RDCK FLOODPLAIN AND STEEP CREEK STUDY

Summary Report

Final
March 31, 2020

BGC Project No.:
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Prepared by BGC Engineering Inc. for:
Regional District of Central Kootenay

TABLE OF REVISIONS

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DRAFT	March 19, 2020		Issued as a completed draft.
FINAL	March 31, 2020		Final issue.

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- Chrystal Williams, GIS Supervisor
- Eileen Senyk, Planner
- AJ Evenson, Project Planner.

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- Sarah Crookshanks, MFLNRO, Research Geomorphologist
- Peter Jordan, MFLNRO, Research Geomorphologist (retired)
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The following 44 BGC personnel were part of the study team, in alphabetical order:

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Reviewer), Sarah Davidson, Sarah Kimball (Project Manager), Sophol Tran, Toby Perkins, Vanessa Cuervo.

LIMITATIONS

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EXECUTIVE SUMMARY

The Regional District of Central Kootenay (RDCK, the District) retained BGC Engineering Inc. (BGC) to complete detailed assessments and mapping of six floodplains and ten steep creeks within the District (Table E-1).

The work focuses on high priority areas identified during a 2018-2019 regional study that prioritized flood and steep creek hazard areas across the District (BGC, March 31, 2019). This report refers to the March 31, 2019 assessment as the “Stream 1” study, and the detailed assessments as the “Stream 2 study”. Because both studies build on each other, this report references both studies when discussing considerations related to long-term geohazard risk management.

The details of the Stream 2 assessments for individual project areas, including methods, results, limitations, and site-specific recommendations, are contained within the site assessment reports. This summary report provides the following:

- Overview of overall study objectives and scope of work
- Overview of deliverables
- Considerations for RDCK in the application of Stream 1 and 2 study results.

The assessment objectives for each study area are as follows:

- Complete the steps of detailed hazard assessments including data compilation, fieldwork, and desktop analyses.
- Prepare deliverables including hazard maps and reports for each study area.
- Deliver hazard maps and reports to RDCK in digital formats amenable to incorporation into RDCK’s internal systems (i.e., web maps), via Cambio™, and as static (pdf) reports.
- Update the Stream 1 study results in Cambio based on the Stream 2 study, where required.

Table E-1. List of study areas.

Site Classification	Geohazard Process	Hazard Code	Jurisdiction	Name
Floodplain	Clear-water Flood	340	Village of Salmo	Salmo River
		372	Village of Slocan	Slocan River
		393	Town of Creston	Goat River
		408	RDCK Electoral Area A	Crawford Creek
		375	RDCK Electoral Area K	Burton Creek
		423	Village of Kaslo	Kaslo River
Steep Creek	Debris Flood	212	RDCK Electoral Area F	Duhamel Creek
		252	RDCK Electoral Area F	Kokanee Creek
		248	RDCK Electoral Area D	Cooper Creek
		137	RDCK Electoral Area H	Wilson Creek
		242	RDCK Electoral Area E	Harrop Creek
		95	RDCK Electoral Area K	Eagle Creek
		238	RDCK Electoral Area F	Sitkum Creek
	Hybrid Debris Flood/Debris Flow	116	RDCK Electoral Area E	Procter Creek
		251	RDCK Electoral Area E	Redfish Creek
	Debris Flow	36	RDCK Electoral Area A	Kuskonook Creek

Through the provision of detailed hazard maps and information, the Stream 2 study supports community planning, bylaw enforcement, emergency response, risk control, and asset management. This assessment also provides impetus and inputs to future work such as:

- Hazard and risk tolerance policy development.
- Quantitative geohazard risk assessments if, and as required, to support the possible implementation of risk tolerance policy.
- Geohazards reduction (structural and non-structural mitigation) plans.
- Work by other parties (i.e. provincial ministries, utility operators, or private consultants) that requires outputs of this assessment.

The deliverables of the Stream 2 study include reports and hazard maps. Specifically, they include the following:

- Summary report (this document)
- Separate assessment reports for each of the study areas listed in Table 1-1
- Separate assessment methodology report for steep creek hazard areas
- Hazard maps provided via access to Cambio™ web application, as geospatial data (GIS files), and appended to final reports as record copies.

BGC provides site-specific considerations for hazards management in the individual assessment reports and strategic recommendations in this summary report. Specifically, this report provides the following considerations for RDCK when applying results in decision making:

- **Regional Geohazard Risk Management:** Adopt the geohazard areas prioritized in the Stream 1 study and further assessed in Stream 2 as a preliminary hazard or risk register and develop a plan to advance long-term geohazard risk management of these sites.
- **Site-Specific Geohazard Risk Management:** Adopt a geohazard risk management framework that considers the "As Low As Reasonably Practicable[1]" principle when developing and implementing geohazard risk management plans.
- **Further Assessments:** Review recommendations in the individual assessment reports and prioritize next steps to obtain funding for further work, where required. Review and update the District-wide inventory of alluvial fans based on newly available lidar. Update the record of geohazard events in the District based on results of the Stream 2 assessment.
- **Policy Integration:** Review and update clear-water flood and steep creek-related bylaws and policies, including Development Permit Areas (DPAs), with consideration of the hazard maps prepared by both the Stream 1 and Stream 2 studies.
- **Training and Stakeholder Communication:** Provide training to RDCK staff and other parties 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 and public engagement.
- **Digital Information Sharing**: Collaborate with private and public sector agencies within and outside the RDCK to share information, methods, and resources about pro-active geohazard risk and emergency management. Clarify professional responsibility and liability in the context of digital data and changing conditions (changing climate, landscape and land use) as well as complex hazard and consequence chains.
- **Multi-Stakeholder Resource Sharing:** Connect geohazards management activities in the private and public sector through the sharing of information and resources. Encourage provincial leadership for resource coordination while recognizing that much leadership can occur from a local government level within the existing governmental divisions of responsibility.
- **Responsibility and Liability:** Clarify roles and responsibilities for government in geohazard and risk management. Clarify how to consider issues of professional responsibility and liability in the context of digital data and changing conditions (changing climate, landscape and land use). Advocate for a strengthened Provincial Government role in funding and coordinating geohazard risk management in BC.

[1] ALARP is a statement by decision makers that risk is low enough and other measures to further reduce the risk are unreasonable, impracticable, or inefficient. See Section 4.2.

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1. INTRODUCTION

1.1. Summary

The Regional District of Central Kootenay (RDCK, the District) retained BGC Engineering Inc. (BGC) to complete detailed assessments and mapping of six floodplains and ten steep creeks within the District (Section 1.3).

The work focuses on high priority areas identified during a 2018-2019 regional study that prioritized flood and steep creek hazard areas across the District (BGC, March 31, 2019). This report refers to the March 31, 2019 assessment as the “Stream 1” study, and the work described herein as the “Stream 2 study”.

The deliverables of the Stream 2 study include reports and hazard maps. Specifically, they include the following:

- Summary report (this document)
- Separate assessment reports for each of the study areas listed in Table 1-1
- Separate assessment methodology report for steep creek hazard areas
- Hazard maps provided via access to Cambio web application (Figure 1-1)
- Hazard maps provided as geospatial data (GIS files)
- Hazard maps appended to final reports as record copies.

Because both studies build on each other, this summary report references both the Stream 1 and Stream 2 assessments when discussing considerations related to long-term geohazard risk management. This summary report provides the following:

- Summary of overall study objectives and scope of work
- Summary of deliverables
- Strategic considerations for RDCK in the application of study results.

The details of the Stream 2 assessments for individual project areas, including methods, results, limitations, and site-specific considerations, are contained within the site assessment reports.

This report is best read with access to Cambio, which displays the results of both the Stream 1 and Stream 2 studies. The application can be accessed at www.cambiocommunities.ca, using either Chrome or Firefox web browsers. Figure 1-1 shows an example of the user interface and Appendix A provides a Cambio user guide.

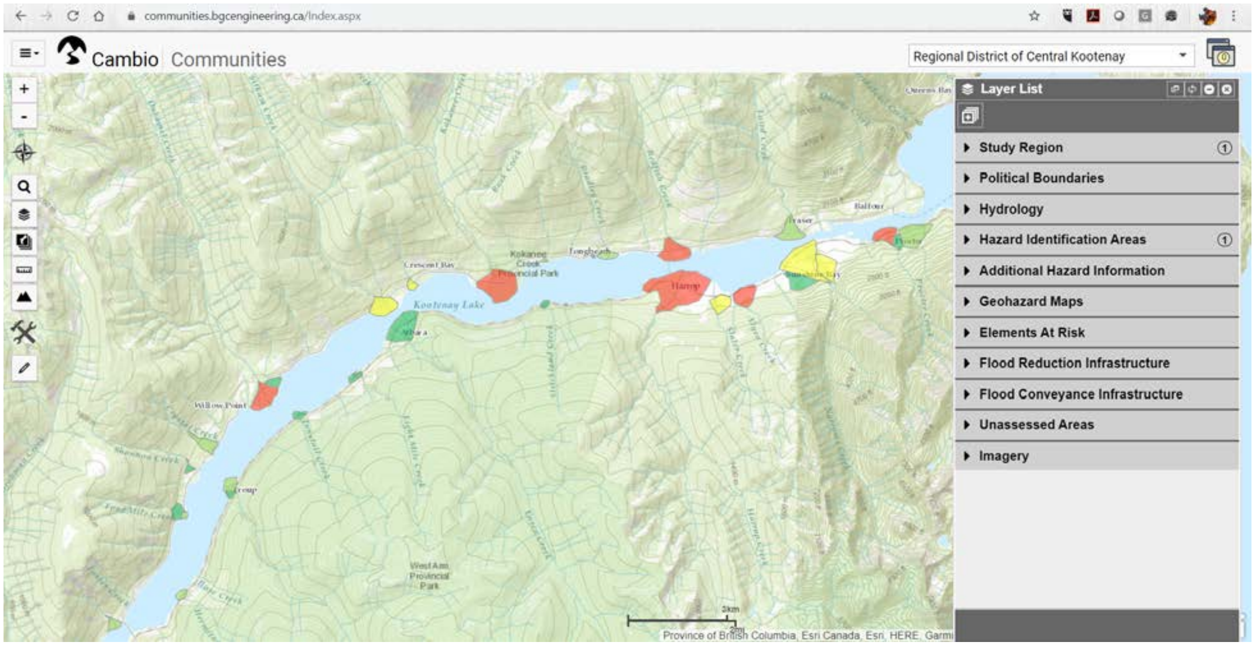

Figure 1-1. Example of Cambio web application showing steep creek hazard areas on the West Arm of Kootenay Lake.

1.2. Objectives

The assessment objectives for each study area are as follows:

- Complete the steps of detailed hazard assessments including data compilation, fieldwork, and desktop analyses.
- Prepare deliverables including hazard maps and reports for each study area.
- Deliver hazard maps and reports to RDCK in digital formats amenable to incorporation into RDCK's internal systems (i.e., web maps), via Cambio, and as static (pdf) reports.
- Update the Stream 1 study results based on the Stream 2 study, where required.

Through the provision of detailed hazard maps and information, the Stream 2 study supports community planning, bylaw enforcement, emergency response, risk control, and asset management. This assessment also provides inputs to future work such as:

- Risk tolerance policy development (i.e., a decision-making process to manage geohazard risk to levels considered tolerable by the District).
- Quantitative geohazard risk assessments as required to support the implementation of risk tolerance policy.
- Geohazards reduction (mitigation) plans.

