total $150M BC Assessment Value. Contents cost estimated with lower confidence as about half the assessed building value, at $75M. Context of ratings: the widespread, 2018 flooding in the town of Grand Forks, BC, which is a slightly larger but comparable town in southern BC, is an approximate analogy to the magnitude of flood damages and displacement that could occur in Salmo. Vulnerability ratings reflect this comparison. Importance rating: important southern BC tourist destination, located on key transportation corridor, and representative of the range of types of flooding that could occur in the RDCK. Municipal assets include $1.2 million in land, $1.6 million in buildings, $823,000 in vehicles and equipment, $1.3 Million in transportation infrastrucutre, $1.3 million in water infrastructure, and $378,000 in sewer infrastructure. The average dailly operating cost for the village is $4383 per. This includes the maintenance and operation of municipal services in regards to Land, Buildings, Transportation, Water, and Sewer.
Other assumptions, variability and/or relevant information	
Identify any assumptions made in describing the risk event; define details regarding any areas of uncertainty or unpredictability around the risk event; and supply any supplemental information, as applicable.	Assumptions related to hydraulics include potential backwater effect from Salmo River into Erie Creek, hydraulic effects of bridges and culverts; log jams, flow hydrograph. Assumptions related to geomorphology include second-order effects of flooding and associated damages (debris impact, channel scour, river encroachment and bank erosion, and slumps and landslides). Assumptions related to emergency response measures include the location of sandbags, response to dike breaches, flood walls or other structural flood control measures; and evacuation.
Existing Risk Treatment Measures	
Identify existing risk treatment measures that are currently in place within the defined geographic area to mitigate the risk event, and describe the sufficiency of these risk treatment measures.	Erie creek is flanked by a dike on the left bank but that does not meet provincial standards. Other risk treatment measures are generally related to emergency response planning as described for the 2018 flood response, including procedures for placing sand bags and planning evacuation. These measures are not sufficient for long-term risk management planning and are based on an inadequate understanding of the frequency, magnitude, extent, and destructive potential of flood hazards.

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Likelihood Assessment	
Return Period	
Identify the time period during which the risk event might occur. For example, the risk event described is expected to occur once every X number of years. Applicants are asked to provide the X value for the risk event.	The most frequent risk event with the potential to result in some undesirable consequences occurs with an average return period of 10-30 years. Widespread flooding and the potential for fatalities could occur at return periods exceeding 100 years. Floods of this and greater magnitude are the basis for the chosen flood impact consequence ratings on the following pages.
Period of interest	
Applicants are asked to determine and identify the likelihood rating (i.e. period of interest) for the risk event described by using the likelihood rating scale within the table below.	

Likelihood Rating	**Definition**	
5	The event is expected and may be triggered by conditions expected over a 30 year period.	5
4	The event is expected and may be triggered by conditions expected over a 30 - 50 year period.	
3	The event is expected and may be triggered by conditions expected over a 50 - 500 year period.	
2	The event is expected and may be triggered by conditions expected over a 500 - 5000 year period.	
1	The event is possible and may be triggered by conditions exceeding a period of 5000 years.	

Provide any other relevant information, notes or comments relating to the likelihood assessment, as applicable.	Screening level modeling of conditions expected over a less than a 30 year period show flood inundation with the potential to result in some damages.

Impacts/Consequences Assessment			
There are 12 impacts categories within 5 impact classes rated on a scale of 1 (least impacts) to 5 (greatest impact). Conduct an assessment of the impacts associated with the risk event, and assign one risk rating for each category. Additional information may be provided for each of the categories in the supplemental fields provided.			
A) People and societal impacts			
	Risk Rating	**Definition**	**Assigned risk rating**
Fatalities	5	Could result in more than 50 fatalities	2
	4	Could result in 10 - 49 fatalities	
	3	Could result in 5 - 9 fatalities	
	2	Could result in 1 - 4 fatalities	
	1	Not likely to result in fatalities	
Supplemental information (optional)	This estimate depends strongly on some factors that are poorly understood with the information available, such as the potential for dike breach whose likelihood increases with increasing flood return period.		
Injuries	5	Injuries, illness and/or psychological disablements cannot be addressed by local, regional, or provincial/territorial healthcare resources; federal support or intervention is required	4
	4	Injuries, illnesses and/or psychological disablements cannot be addressed by local or regional healthcare resources; provincial/territorial healthcare support or intervention is required.	
	3	Injuries, illnesses and/or psychological disablements cannot be addressed by local or regional healthcare resources additional healthcare support or intervention is required from other regions, and supplementary support could be required from the province/territory	
	2	Injuries, illnesses and/or psychological disablements cannot be addressed by local resources through local facilities; healthcare support is required from other areas such as an adjacent area(ies)/municipality(ies) within the region	
	1	Any injuries, illnesses, and/or psychological disablements can be addressed by local resources through local facilities; available resources can meet the demand for care	
Supplemental information (optional)	Any flood emergency in Salmo would require support at least at the Regional District and Provincial level. The assigned risk rating relates to floods with return periods equal to or greater than 100 years.		