The proposed study approach is consistent with the following guidelines:

- Flood Mapping in BC, Professional Practice Guidelines, Engineers and Geoscientists BC (EGBC, January 2017)
- Legislated Flood Assessments in a Changing Climate in BC, Version 2.1, Professional Practice Guidelines (EGBC, August 28, 2018)
- Specifications for airborne LiDAR for the Province of British Columbia, MFLNRO GeoBC, (GeoBC, 2019)

- Federal Floodplain Mapping Guidelines (NRCan, 2018)
- Guidance for Selection of Qualified Professionals and Preparation of Flood Hazard Assessment Reports, MFLNRO and Rural Development (MFLNRO, n.d.).

1.3. Areas Assessed

Table 1-1 and Figure 1-2 show the Stream 2 assessment areas, which include six floodplain mapping areas and ten steep creek fans subject to clear-water flood, debris-flood, or debris-flow processes. These areas were selected in collaboration with RDCK based on hazard, consequence and priority ratings assigned in the Stream 1 study, records of previous events; reference to previous reports, and available funding. The sites are not necessarily the locations where the "next" damaging geohazards event will occur in the District, which is not known, and they do not include all high priority sites identified in the Stream 1 study.

The list of areas selected for detailed assessment should not be considered exhaustive as the Stream 1 study identified a longer list of geohazard areas that RDCK may consider for detailed assessment as part of future scopes of work (BGC, March 31, 2019).

Table 1-1. List of study areas.

Site Classification	Geohazard Process	Hazard Code	Jurisdiction	Name
Floodplain	Clear-water Flood	340	Village of Salmo	Salmo River
		372	Village of Slocan	Slocan River
		393	Town of Creston	Goat River
		408	RDCK Electoral Area A	Crawford Creek
		375	RDCK Electoral Area K	Burton Creek
		423	Village of Kaslo	Kaslo River
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		248	RDCK Electoral Area D	Cooper Creek
		137	RDCK Electoral Area H	Wilson Creek
		242	RDCK Electoral Area E	Harrop Creek
		95	RDCK Electoral Area K	Eagle Creek
		238	RDCK Electoral Area F	Sitkum Creek
	Hybrid Debris Flood/Debris Flow	116	RDCK Electoral Area E	Procter Creek
		251	RDCK Electoral Area E	Redfish Creek
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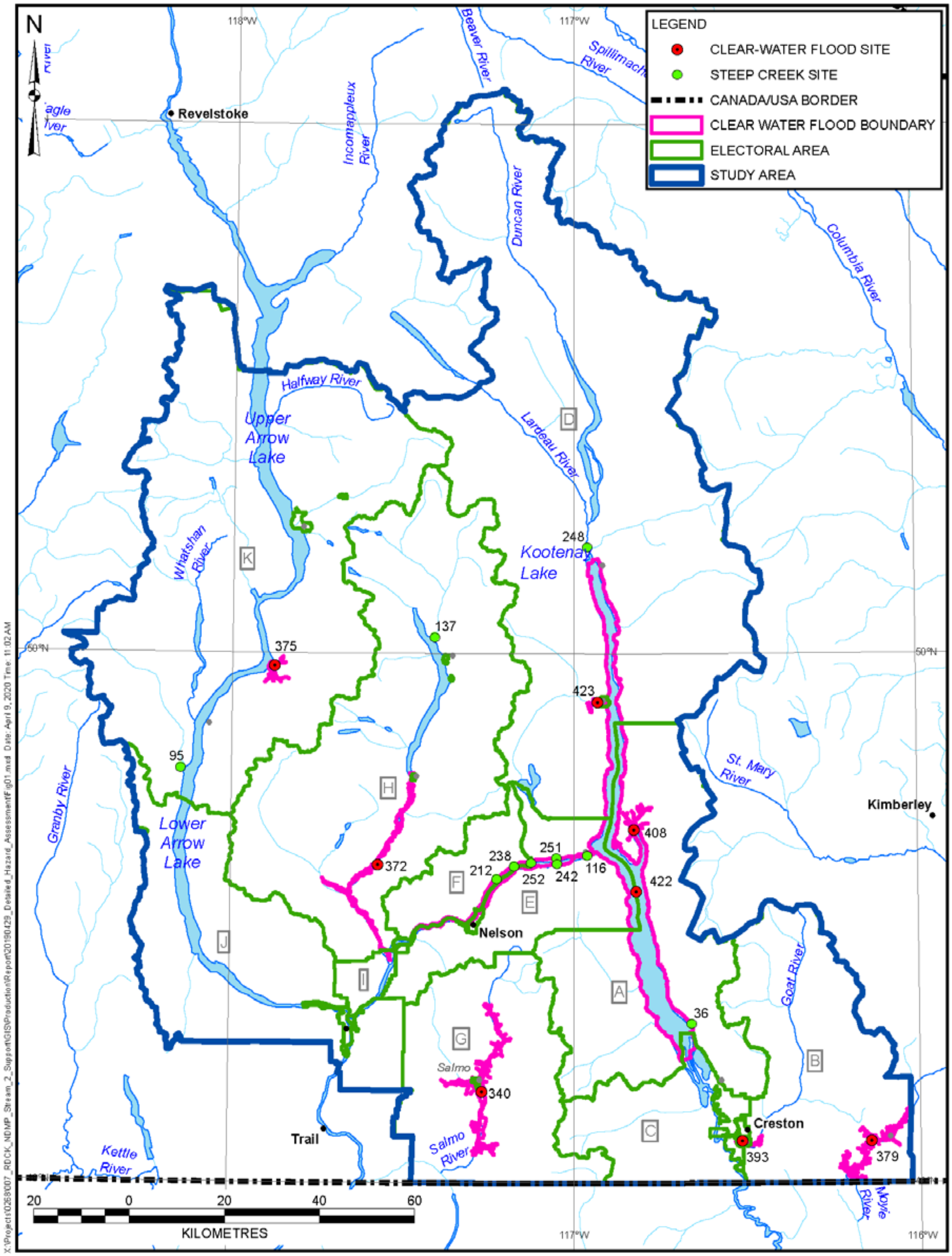

Figure 1-2. Study areas. Hazard codes shown on the figure are the same as those in the Cambio web application.

1.4. Terminology

The RDCK is subject to a spectrum of geohazard types occurring in stream channels. The scope of this assessment was divided into geohazards occurring on alluvial fans at the outlet of steep creeks (“steep creek geohazards”) and clear-water floods on main valley rivers (“floodplains”).

The geohazards assessed span a continuum of processes from clear-water floods to debris floods and debris flows (Figure 1-3). Each process is described in detail in the site assessment reports.

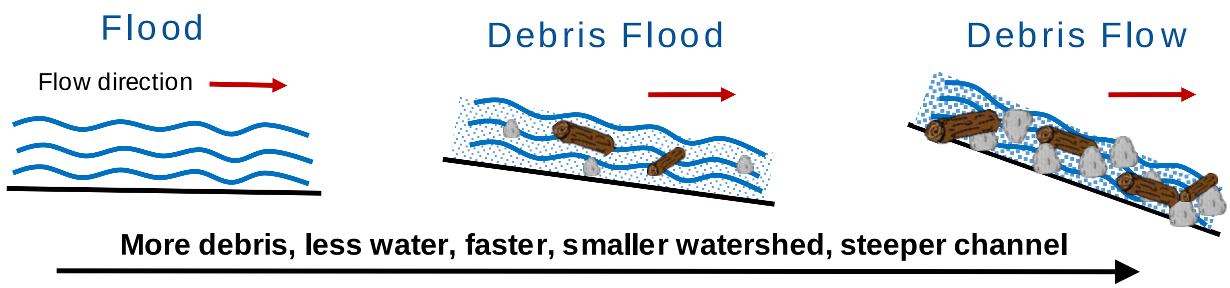

Figure 1-3. Continuum of steep creek hazards.

This summary report uses the following definitions:

Clear-water flooding: riverine and lake flooding resulting from inundation. Herein we define inundation as: flooding resulting from 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 or inundated.

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 small tributary 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) than clear-water floods. Debris floods occurs when stream flow entrains the gravel, cobbles and boulders on the channel bed; this is known as “full bed mobilization”. Debris flows have higher sediment concentrations than debris floods and can approach consistencies of wet concrete. They are typically more destructive than debris floods and are considered a landslide process. Figure 1-4 displays terms for steep creek hazard features referenced in the steep creek hazard assessment reports.

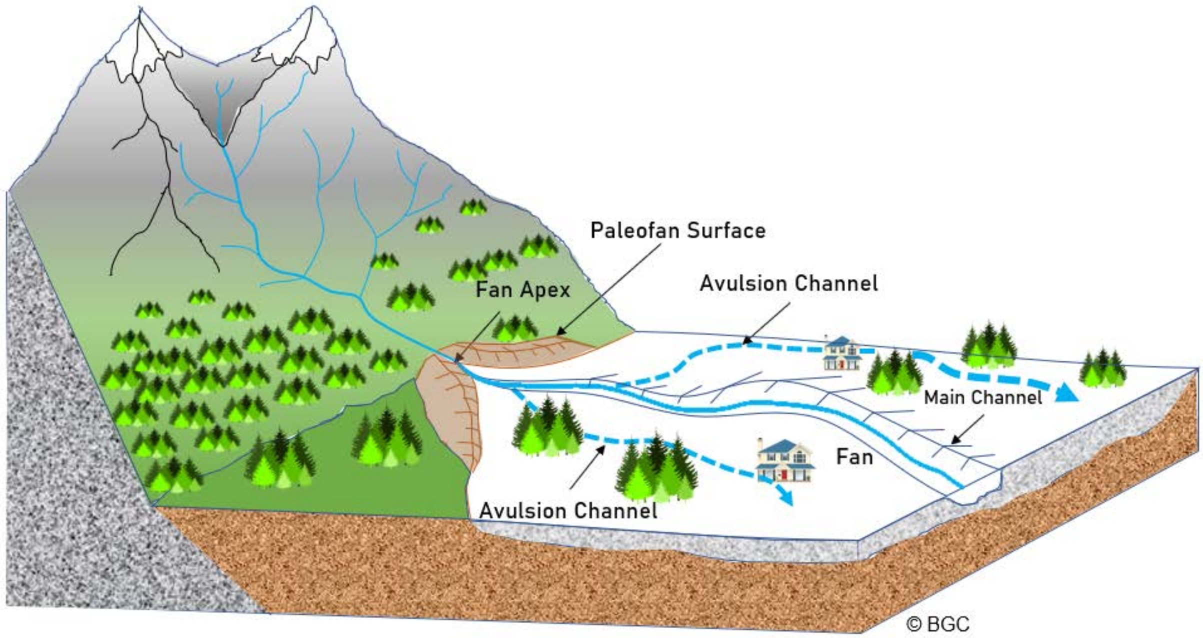

Figure 1-4. Schematic sketch showing terms for steep creek hazard features used in the reports. Artwork by BGC.

2. SCOPE OF WORK

2.1. Summary

The Stream 2 scope of work is based on BGC's proposed work plan (BGC, May 24, 2019), which was refined to best meet RDCK's needs as the project developed (BGC, November 15, 2019). It was carried out under the terms of contracts between RDCK and BGC (June 20, 2019) and between the Village of Salmo and BGC (July 19, 2019). The Stream 2 study builds from regional scale assessments completed as part of the Stream 1 study.

The scope of work for RDCK was funded by Emergency Management BC (EMBC) and Public Safety Canada under Stream 2 of the Natural Disaster Mitigation Program (NDMP). The assessment for the Village of Salmo (Table 1-1) was funded by the Union of BC Municipalities Emergency Preparedness Fund (UBCM CEPF). The scope of services for the Village of Salmo was completed concurrently with that for RDCK using the same methodology. The RDCK is overseeing the entire scope of work (including the Salmo portion).

A detailed scope of work is provided in the individual site assessment reports. Table 2-1 provides a general work plan framework and timeline. While details differ between sites, the scope of services for each study area followed this framework.

BGC notes that the current study is a hazard assessment. No estimation of geohazard consequences or risk, which combines hazards and consequences, was completed as part of the Stream 2 scope of work.

Table 2-1. Work plan framework

Activity	Tasks	Deliverables/Products
1. Project Management	• Meetings, project management and administration	• Presentations and updates
2. Data Compilation and Review	• Compile previous work: previous flood assessments; existing reports and drawings of existing flood mitigation structures.[2] • Compile existing baseline data not previously compiled for Stream 1 study: surveys, topography (LiDAR, bathymetry, dike surveys). • Compile existing hazard input data not previously compiled for Stream 1 study: geology, terrain, hydrology. • Compile existing asset input data not previously compiled for Stream 1 study (i.e., as required for hazard model setup). • Compile wildfire data and observed hydro-geomorphic response. • Complete bathymetric and cross-section surveys.	• Study objectives, scope of work and study areas • Over-arching study framework • Compiled baseline, hazard, asset data in geospatial format • Fieldwork plans • Survey data and merged digital elevation model (DEM) • Historic timeline graphics for steep creek sites
3. Fieldwork	• Conduct site visits and collect field data.	• Field data for modelling and assessment inputs
4. Hazard Assessment and Modelling	• Complete clear-water and steep creek hazard identification, analyses and modelling. • Prepare outputs for hazard map deliverables and update the regional study to reflect the new results.	• Analysis results including hazard frequency-magnitude relationships, geohazard scenarios, and outputs of hydrologic, hydraulic and debris flow modelling.
5. Final Deliverables	• Reporting	• Description of methods, results, and limitations.
	• Hazard Maps	• Hazard maps provided in geodatabase format and added to Cambio Communities

2.2. Climate Change

Planning decisions based on hazard maps can have implications for half a century or longer, and the RDCK has indicated that climate change is an urgent priority for planning, policy, and bylaw implementation in the District[3].

Section 4 of the Steep Creek Assessment Methodology report and Appendix D of individual clear-water flood hazard assessment reports describe how climate change was considered in the scope of work. In summary, climate change was considered in the scope of work through adjustments to stream flow discharges for different return periods used for hazard modelling for clear-water and steep creeks.

BGC adjusted flood quantiles (peak discharges at each return period) upwards by 20% according to professional practice guidelines (EGBC, August 28, 2018). As part of this work, BGC quantitatively considered impacts of climate change in the development of flood estimates based on Representative Concentration Pathway (RCP) 6.5 and 8.5 for the 2050s, as defined by the Intergovernmental Panel on Climate Change (IPCC). This quantitative analysis, while not conclusive, supported the adjustment according to EGBC guidelines.

It must be stressed that the effects of anthropogenic climate change are extremely complex in their manifestation in watershed geophysics and hence runoff change (Jakob, 2020). Changes in beetle infestations, wildfires, and shifts from nival (snow) to hybrid (rainfall and snow) or hybrid to rainfall-dominated systems are all intertwined and non-linear. Society has entered a climate with characteristics outside the recorded human experience. What this means for this study is that historic events and flows on stream systems may not be adequate predictors of future conditions. Changes will likely be profound, and the understanding of the trajectory and magnitude of change will evolve rapidly in the coming years. All climate change assumptions applied in this study warrant periodic review as climate science evolves in the future.

[2] This assessment builds from an extensive compilation of previous assessment reports completed during BGC's Stream 1 assessment. References for this compilation are provided as part of the Stream 1 assessment report. Compiled reports can also be accessed by navigating to a hazard area on Cambio and clicking to reveal further information about the hazard area.

[3] Per a 2019 RDCK Board Resolution as follows: *"That the Regional District of Central Kootenay Board recognizes that the world is in a global state of climate crisis. This reality creates an imperative for ALL ORDERS OF GOVERNMENT to undertake "rapid and far reaching" changes to building construction, energy systems, land use and transportation".*

3. DELIVERABLES

The deliverables of this study are provided in the form of reports and appendices, and as digital deliverables provided as web maps and data services or downloads.

3.1. Users and Use-Cases

BGC anticipates that a wide range of parties will use the hazard mapping results of both the Stream 1 and Stream 2 studies in one form or another. Table 3-1 provides examples of potential users and scenario applications. While the table is written from the perspective of a user accessing results via Cambio, it applies broadly to viewing study results via digital platforms. The use cases presented were developed in consultation with RDCK to reflect the anticipated applications of study results.

Table 3-1. Intended use cases of the Stream 1 and Stream 2 studies.

Nos.	Potential User	User Interests	Comments
1	Local and First Nations Government: • Planner • Building Permit Officer • Emergency Management Staff • GIS Staff Qualified Professionals	"I want to check whether a location of interest falls within a specific hazard area. If it does, I would like to check hazard and risk ratings, and supporting information, to decide what further actions may need to be taken at the site of interest." Example use cases could include determining higher priority areas for land use planning, identifying development permit areas (DPA) and associated permitting requirements, or emergency response scenario planning.	For areas encompassed by the Stream 1 study, users can: • Obtain priority, hazard and consequence ratings, and supporting information about geohazards and elements at risk • View elements at risk layers to see their location in relation to hazard areas • Download catalogued geotechnical reports (steep creeks only) For areas additionally encompassed by the Stream 2 study, users can: • View and apply flood or steep creek hazard maps for the range of geohazard scenarios assessed to support permit applications • View flood construction level (FCL) maps (floodplain areas only) • View "composite" maps showing combined hazard frequency and intensity (steep creeks only).
2	Local Government: • Senior Manager • Executive Director • Elected Officials	"I want to view the extent of mapped hazards within my administrative area, so I can see what areas and infrastructure are exposed to various hazards, and review priority ratings and supporting information for each area." Example use cases could include determining annual and longer-term geohazard risk management plans, engagement with third parties (e.g., major asset owners) and providing guidance to staff regarding priorities.	All of the above, plus: For areas encompassed by the Stream 1 study, users can: • View hazard extents and priority, hazard, and consequence ratings across multiple areas. For areas encompassed by detailed (NDMP Stream 2) hazard mapping, users can: • View detailed hazard maps across multiple areas for specific return periods, such as to support scenario planning for emergency response during multiple concurrent geohazard events.
3	Provincial or Federal Government • Program manager or regulator Non-government agency • e.g., Columbia Basin Trust	"I want to visually explore the extent of mapped hazards within multiple administrative areas, so I can see what areas and infrastructure are exposed to various hazards. I may use this information to submit or evaluate funding or permit applications related to geohazards management."	All of the above, plus: • Access and view results across multiple administrative areas. • Checking what level of assessment has been completed to date for a given area, in the context of provincial geohazards management strategy.

The current work also lays a foundation for future use-cases such as to incorporate real-time and forecast weather and streamflow data applicable to emergency monitoring, warning and response. Section 4.3 provides further details for consideration by RDCK.

3.2. Reporting

Table 3-2 lists the reports prepared for each of the study areas. BGC also prepared a methodology report applicable to all ten steep creek hazard areas. Each individual assessment report also contains appendices with detailed information on terminology, assessment methods, and supporting information based on site visits and desktop analyses.

BGC adapted methods to consider site specific conditions, but the assessment methods were fundamentally consistent for study areas of the same classification (floodplain or steep creek). The hybrid debris flood / debris flow steep creeks (Redfish, Procter; Table 1-1), and debris flow creek (Kuskonook) integrate additional assessment methods due to the type of geohazard (debris flow) and presence of existing structural debris flow mitigation (Kuskonook Creek).

Table 3-2. Report outline for floodplain study areas.

Type	Jurisdiction	Watercourse	Document No.
Floodplain	Village of Salmo	Salmo River	RDCK2-CW-005
	Village of Slocan	Slocan River	RDCK2-CW-006
	Town of Creston	Goat River	RDCK2-CW-001
	RDCK Electoral Area A	Crawford Creek	RDCK2-CW-004
	RDCK Electoral Area K	Burton Creek	RDCK2-CW-002
	Village of Kaslo	Kaslo River	RDCK2-CW-003
Alluvial Fans (Steep Creeks)	RDCK Electoral Area F	Duhamel Creek	RDCK2-SC-008
	RDCK Electoral Area F	Kokanee Creek	RDCK2-SC-005
	RDCK Electoral Area D	Cooper Creek	RDCK2-SC-007
	RDCK Electoral Area H	Wilson Creek	RDCK2-SC-006
	RDCK Electoral Area E	Harrop Creek	RDCK2-SC-002
	RDCK Electoral Area K	Eagle Creek	RDCK2-SC-001
	RDCK Electoral Area E	Procter Creek	RDCK2-SC-009
	RDCK Electoral Area E	Redfish Creek	RDCK2-SC-003
	RDCK Electoral Area F	Sitkum Creek	RDCK2-SC-004
	RDCK Electoral Area A	Kuskonook Creek	RDCK2-SC-010
Steep Creek Assessment Methodology	All steep creeks	All steep creeks	RDCK2-SC-011
Summary Report (this document)	All	All	RDCK2-SR-01

3.3. Hazard Map Level of Detail

This study provides more detailed geohazard maps than the Stream 1 study. Table 3-3 summarizes points of comparison between Stream 1 and Stream 2 mapping.

Table 3-3. Hazard assessment levels of detail.

Points of Comparison	Stream 1 Study	Stream 2 Study
	Hazard Identification Maps	**Detailed Hazard Maps**
Objective	Identify areas potentially prone to the hazard and provide hazard characteristics at a level of detail of the entire hazard extent.	Map hazard extents by considering specific event scenario(s) and site factors (e.g., flood protection structures)
Applicability for decision making	Prioritization; basis to define hazard Development Permit Areas (DPA) according to the outer hazard boundary.	Mitigation planning; basis to define DPAs for sub-areas within the hazard boundary; support quantitative risk assessment where required; hazard monitoring and emergency response planning.
Level of detail	Hazard boundary (no further division of hazard levels within the boundary).	Sub-hazard boundary level of detail (hazard characteristics vary within the boundary). Mapping includes a range of hazard scenarios at different frequencies and magnitudes.
Level of effort (cost)	$	$$$
Inputs	Desktop analyses	Desktop analyses, hydrometric surveys, fieldwork, numerical modelling, professional judgment
Hazard return periods considered	Single (to compare sites)	Multiple return periods & hazard scenarios
Qualitative/Quantitative	Relative, qualitative	Mostly quantitative
Map Deliverables	Hazard boundaries	Hazard maps
Applicable Guidelines	NRCAN (2018)	EGBC (2010, 2017, 2018)

3.4. Steep Creek Hazard Maps

Hazard maps prepared as part of this study are provided as:

- Digital (GIS) files
- Static (pdf) maps included with individual assessment reports
- Map layers displayed in Cambio web application.

The objective of steep creek hazard mapping is to estimate the extent and intensity (destructive potential) of a range of possible hazard scenarios on each creek. Table 3-4 lists the types of geohazard maps prepared for each creek. Each map type is described further in the sections below.