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		Risk Rating	Definition	Assigned risk rating
Displacement	Percentage of displaced individuals	5	> 15% of total local population	5
		4	10 - 14.9% of total local population	
		3	5 - 9.9% of total local population	
		2	2 - 4.9% of total local population	
		1	0 - 1.9% of total local population	
	Duration of displacement	5	> 26 weeks (6 months)	4
		4	4 weeks - 26 weeks (6 months)	
		3	1 week - 4 weeks	
		2	72 hours - 168 hours (1 week)	
		1	Less than 72 hours	
Supplemental information (optional)		The assigned risk ratings refer to floods of equal to or greater than 100 year return period.		

B) Environmental impacts			
	5	> 75% of flora or fauna impacted or 1 or more ecosystems significantly impaired; Air quality has significantly deteriorated; Water quality is significantly lower than normal or water level is > 3 meters above highest natural level; Soil quality or quantity is significantly lower (i.e., significant soil loss, evidence of lethal soil contamination) than normal; > 15% of local area is affected	2
	4	40 - 74.9% of flora or fauna impacted or 1 or more ecosystems considerably impaired; Air quality has considerably deteriorated; Water quality is considerably lower than normal or water level is 2 - 2.9 meters above highest natural level; Soil quality or quantity is moderately lower than normal; 10 - 14.9% of local area is affected	
	3	10 - 39.9% of flora or fauna impacted or 1 1 or more ecosystems moderately impaired; Air quality has moderately deteriorated; Water quality is moderately lower than normal or water level is 1 - 2 meters above highest natural level; Soil quality is moderately lower than normal; 6 - 9.9 % of area affected	

	2	< 10 % of flora or fauna impacted or little or no impact to any ecosystems; Little to no impact to air quality and/or soil quality or quantity; Water quality is slightly lower than normal, or water level is less than 0.9 meters above highest natural level and increased for less than 24 hours; 3 - 5.9 % of local area is affected	
	1	Little to no impact to flora or fauna, any ecosystems, air quality, water quality or quantity, or to soil quality or quantity; 0 - 2.9 % of local area is affected	
Supplemental information (optional)	The assigned risk ratings refer to floods of equal to or greater than 100 year return period. Note that no detailed environmental/ecological impact study has been conducted for the area.		

C) Local economic impacts

	Risk Rating	Definition	Assigned risk rating
	5	> 15 % of local economy impacted	5
	4	10 - 14.9 % of local economy impacted	
	3	6 - 9.9 % of local economy impacted	
	2	3 - 5.9 % of local economy impacted	
	1	0 - 2.9 % of local economy impacted	
Supplemental information (optional)	This high rating reflects the high proportion of the village area and associated facilities that could be impacted by a flood. The assigned risk ratings refer to floods of equal to or greater than 100 year return period.		