Table 3-4. Steep creek hazard maps.

Map Type	Information Displayed	Application	Typical Users
Hazard Model Result Maps	Extents and intensities of a range of potential geohazard scenarios (20-year to 500-year return period).	Emergency planning and risk analysis	Emergency Management Staff; Qualified Professionals
Composite Hazard Rating Map	Map showing BGC's interpretation of the range of hazard model scenarios considered in the assessment. The hazard levels displayed on the map consider both hazard frequency and intensity.	Policy and bylaws	Planners, Building Permit Officers; Managers; Elected Officials.

3.4.1. Hazard Model Scenario Maps

BGC assessed a range of geohazard frequencies and magnitudes at each site, where larger and more destructive events occur more rarely.

Table 3-5 lists the range of return periods that were considered in the hazard assessment and presented on geohazard model result maps, which can be accessed on Cambio by navigating to a site of interest and turning on the map layers. Depending on the watercourse, more than one hazard scenario map may also be produced for a given return period, such as to show different channel avulsion[4] or bridge blockage scenarios.

Table 3-5. Return period classes.

Return Period Range (years)	Representative Return Period (years)
10-30	20
30-100	50
100-300	200
300-1000	500

Table 3-5 displays "return period ranges" and "representative return periods". The representative return periods fall close to the mean of each range[5]. They are the return periods for which maps are produced. Given uncertainties, they generally represent the event magnitudes within the return period ranges shown in the table. Note that in the context of climate change, the term "return period" is a moving target. There are two ways to look at it: one is that an event of the same magnitude can be associated with a lower return period in the future (i.e. occur more frequently). The other is that for the same return period, the magnitude of the event (i.e., the discharge or runoff volume or bank erosion) can increase over time.

4 A channel avulsion occurs when flows partially or completely abandon the existing channel in favour of a new course.

5 The 50- and 500- year events do not precisely fall at the mean of the return period ranges shown in Table 3-5 but were chosen as round figures due to uncertainties and because these return periods have a long tradition of use in BC.

Cambio users can display for the following for each hazard scenario:

1. Hazard intensity (destructive potential), as defined further below.
2. Bank erosion extents (shown as a likely and potential/improbable corridors as described in the Steep Creek Assessment Methodology Report and site reports).
3. For scenarios modelled with sediment transport, the associated areas of sediment deposition

Hazard model scenario maps show hazard intensity for a given area of impact. Hazard intensity is expressed by an impact force per metre flow width (kilo Newtons/metre or kN/m), calculated as the product of modelled flow depth, density, and the square of flow velocity. Sites with a lower chance of being impacted and lower intensities (e.g., slow flowing ankle-deep muddy water) have a lower level of hazard than sites that are impacted more frequently and at higher intensities (such as water and rocks flowing at running speed).

BGC emphasizes that the hazard model scenario maps show the direct output of numerical hazard modeling. All models, while useful, are a simplification of "reality", and should be interpreted with caution. The individual hazard model scenario maps were not created for public policy application in the absence of involvement by a qualified professional. However, they may be applicable to emergency response scenario planning and application in further hazard and risk analyses by qualified professionals.

For assessment areas containing existing structural flood protection (e.g., dikes), BGC applied site-specific assumptions about how or if these structures would be considered in hazard modelling and the preparation of geohazard scenario maps. These assumptions are outlined in the individual site assessment reports.

Figure 3-1 shows an example of a hazard model scenario map at Eagle Creek[6]. Table 3-6 provides a qualitative description of the flow intensity ranges displayed on the map. For completeness, Table 3-6 describes a wider range of possible impact force ranges than are displayed in this example.

[6] The map layout shown on Figure 3-1 has been modified to enlarge the legend and remove the map border. It is shown for example purposes; the original version provided in the Eagle Creek steep creek hazard assessment (BGC 2020; Doc. No. RDCK2-SC-001).

Table 3-6. Intensity values shown on geohazard scenario maps.

≤ 1	Slow flowing shallow and deep water with little or no debris. High likelihood of water damage. Potentially dangerous to people in buildings, in areas with higher water depths.
1 to 10	Mostly slow but potentially fast flowing shallow or deep flow with some debris. High likelihood of sedimentation and water damage. Potentially dangerous to people in the basement or first floor of buildings without elevated concrete foundations.
10-100	Fast flowing water and debris. High likelihood of structural building damage and severe sediment and water damage. Dangerous to people on the first floor or in the basement of buildings. Replacement of unreinforced buildings likely required.
100 - 1000	Fast flowing debris. High likelihood of building destruction. Very dangerous to people in buildings irrespective of floor.
>1000	Fast flowing debris. Certain building destruction. Extremely dangerous to people in buildings irrespective of floor.

Figure 3-1. Example of steep creek hazard model result map at Eagle Creek.

3.4.2. Composite Hazard Rating Map

BGC prepared a “composite” hazard rating map that displays all modelled scenarios together on a single map. The composite hazard rating map is intended for hazard communication and decision making, where different zones on the map may be subject to specific land use prescriptions, covenants, bylaws or other limiting clauses for existing or proposed development.

Figure 3-2 displays an example of the composite hazard rating map for Kokanee Creek[7]. Figure 3-3 defines the ratings shown on the map according to two factors: the frequency (return period) and expected intensity of hazard impact. Hazard intensity is categorized according to impact force, which is proportional to flow velocity, depth, and fluid density. Details of impact force calculation are provided in the site assessment reports.

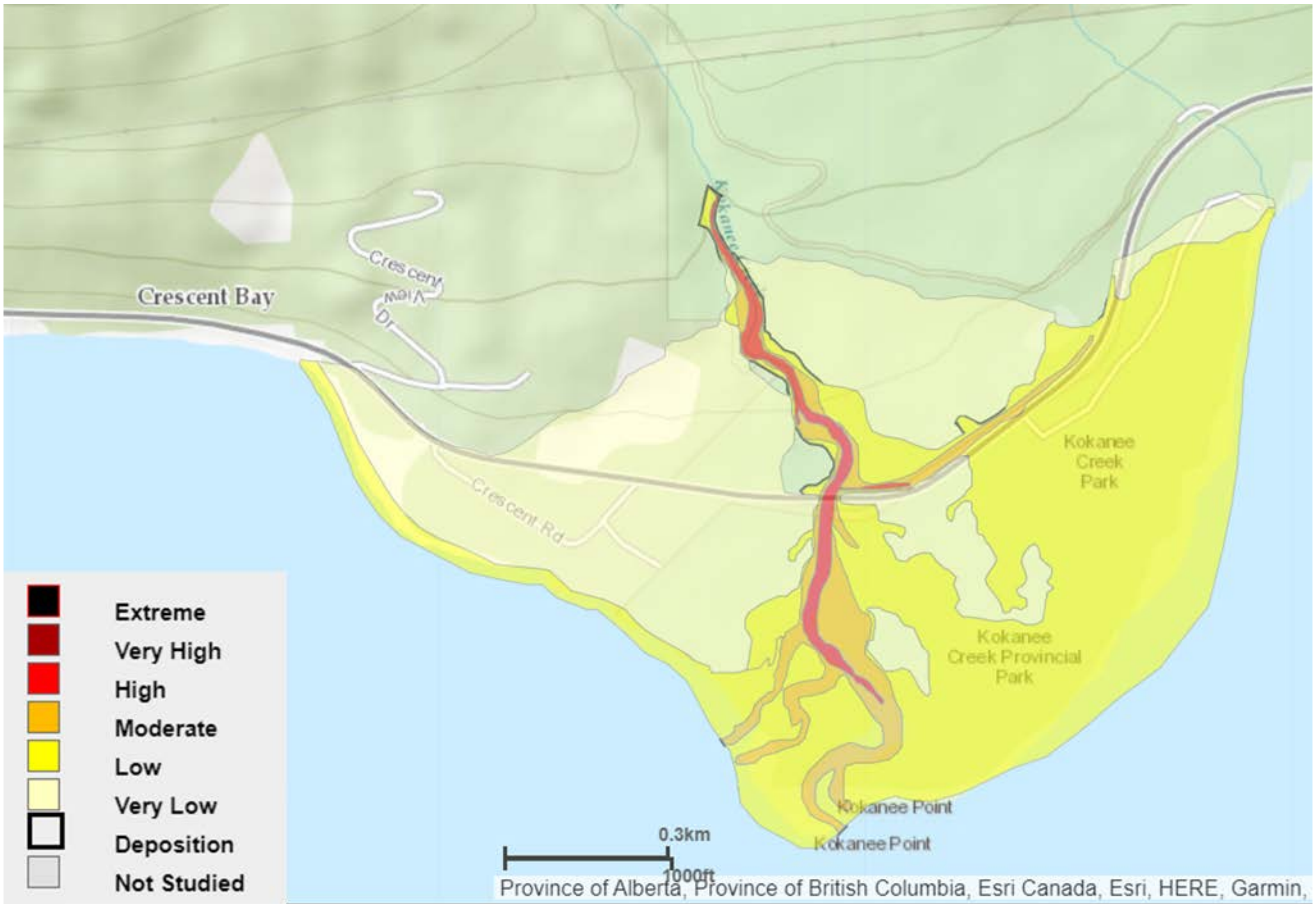

Figure 3-2. Example of composite hazard rating map for Kokanee Creek.

[7] The map layout shown on Figure 3-2 has been modified to enlarge the legend and remove the map border. It is shown for example purposes; the original version provided in the Kokanee Creek steep creek hazard assessment (BGC 2020; Doc. No. RDCK2-SC-005).

Return Period Range (years)	Representative Return Period (years)	Geohazard Intensity				
		Very Low	Low	Moderate	High	Very High
1 - 3	2					
10 - 30	20					
30 - 100	50					
100 - 300	200					
300 - 1000	500					

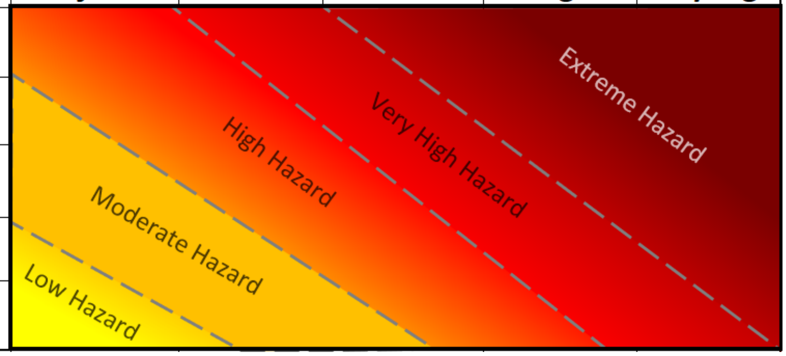

Figure 3-3. Simplified geohazard impact intensity frequency matrix.

BGC notes the following about the composite hazard rating maps:

1. Areas subject to frequent, more destructive flows are generally considered higher hazard and, all else being equal, may define areas of higher risk. However, the composite hazard rating maps are not risk maps. They do not consider vulnerability to loss of life, or the chance that elements at risk are present at the time of impact. For example, a home located in a Moderate-rated area could reduce their risk by reducing their vulnerability through design and the location of habitable space (i.e., no habitable space on the first floor). If required, quantitative risk assessment can be used to estimate the level of risk reduction that could be achieved through such measures.
2. The composite hazard rating maps contain some degree of generalization, at the resolution of the intensity bins reported in Figure 3-3. Site-specific characteristics may be present that are not reflected in the ratings. Assessments triggered as a requirement of development permit applications could identify, for example, that an individual property is raised above surrounding terrain and less prone to hazard impact than is implied by the map. Where needed for site-specific assessment, individual scenario maps can help identify where flows might follow avulsion channels (older channels occupied only in rare floods) that are not reflected on the composite map.

3.5. Clear-water Flood Hazard Maps

BGC prepared clear-water flood hazard maps based on the results of numerical flood modelling. The individual site-assessment reports describe methods to prepare hazard maps for each area.

In summary, BGC prepared two types of maps for the return period classes shown in Table 3-7: flood hazard model result maps and Flood Construction Level (FCL) maps. The flood hazard model scenario maps are intended to be used by emergency management staff and qualified professionals. Three versions are produced for each return period, to show flow depth, velocity, and flow impact force. The FCL maps are intended to be incorporated into policy and regulation as deemed appropriate by RDCK.

Table 3-7. Return period classes.

Return Period (years)	Annual Exceedance Probability
20	0.05
50	0.02
200	0.005
500	0.002

Individual site reports include static copies of the following types of maps:

- Flood hazard model scenario map (200-year flood depth)
- Flood Construction Level (200-year flood elevation plus 0.6 m freeboard).

Cambio displays the following map types for the return periods displayed in Table 3-7:

- Flood hazard model scenario maps for flood depth, velocity, and flow impact force (20-, 50-, 200- and 500-year return periods)
- Flood Construction Level (200-year flood elevation plus 0.6 m freeboard).

3.5.1. Flood Hazard Model Result Maps

The flood hazard scenario maps display the hazard intensity (destructive potential) and extent of inundated areas for each scenario assessed. Two versions of the hazard scenario maps for each return period are provided: i) maps showing flood depth, and ii) maps showing flow impact force. Similar to the steep creeks, hazard intensity is expressed by an impact force per metre flow width (kilo Newtons/metre or kN/m) calculated as the product of modelled flow depth, fluid density (1000 kg/m^3), and the square of flow velocity.

Maps displaying flow depth support assessments where inundation is the primary mechanism of damage. Flow impact force maps highlight locations where a combination of higher flow velocity and depth may warrant additional assessment (i.e., analyses of bank stability, erosion, or life safety). Table 4-9 provides a description of the flow impact force ranges and their impacts on life safety and impacts on the built environment. Flow depth and flow impact force maps for all return periods are displayed on Cambio.

Figure 3-4 shows an example flood hazard model scenario map (200-year flood depth) for Kaslo River. Figure 3-5 shows an example of flood hazard mapping for Burton Creek, as displayed in Cambio.

Table 4-8. Flow intensity values shown on the flood hazard scenario maps (Cambio)

≤ 1	Slow flowing shallow and deep water with little or no debris. High likelihood of water damage. Potentially dangerous to people in buildings, in areas with higher water depths.
1 to 10	Mostly slow but potentially fast flowing shallow or deep flow with some debris. High likelihood of sedimentation and water damage. Potentially dangerous to people in the basement or first floor of buildings without elevated concrete foundations.
10-100	Fast flowing water and debris. High likelihood of structural building damage and severe sediment and water damage. Dangerous to people on the first floor or in the basement of buildings. Replacement of unreinforced buildings likely required.
>100[1]	Fast flowing debris. High likelihood of building destruction. Very dangerous to people in buildings irrespective of floor.

Note:

1. Flow intensities greater than 100 kN/m in clear-water watercourses occur primarily on steeper creeks within the main channel.

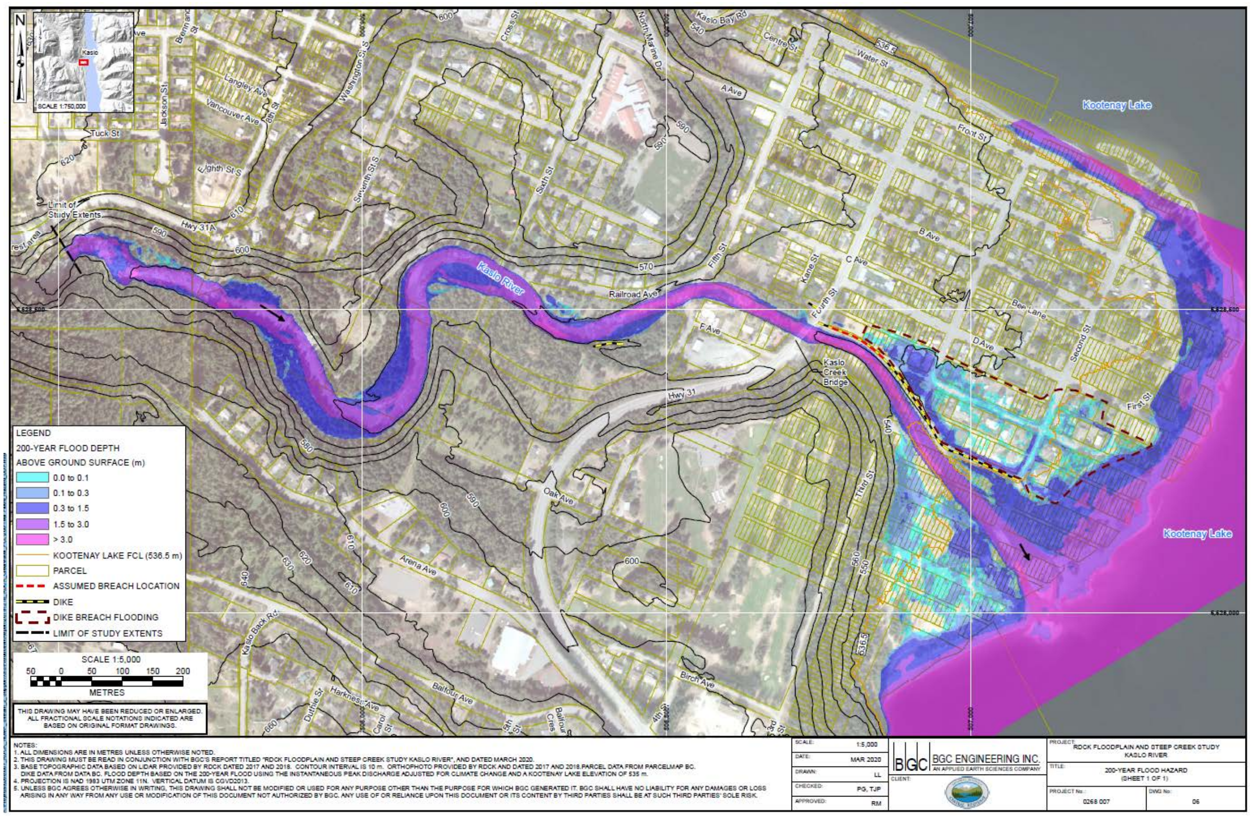

Figure 3-4. Example of the static flood hazard model scenario map (200-year flood depth) for Kaslo River.

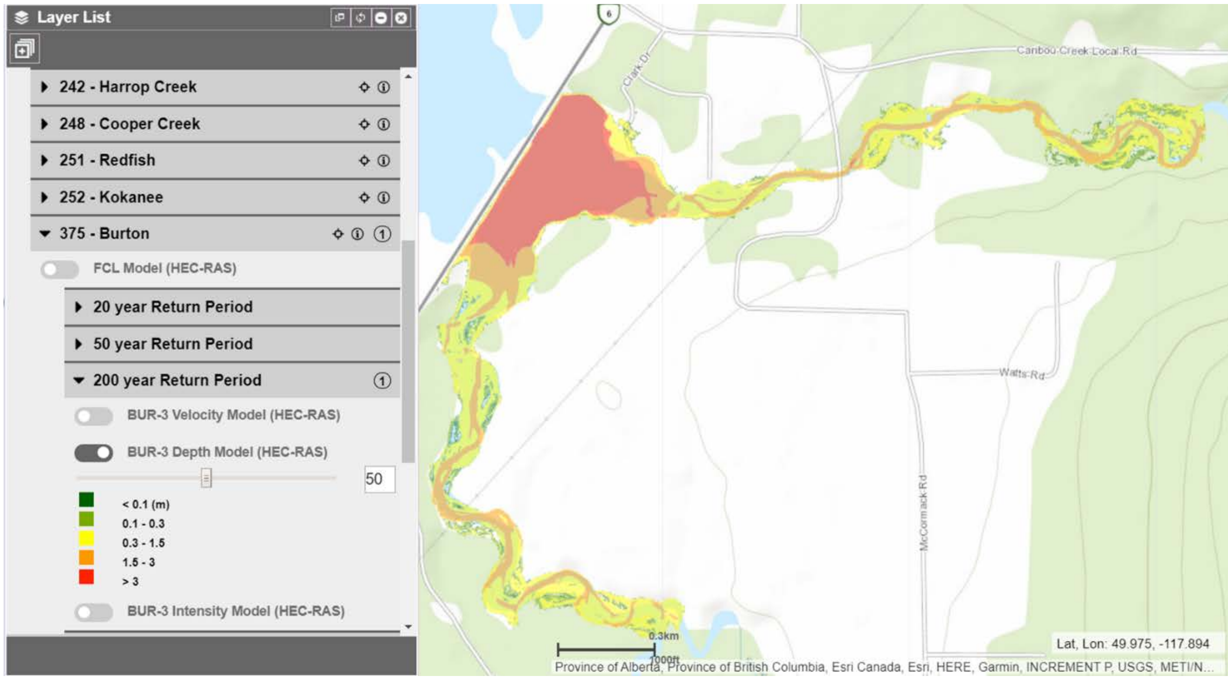

Figure 3-5. Example of the flood hazard mapping displayed in Cambio for Burton Creek.

3.5.2. Flood Construction Level (FCL) Mapping

FCLs are required for areas adjacent to river floodplains for consideration during planning. An FCL can be incorporated into regulation by authorities to provide guidance for new construction on the extent and elevation of possible flooding in the area. FCLs provide a standards-based approach that is relatively straightforward to apply and interpret.

In BC, FCLs have historically been calculated as the higher of the following:

- Water surface profile for the design peak instantaneous flow plus 0.3 m of freeboard
- Water surface profile for the design daily flow plus 0.6 m of freeboard.

The freeboard is applied to the estimated water surface profile to account for uncertainties in the calculation of the water surface. As noted in EGBC (January 2017, August 28, 2018), for many BC rivers, freeboard has been set higher than these minimum values to account, for example, for sediment deposition and debris jams. Recently, several studies have recommended using 0.6 m of freeboard above the design peak instantaneous flow (KWL, 2014, 2017; NHC, 2008, 2014, 2016, 2018). Nolde and Jakob (2015) challenged the use of standard freeboards for flood defense structures and recommended the use of approaches that account for stochastic uncertainty; specifically, the use of statistical confidence intervals. Presently, this approach is not an accepted practice in BC and as the authors discuss, the selection of the appropriate confidence level is critical, but guidance is not yet available. Therefore, BGC decided to apply the standard freeboards consistent with the recent studies applying a 0.6 m freeboard to the 200-year FCL.

To accommodate requirements for spatial analysis (e.g., GIS queries), BGC adopted the following approach to display FCLs:

- Generate FCL isolines by extending the predicted 200-year water surface elevation plus freeboard across the floodplain.
- Close the isolines into polygons around the edges where the FCL blends with the elevation of surrounding topography.
- Define FCL attributes for each polygon corresponding to the upper (upstream) and lower (downstream) isoline values.