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D) Local infrastructure impacts			
	Risk Rating	**Definition**	**Assigned risk rating**
Transportation	5	Local activity stopped for more than 72 hours; > 20% of local population affected; lost access to local area and/or delivery of crucial service or product; or having an international level impact	4
	4	Local activity stopped for 48 - 71 hours; 10 - 19.9% of local population affected; significantly reduced access to local area and/or delivery of crucial service or product; or having a national level impact	
	3	Local activity stopped for 25 - 47 hours; 5 - 9.9% of local population affected; moderately reduced access to local area and/or delivery of crucial service or product; or having a provincial/territorial level impact	
	2	Local activity stopped for 13 - 24 hours; 2 - 4.9% of local population affected; minor reduction in access to local area and/or delivery of crucial service or product; or having a regional level impact	
	1	Local activity stopped for 0 - 12 hours; 0 - 1.9% of local population affected; little to no reduction in access to local area and/or delivery of crucial service or product	
Supplemental information (optional)	The assigned risk ratings refer to floods of equal to or greater than 100 year return period.		
Energy and Utilities	5	Duration of impacts > 72 hours; > 20% of local population without service or product; or having an international level impact	3
	4	Duration of impact 48 - 71 hours; 10 - 19.9% of local population without service or product; or having a national impact	
	3	Duration of impact 25 - 47 hours; 5 - 9.9% of local population without service or product; or having a provincial/territorial level impact	
	2	Duration of impact 13 - 24 hours; 2 - 4.9% of local population without service or product; or having a regional level impact	
	1	Local activity stopped for 0 - 12 hours; 0 - 1.9% of local population affected; little to no reduction in access to local area and/or delivery of crucial service or product	

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Supplemental information (optional)	The assigned risk ratings refer to floods of equal to or greater than 100 year return period.		
Information and Communications Technology	5	Service unavailable for > 72 hours; > 20 % of local population without service; or having an international level impact	4
	4	Service unavailable for 48 - 71 hours; 10 - 19.9 % of local population without service; or having a national level impact	
	3	Service unavailable for 25 - 47 hours; 5 - 9.9 % of local population without service; or having a provincial/territorial level impact	
	2	Service unavailable for 13 - 24 hours; 2 - 4.9 % of local population without service; or having a regional level impact	
	1	Service unavailable for 0 - 12 hours; 0 - 1.9 % of local population without service	
Supplemental information (optional)	The assigned risk ratings refer to floods of equal to or greater than 100 year return period.		
Health, Food, and Water	5	Inability to access potable water, food, sanitation services, or healthcare services for > 72 hours; non-essential services cancelled; > 20 % of local population impacted; or having an international level impact	4
	4	Inability to access potable water, food, sanitation services, or healthcare services for 48-72 hours; major delays for nonessential services; 10 - 19.9 % of local population impacted; or having a national level impact	
	3	Inability to access potable water, food, sanitation services, or healthcare services for 25-48 hours; moderate delays for nonessential services; 5 - 9.9 % of local population impacted; or having a provincial/territorial level impact	
	2	Inability to access potable water, food, sanitation services, or healthcare services for 13-24 hours; minor delays for nonessential; 2 - 4.9 % of local population impacted; or having a regional level impact	
	1	Inability to access potable water, food, sanitation services, or healthcare services for 0-12 hours; 0 - 1.9 % of local population impacted	

Supplemental information (optional)	The assigned risk ratings refer to floods of equal to or greater than 100 year return period.		
Safety and Security	5	> 20 % of local population impacted; loss of intelligence or defence assets or systems for > 72 hours; or having an international level impact	2
	4	10 - 19.9 % of local population impacted; loss of intelligence or defence assets or systems for 48 – 71 hours; or having a national level impact	
	3	5 - 9.9 % of local population impacted; loss of intelligence or defence assets or systems for 25 – 47 hours; or having a provincial/territorial level impact	
	2	2 - 4.9 % of local population impacted; loss of intelligence or defence assets or systems for 13 – 24 hours; or having a regional level impact	
	1	0 - 1.9 % of local population impacted; loss of intelligence or defence assets or systems for 0 – 12 hours	
Supplemental information (optional)	The assigned risk ratings refer to floods of equal to or greater than 100 year return period. Little is known about intelligence and defence assets in Salmo.		

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E) Public sensitivity impacts			
	Risk Rating	**Definition**	**Assigned risk rating**
	5	Sustained, long term loss in reputation/public perception of public institutions and/or sustained, long term loss of trust and confidence in public institutions; or having an international level impact	3
	4	Significant loss in reputation/public perception of public institutions and/or significant loss of trust and confidence in public institutions; significant resistance; or having a national level impact	
	3	Some loss in reputation/public perception of public institutions and/or some loss of trust and confidence in public institutions; escalating resistance	
	2	Isolated/minor, recoverable set-back in reputation, public perception, trust, and/or confidence of public institutions	
	1	No impact on reputation, public perception, trust, and/or confidence of public institutions	
Supplemental information (optional)	The assigned risk ratings refer to floods of equal to or greater than 100 year return period.		