BGC also made site-specific adjustments of freeboard in select areas based on evaluation of hydraulic modelling results.

Figure 3-6 shows an example of an FCL map as provided in the Goat River report. Figure 3-7 displays an FCL map for Burton River as displayed in Cambio, overlaid on a 200-year hazard model scenario map.

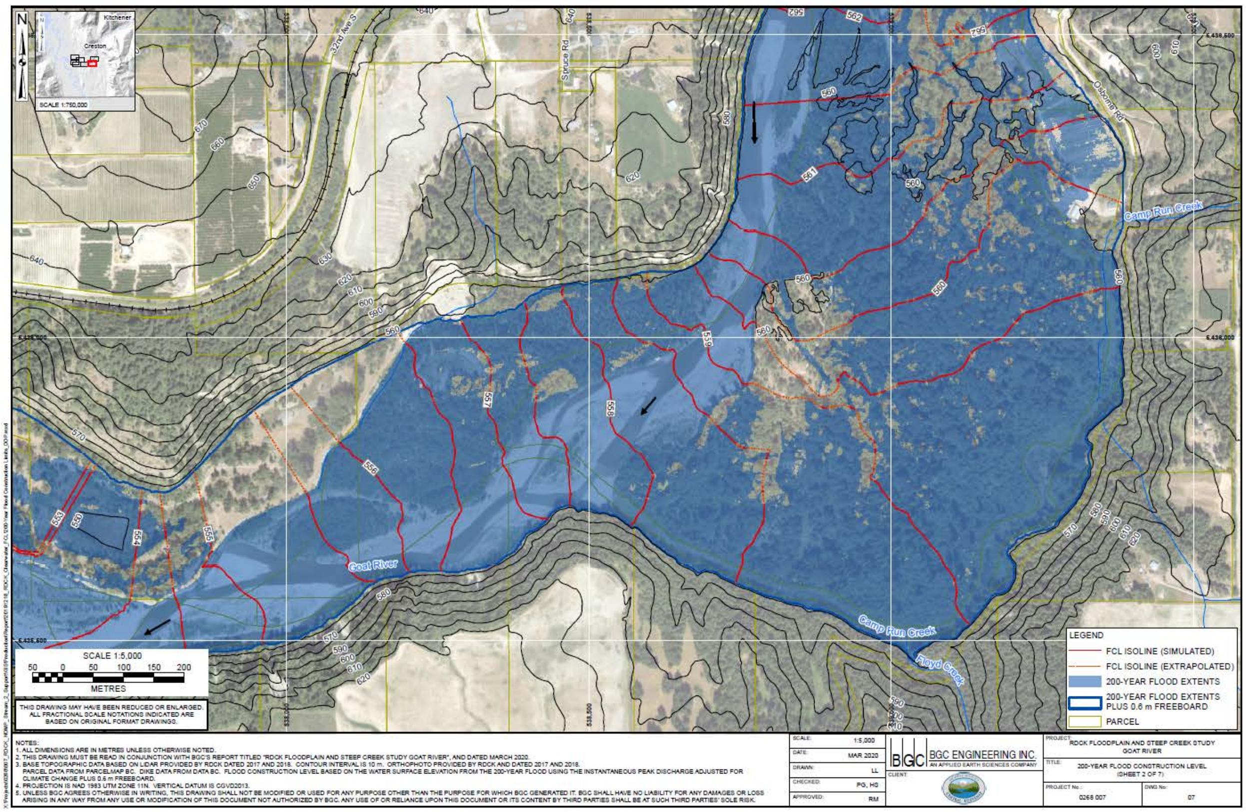

Figure 3-6. Example of the Flood Construction Level map (200-year flood depth) for the Goat River.

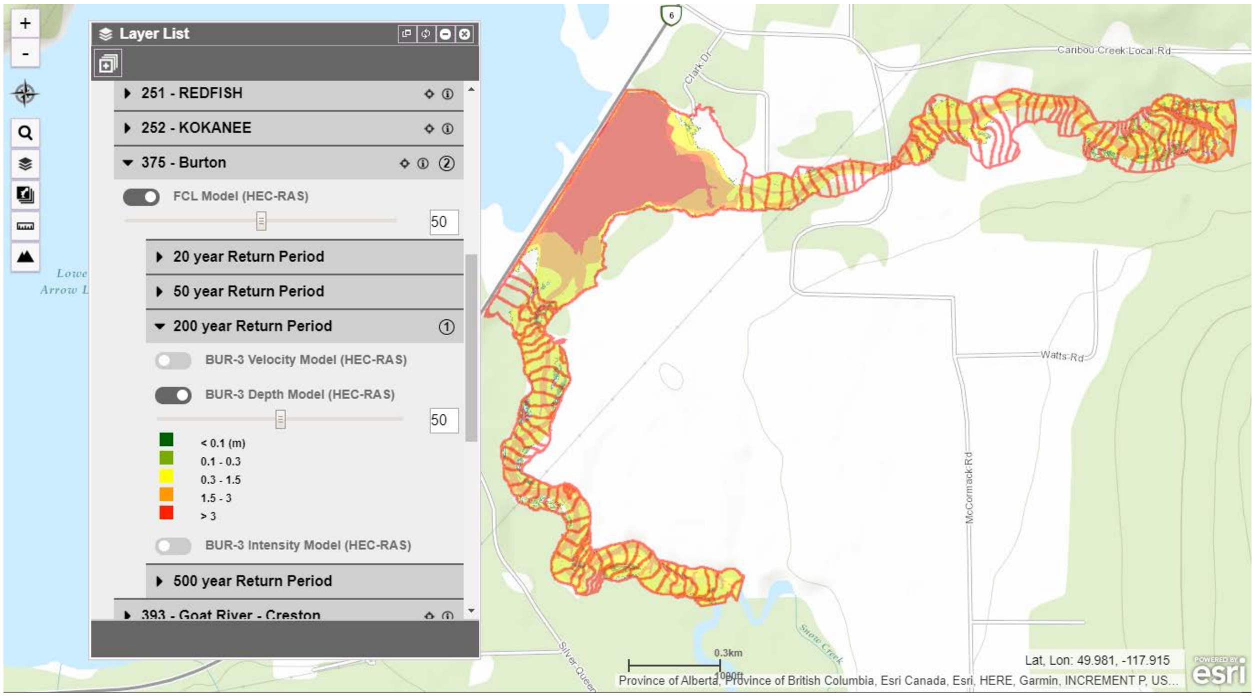

Figure 3-7. Example of the Flood Construction Level displayed in Cambio™ for Burton Creek.

4. ADDITIONAL CONSIDERATIONS

This section highlights ways that this assessment and the Stream 1 study may be incorporated into long-term geohazards risk management strategy by the RDCK and member municipalities.

4.1. Regional Geohazard Risk Management Strategy

Consideration:

- *Adopt the geohazard areas prioritized in the Stream 1 study and further assessed in this study as a preliminary risk register and develop a plan to advance long-term geohazard risk management of these sites.*

The Stream 1 and this study support the RDCK and municipalities with decision making as part of a long-term geohazards management program. This section summarizes points of consideration when developing and implementing geohazard risk management decisions for multiple sites.

Figure 4-1 provides a simple conceptual sketch of the process. The current work provides the starting point to build a 'risk register' where at-risk sites are addressed according to their stage in the risk management process (ISO 31000:2009). Section 4.2 provides further considerations for the "Site Specific Risk Management" box in Figure 4-1.

The primary objective is to support an iterative and continuous approach to risk management that:

- dynamically addresses changing conditions (landscape, hydro-climate, and land use)
- is consistent across multiple geohazard types
- leverages multiple funding sources as available (i.e. does not wait for a single large grant)
- integrates multiple projects at watershed scale, to avoid duplicated effort.
- leverages digital approaches to information management (web maps and applications).
- ideally, includes sharing of information and resources between the public and private sectors (Section 4.8).

Procedures to address changing conditions would need to consider factors such as landscape changes affecting hazard levels (e.g., forest fires, beetle infestations, logging, mining, new hazard events, construction of mitigation measures), and changes to elements at risk (e.g., new development). Future geohazards studies should be incorporated into the integrated knowledge base.

To maintain priorities and actions between geohazard areas (i.e., those tabulated in the risk register), any work carried out for a specific site should be incorporated into the common knowledge base and include recommendations for next steps in the risk management cycle.

BGC notes that new work often occurs in the aftermath of a geohazard event. This provides an opportunity to capture time-sensitive information about hazards and consequences, and a challenge posed by the urgent schedule of emergency response. BGC suggests RDCK assemble a checklist of key inputs to collect following an emergency that are critical to improving geohazards understanding in the District. Guidelines for forensic assessment of geohazard events are outside the scope of this assessment but can be provided on request.

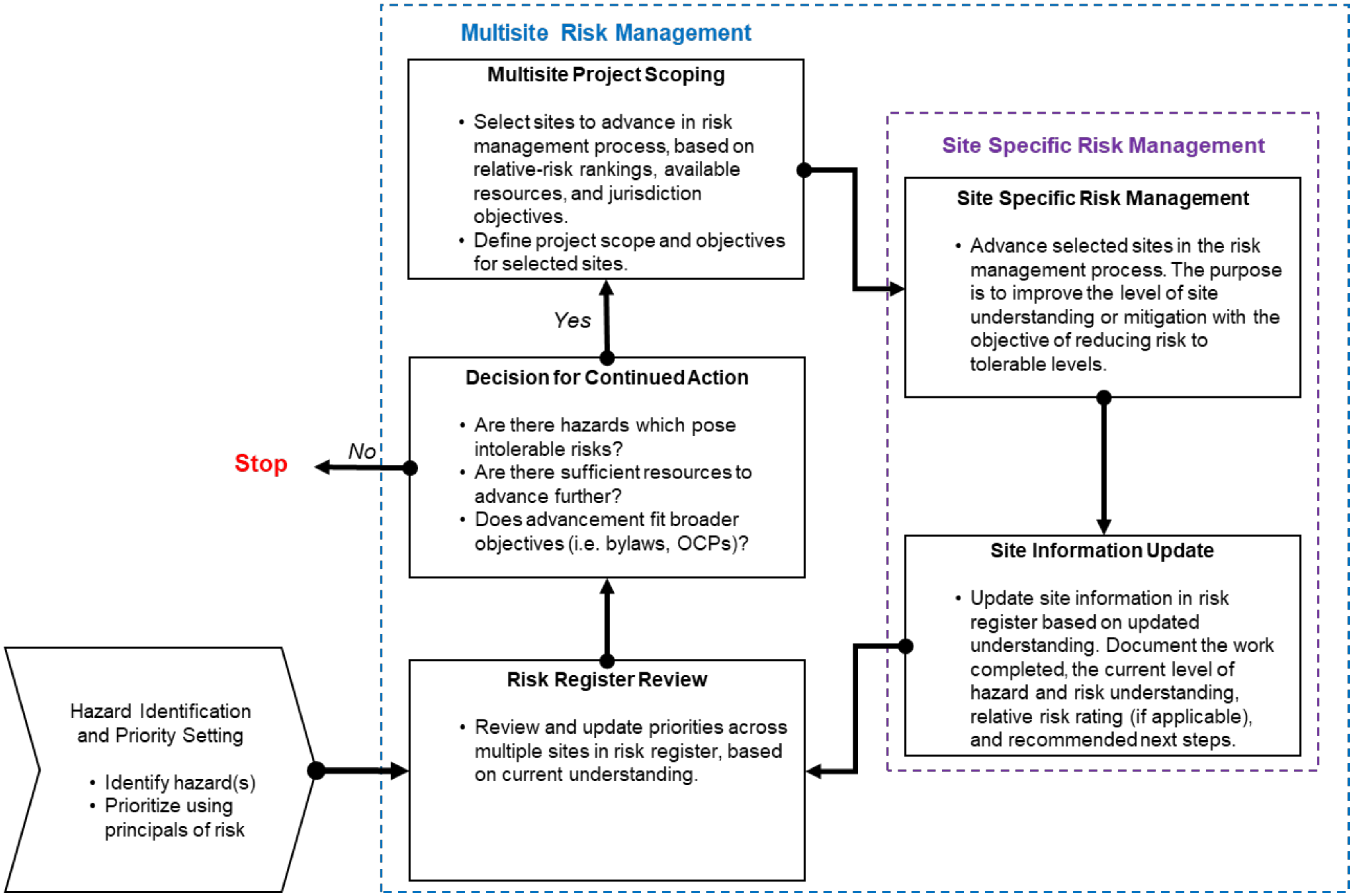

Figure 4-1. Schematic of multi-site risk management approach.