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Confidence Assessment

Based on the table below, indicate the level of confidence regarding the information entered in the risk assessment information template in the "Confidence Level Assigned" column. Confidence levels are language-based and range from A to E (A=most confident to E=least confident).

Confidence Level	Definition	Confidence Level Assigned
A	Very high degree of confidence Risk assessment used to inform the risk assessment information template was evidence-based on a thorough knowledge of the natural hazard risk event; leveraged a significant quantity of high-quality data that was quantitative and qualitative in nature; leveraged a wide variety of data and information including from historical records, geospatial and other information sources; and the risk assessment and analysis processes were completed by a multidisciplinary team with subject matter experts (i.e., a wide array of experts and knowledgeable individuals on the specific natural hazard and its consequences) Assessment of impacts considered a significant number of existing/known mitigation measures	
B	High degree of confidence Risk assessment used to inform the risk assessment information template was evidence-based on a thorough knowledge of the natural hazard risk event; leveraged a significant quantity of data that was quantitative and qualitative in nature; leveraged a wide variety of data and information including from historical records, geospatial and other information sources; and the risk assessment and analysis processes were completed by a multidisciplinary team with some subject matter expertise (i.e., a wide array of experts and knowledgeable individuals on the specific natural hazard and its consequences) Assessment of impacts considered a significant number of potential mitigation measures	

C	Moderate confidence Risk assessment used to inform the risk assessment information template was moderately evidence-based from a considerable amount of knowledge of the natural hazard risk event; leveraged a considerable quantity of data that was quantitative and/or qualitative in nature; leveraged a considerable amount of data and information including from historical records, geospatial and other information sources; and the risk assessment and analysis processes were completed by a moderately sized multidisciplinary team, incorporating some subject matter experts (i.e., a wide array of experts and knowledgeable individuals on the specific natural hazard and its consequences) Assessment of impacts considered a large number of potential mitigation measures	
D	Low confidence Risk assessment used to inform the risk assessment information template was based on a relatively small amount of knowledge of the natural hazard risk event; leveraged a relatively small quantity of quantitative and/or qualitative data that was largely historical in nature; may have leveraged some geospatial information or information from other sources (i.e., databases, key risk and resilience methodologies); and the risk assessment and analysis processes were completed by a small team that may or may not have incorporated subject matter experts (i.e., did not include a wide array of experts and knowledgeable individuals on the specific natural hazard and its consequences). Assessment of impacts considered a relatively small number of potential mitigation measures	C
E	Very low confidence Risk assessment used to inform the risk assessment information template was not evidence-based; leveraged a small quantity of information and/or data relating to the natural risk hazard and risk event; primary qualitative information used with little to no quantitative data or information; and the risk assessment and analysis processes were completed by an individual or small group of individuals little subject matter expertise (i.e., did not include a wide array of experts and knowledgeable individuals on the specific natural hazard and its consequences). Assessment of impacts did not consider existing or potential mitigation measures	

Rationale for level of confidence	
Provide the rationale for the selected confidence level, including any references or sources to support the level assigned.	Comprehensive, systematically developed asset inventory exists to support estimation of hazard exposure. Previous damaging floods have occurred and provide some level of calibration Flood hazard, exposure and vulnerability have been assessed at initial level of ideal by Qualified Registered Professionals (geoscientists and engineers) Both historical floodplain maps and screening level hydraulic modelling support the conclusions stated in this RAIT High level of flood response in 2018 indicates the high level of government and public concern about flooding.

Key Information Sources	
Identify all supporting documentation and information sources for qualitative and quantitative data used to identify risk events, develop the risk event description, and assess impacts and likelihood. This ensures credibility and validity of risk information presented as well as enables referencing back to decision points at any point in time. Clearly identify unclassified and classified information.	BGC Engineering, 2017-Present. Regional District of Central Kootenay Flood and Geohazard Risk Review. Report In Progress prepared for Regional District of Central Kootenay, supported by NDMP Stream 1. Includes the Village of Salmo, BC. BGC Engineering , 2018. Hydraulic Modelling for Flood Response, Salmo, BC. Report and drawings dated May 15, 2018 prepared for Regional District of Central Kootenay showing predicted inundation areas based on forecasted river flows. BGC Engineering 2018. Comprehensive geodatabase of buildings and critical infrastructure provided May 18, 2018 via ESRI REST Endpoint to RDCK. RDCK (2018). Personal communication and meetings between BGC Engineering, RDCK and EMBC during the week of May 15 related to Salmo flood response.

Description of the risk analysis team	
List and describe the type and level of experience of each individual who was involved with the completion of the risk assessment and risk analysis used to inform the information contained within this risk assessment information template.	Kris Holm, M.Sc., P.Geo. Mr. Holm has 20 years of geoscience consulting experience and leads BGC's geohazards group. His experience includes geohazard and risk assessments for transportation, development and industry at scales ranging from site-specific studies to broad regions. Mr. Holm is leading the current regional study for the District, and has previously led regional flood and geohazard risk prioritization studies for the Province of Alberta, several BC Regional and Local Goverments, and major industry clients in North and South America. Rebecca Lee, P.Eng., P.Geo.. Ms. Lee is a Senior Water Resources Engineer with a background in flood risk assessment and mitigation for municipal infrastructure and major industry. Her experience includes hydrologic characterization, geohazard risk assessment, 1D and 2D hydraulic modelling, flood mitigation design and design of water management structures from conceptual stage to construction, integrated flood risk management planning, dam and landslide dam breach assessments, erosion characterization and mitigation, and independent engineering review. Ms. Lee is the technical lead for clear-water flood hazard assessment in the current regional study. Hamish Weatherly, M.Sc., P.Geo. Mr. Weatherly is BGC's team lead for the surface water discipline and has more than 20 years of experience in hydrology, fluvial geomorphology, and hydraulic modelling (including floods, debris floods and debris flows). Hamish has completed extensive work on channel stability problems in Western Canada, as well as the integration of river morphology and flow hydraulics in assessing bank erosion and scour.

APPENDIX I
RESULTS SPREADSHEET
(PROVIDED SEPARATELY IN EXCEL FORMAT)

APPENDIX J
RECOMMENDATIONS – DETAILED STUDIES

J.1. INTRODUCTION

Section 8.0 of the Main Document made the following recommendations

- *Complete detailed clear-water floodplain mapping for the areas identified by RDCK as top priority, following review of this assessment.*
- *Complete detailed steep creek geohazards assessments for areas identified by RDCK 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.

J.1.1. Clear-Water Floodplains

J.1.1.1. 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
- Site visit and qualitative assessment of flood hazards
- 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.

J.1.1.2. Suggested Work Plan

Table J-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 J-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

All the top prioritized study areas were flown with high resolution LiDAR in 2018, and BGC understands that these data will be available by Spring 2019 (RDCK, email dated January 24, 2019). 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, as well as geo-referenced photos of surveyed features.

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 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 inputs used in hydraulic modelling.

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.

J.1.2. Steep Creeks

J.1.2.1. Approach 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) graph 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
- Mapping of inundation 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.

J.1.2.2. Recommended Work Plan

Table J-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.

Table J-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 frequency-magnitude 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	• Qualified Professional

[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.

Activities	Tasks	Deliverables/Products	Resources
		and velocity), that form the basis for hazard mapping	
	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

Data Compilation

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 readily available)
- Previous reports (e.g., flood hazard, risk assessments, terrain maps, watershed assessments, resource inventory maps, geological/geotechnical reports and/or maps).

All the top priority study areas have been recently flown with high resolution LiDAR. The derivative high-resolution DEMs 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 mechanism, causal factors, trigger conditions, intensity (destructive potential), extent, and change; developing hazard 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 RDCK 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.

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).

Subsurface field observations (i.e., machine-dug test pits) and additional techniques such as ^{14}C dating of organic materials in prehistoric deposits may also be required, depending on the site.

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 frequency-magnitude 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 emerge from time to time, 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 existing. 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.