4.2. Site-Specific Geohazard Risk Management Strategy

Consideration:

- *Adopt a geohazard risk management framework that considers the "As Low As Reasonably Practicable" principle when developing and implementing geohazard risk management plans.*

This section provides considerations for RDCK when advancing beyond the current work to implement steps to assess, evaluate, and manage geohazard risk.

Table 4-1 provides a typical risk management framework. This risk management framework is most clearly applicable at sites where risk can be managed through, for example, engineering controls and development decisions. BGC emphasizes that other areas of proactive emergency management such as resiliency (i.e., ability to resist and recover from geohazard events), while not explicitly called out in this table, are equally important considerations to manage vulnerability.

Within this framework, the Stream 1 study included the first four steps of Table 4-1 at a screening level of detail, from the perspective of prioritizing relative risk across multiple sites. This assessment focused entirely on the second step, geohazard analysis. This study was not a risk assessment and did not address Steps 4 to 7 in Table 4-1.

Table 4-1. Risk management framework (adapted from Fell et al., 2005; AGS, 2007a; 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 rowspan="1">1. Project Initiation
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 and Monitoring
a. Implement chosen risk control options
b. Define and document ongoing monitoring and maintenance</td></tr>
</table>

Where RDCK and municipalities plan to advance to the next steps of risk management in areas considered in this study, BGC notes that the “worst” (highest risk) location may not necessarily be where the greatest overall level of risk reduction can be achieved, given limited resources.

BGC suggests that RDCK and municipalities develop a risk evaluation process that includes both risk tolerance criteria and a process to apply the “As Low As Reasonably Practicable” (ALARP) principle in decision making.

The concept of a risk that is “as low as reasonably practicable” is derived from British common law (Baecher et al., 2015), and has since been applied to landslide risk management in Hong Kong, the District of North Vancouver, Town of Canmore, and the District of Squamish (GEO, 1998; Malone, 2004; Hungr et al., 2016). The Canadian Dam Association, United States (US) Bureau of Reclamation, and US Army Corps of Engineers also rely heavily on the ALARP principle in risk management decision making (Hungr et al., 2016; FERC, 2016).

While guidance is available, there are no prescriptive criteria for determining when ALARP is reached, as ALARP is a matter of judgement. It is a statement by decision makers that the risk is low enough, and other measures to further reduce the risk are unreasonable, impracticable, or inefficient. In the geohazard risk management literature, there are few examples of quantitative application of the ALARP principle. Subjective application of the ALARP principle is much more common (Hungr et al., 2016). FERC (2016) provides guidance for determining ALARP for dam safety.

As users apply the Stream 2 study results and additional risk assessment to develop mitigation plans, BGC suggests considering the concept of "disproportion" to guide decisions about "reasonable" levels of mitigation where design decisions have costly implications. In summary, disproportion is a concept used to test whether the risk is insignificant in relation to the cost required to reduce it further. In other words, it is a method for showing that further risk reduction is 'grossly disproportional' to the benefit gained[8]. A concept called a "Disproportionality Ratio" can be used to define thresholds beyond which there is 'gross disproportion' (i.e., where further investment in mitigation is not justified).

A Disproportionality Ratio can be used to evaluate multiple types of risk, including both economic and life safety. It could also be used to evaluate applications by stakeholders for a reduction in FCL requirements where costs are perceived to be excessive in relation to risk reduction benefit. BGC would be happy to provide further details on the application of the ALARP principal in risk management decision making, on request.

4.3. Further Assessments

Consideration:

- *Review recommendations in the individual assessment reports and prioritize next steps to obtain funding for further work, where required.*
- *Update Stream 1 hazard areas to consider newly available lidar topography.*
- *Update the record of geohazard events in the District based on the Stream 2 study.*

BGC suggests reviewing site-specific recommendations in the individual assessment reports from the perspective of District-wide priorities. As a first step, BGC suggests developing a short-list of needs eligible for funding via the Union of BC Municipalities Emergency Preparedness Fund. The 2020 intake for structural mitigation has yet to be announced, but the 2019 application guide describes requirements[9]. Advance planning will be required to develop design concepts to a level that provides a strong justification for funding. BGC is happy to discuss further, on request.

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[8] For example, individuals assess disproportionality when purchasing car insurance. Imagine you are renting a car. Most individuals would purchase the supplemental unlimited accident coverage if it was offered for $1, but many would decline the coverage if offered at a significantly higher price, say $30 per day. We reject the risk reduction offered by the supplemental insurance because we assess that the benefit is disproportionately small ("I've never been in an accident before") compared to the cost of the insurance ("the insurance costs twice as much as the rental!").

[9] https://www.ubcm.ca/EN/main/funding/lgps/community-emergency-preparedness-fund/structural-flood-mitigation.html

Since issue of BGC's Stream 1 assessment (BGC, March 31, 2020), lidar topography has become available for large portions of the District. These data were applied to the detailed assessment areas considered in this Stream 2 study, but not the Stream 1 study areas. BGC's Stream 2 study also developed a more extensive record of geohazard events and identified several gaps in the regional fan inventory. BGC recommends the following:

- Review the Stream 1 alluvial fan boundaries and characteristics in areas where lidar is now available and resolve any identified gaps. For example, BGC recommends that Gar Creek be added to the inventory.
- Update the record of geohazard events in the District based on new information compiled during the Stream 2 study and (if available) data on file with MOTI and FLRNO.

BGC suggests that the above updates be completed before the Stream 1 assessment areas are incorporated into bylaws.

4.4. Geohazard Monitoring and Warning Systems

Consideration:

- *Combine hazard mapping with precipitation and streamflow monitoring and forecasts to develop alerts to support emergency management.*
- *Re-apply the hydraulic models developed for this study to support real-time emergency response.*

Combined with mapping of geohazards and exposure (elements at risk), precipitation and streamflow (hydroclimatic) monitoring and forecasts are critical information for geohazard risk and emergency management.

Where precipitation and streamflow monitoring and forecasts are available, the Stream 2 studies provide a stepping-stone to support the establishment of hazard monitoring and warning systems in the RDCK. Such approaches would support emergency management and could support risk management where existing structural measures are absent or inadequate, or where the cost of new mitigation would be grossly disproportional to the benefit gained.

This section provides considerations to develop flood and steep-creek hazard monitoring and warning in the RDCK. The approach described in this section makes use of the following software resources:

- Cambio, which is used to deliver the current Stream 1 and Stream 2 studies.
- Precipitation, snow pack, and streamflow monitoring systems implemented through software referred to as River Network Tools^{TM} (RNT).

4.4.1. Streamflow Data

The Water Survey of Canada (WSC) maintains approximately 1,900 real-time stream flow gauges across Canada. Accessed from the RNT, Cambio currently displays all real-time flow gauges within the RDCK (e.g., Figure 4-2).

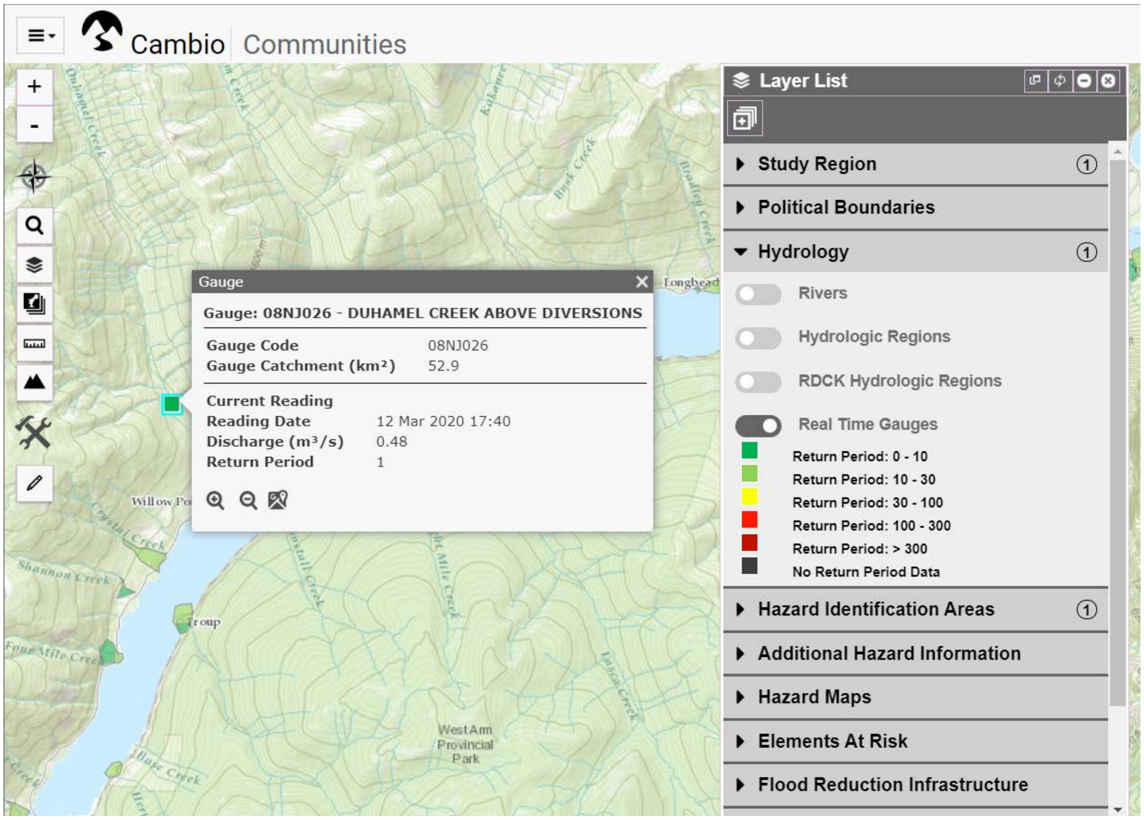

Figure 4-2. Example of a real-time streamflow gauge on Duhamel Creek.

4.4.2. Precipitation Data

Environment and Climate Change Canada (ECCC) administrates the Regional Deterministic Precipitation Analysis based on the Canadian Precipitation Analysis (RDPA-CaPA) system, which provides estimates of accumulated precipitation in 10 km grids for all of North America every 6 hours and then produces a 24-hour summary for each day. The RDPA-CaPA system combines data from the regional numerical weather forecast (i.e., an atmospheric model) with precipitation measurements from rain gauges (i.e., a surface network) and the precipitation estimates from the Canadian weather radar networks and satellite observations to provide the best estimate of actual precipitation. Figure 4-4 shows an example of 24-hour accumulated precipitation in southern British Columbia as currently reported through BGC's RNT[10].

ECCC also provides the Regional Deterministic Prediction System (RDPS)[11], a 48-hour forecast dataset that is produced four times a day at similar resolution to the RDPA-CaPA data. The forecast dataset includes many climate variables, including forecasted precipitation.

Precipitation data are not yet provided in the current version of Cambio Communities but may be added as part of a future release.

[10] RNT is a BGC proprietary hydroclimatic analyses tool. Reporting of RDPA-CaPA at finer resolution (3 km grid) is currently under development.

[11] Reporting of the RDPS at a finer resolution (3 km grid) is currently under development.

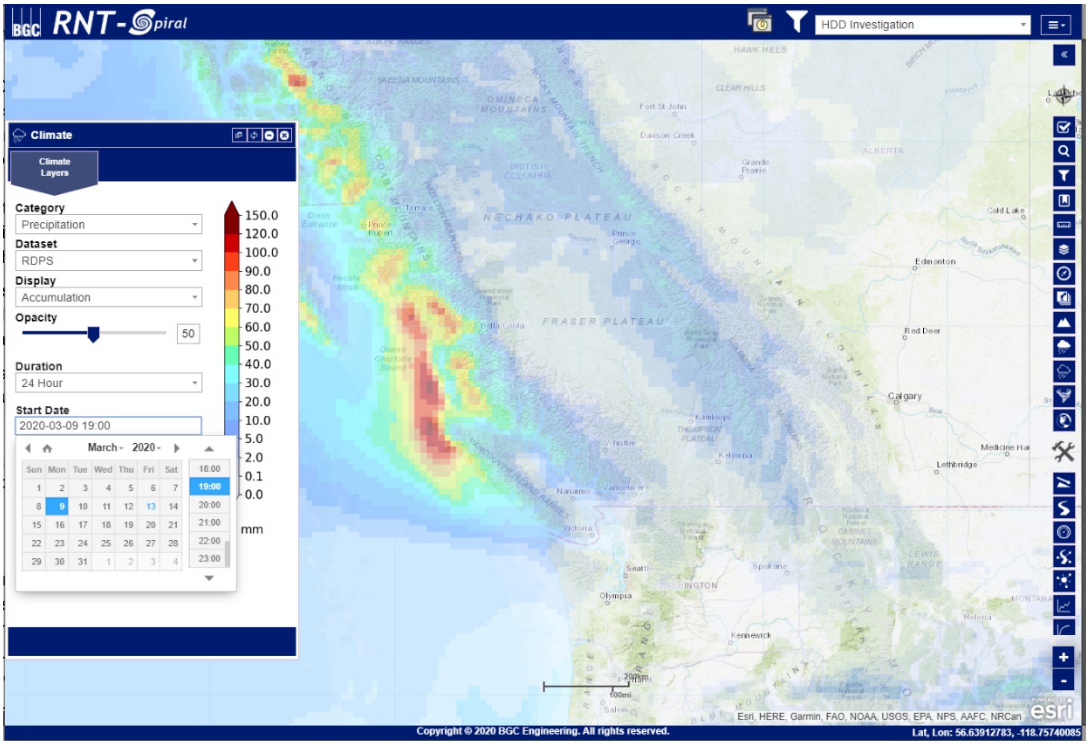

Figure 4-3. Example of 24-hour accumulated precipitation in southern British Columbia on March 9, 2020. Source: RDPA-CaPA (2020, BGC's River Network ToolTM).

4.4.3. Automated Stream Flow Alerts

The Precipitation Network Tool (PNT) conducts near real-time monitoring by comparing the rainfall measured in the past 6, 12, 18, and 24 hours (according to RDPA-CaPA) to the published Intensity-Duration-Frequency (IDF) curves of the nearest ECCC weather station. If the observed rainfall intensity exceeds the specified return period (e.g., 25-year return period, 24-hour rainfall) then an alert can be sent notifying recipients that an extreme event has occurred. This calculation is based on the individual exceedances in the 10 km grids that intersect the known catchment areas that have been already calculated as part of the RNT.

For real-time monitoring, a monitoring system could be compared to predetermined thresholds and an alert sent to relevant emergency response staff if the threshold is exceeded. The monitoring system could have the ability to monitor multiple thresholds for a given site (i.e., alert levels), with alerts also displayed on Cambio (i.e., highlighting alerts across the watershed). Figure 4-5 provides an example of a notification email provided to a linear infrastructure operator.

For forecasted data, a precipitation forecast monitoring system could calculate a weighted average of precipitation 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.

These thresholds would need to be developed in discussion with RDCK, with reference to the hazard scenario modelling completed as part of this study, as well as its limitations and uncertainties. BGC notes that additional hazard scenario modelling may be required beyond that completed in this study, in order to develop site-specific thresholds triggering alerts.

BGC **Precipitation Monitoring Alerts**

Precipitation observation ending at: 03 Jul 2018 12:00 UTC
Number of sites analyzed: 19554
Number of exceeded sites: 3
Number of exceeded thresholds: 3

Site Code	Site Name	Site Type	Exceeded Threshold
41666	41666 - EDS Stream ()	Hydrotechnical	25-year 24-hour precipitation (Frequency-Duration)
41728	41728 - EDS Stream (41728)	Hydrotechnical	25-year 24-hour precipitation (Frequency-Duration)
41960	41960 - EDS Stream (41960)	Hydrotechnical	25-year 24-hour precipitation (Frequency-Duration)

DISCLAIMER
BGC Engineering Inc. ("BGC") provides this precipitation monitoring system (the "System") solely for use by BGC's authorized clients. System users agree to this Disclaimer by using the System.

The System is only intended to issue certain kinds of email notifications based on: (a) precipitation data made available by third parties, and (b) precipitation threshold levels established by BGC's clients. BGC does not verify precipitation data used in the System. Such data is used or provided 'as is'. The System does not monitor all geographical areas. Careful attention should be given to the date and time notifications are issued.

BGC makes no warranties of any kind, either express or implied, concerning the System, System outputs, or any data in the System. BGC disclaims all warranties concerning the System, System outputs, or data in the System, including (without limitation) implied warranties of merchantability or fitness for a particular use. The System is one of multiple measures that should be taken to manage risk. System users are responsible for independently verifying any information obtained from the System. BGC will not be responsible for any claims, damages, losses, expenses, or liabilities of any nature resulting from: (a) any use of or reliance upon the System, or (b) any failure of the System to function as intended. **Entities and persons who use or rely upon the System do so at their own risk.**

Figure 4-4. Example email notification from the PNT.

4.4.4. Automated Storm Alerts

BGC has initiated a collaboration with ECCC to develop a 5-class provincial extra-tropical[12] storm classification and emergency response system. The objective would be to provide alerts when forecasted synoptic storms are considered capable of triggering geohazard events (e.g., clear-water floods, steep creek geohazard events, or precipitation-triggered landslides) at levels ranging from nuisance to catastrophic.

Development of such an approach will require the following fundamental components:

- Storm classification system and region-specific calibration (e.g., ECCC collaboration).
- Hazard and hazard exposure information (e.g., Stream 1 and Stream 2 study).
- Hydroclimatic monitoring and forecast systems (e.g., Sections 4.4.1 and 4.4.2)
- Risk management system (e.g., via Cambio; Section 4.4.3)

[12] Extra-tropical in this context means all synoptic (large-scale). storms that can affect BC. These are usually mid-latitude cyclones

- Emergency management protocols (e.g., local government emergency management programs)

The current work is at a preliminary planning level. With the current level of detail of study, RDCK is potentially well-positioned to participate as a strategic partner given the system is likely to be initiated first in areas where the above components are furthest advanced. BGC suggests that RDCK consider their level of interest in applying storm alerts to emergency management and is happy to provide further details on request.

4.4.5. Emergency Response Support

Consideration:

- *Make use of the hydraulic models developed for this study to support emergency response.*

This study included the development of hydraulic models for all areas assessed. Combined with streamflow and precipitation data and forecasts (Sections 4.4.1, 4.4.2), these hydraulic models can potentially be re-run with forecast data to simulate potential flood scenarios. While the results of hydraulic modeling in a flood emergency should be considered highly approximate, this work can support Emergency Operations Centres (EOC) to more efficiently allocate materials and resources where it is needed most. BGC completed similar emergency hydraulic modelling for RDCK in support of their 2018 flood response at Salmo, and the hydrologic and hydraulic models developed for this study are much advanced over those used in 2018.

4.5. Policy Integration

Considerations:

- *Review and update clear-water flood and steep creek- related bylaws and policies, including Development Permit Areas (DPAs), with consideration of the hazard maps prepared by both the Stream 1 and Stream 2 studies.*

4.5.1. Development Permit Areas (DPAs)

DPAs are areas where special requirements and guidelines for any development or alteration of the land are in effect. In such areas, permits are typically required to ensure that development or land alteration is consistent with objectives outlined within applicable OCPs.

The *Local Government Act, Sections 919.1 and 920*[13] provides local governments with the authority to designate a DPA. These areas identify locations that need special treatment for certain purposes including the protection of development from hazardous conditions (Government of British Columbia, 2019). Relevant examples of hazardous land DPA categories in RDCK include flood and non-standard flooding and erosion area (NSFEA).

DPAs are designated through an OCP. To support the designation, the OCP must describe:

- The special conditions or objectives that justify the designation.

[13] http://www.bclaws.ca/civix/document/id/complete/statreg/r15001_14#division_d0e44295

- The guidelines for how proposed development in that area can address the special conditions or objectives. These guidelines can be specified in the OCP or in an accompanying zoning bylaw.

Within a DPA, any proposed subdivision or building improvement (i.e., adding to or altering a building) requires a development permit be issued from the local government. This provides Council the flexibility to exercise its discretion in granting or refusing a permit on a case by case basis, as they can review how special conditions which justify the designation can be satisfied.

BGC suggests RDCK consider an iterative approach where level of detail of DPAs is aligned with the level of detail of hazard mapping. For example, the Stream 1 study can be considered when defining the outer boundary of a hazardous land DPA. This Stream 2 study can be further considered to refine the outer boundary and create further subdivisions within the boundary. Doing so will allow RDCK to introduce requirements and restrictions where needed, while reducing excessive requirements where the level of hazard is not zero but is very low. The intention is to advance from an initial phase of hazard identification (i.e., the Stream 1 study) through detailed mapping (the Stream 2 study) at selected sites, with a risk-informed process in place to explain why certain areas are prioritized over others.

The following text discusses how the hazard extents mapped as part of both the Stream 1 and Stream 2 studies may be applicable to define DPAs.

Steep Creek Hazards (Stream 1 Study)

For steep creek hazards, the delineated fan boundaries can be considered as a basis to define a preliminary set of steep creek DPAs in the RDCK. Application of study results to define DPAs should consider geohazard mapping uncertainties and the limitations listed in the Stream 1 study report.

BGC notes that the steep creek mapping completed for the Stream 1 study was not exhaustive, as the fan inventory only considered ‘developed’ fans. Undeveloped fans and areas subject to hazard but located upstream of a fan apex were not mapped.

BGC also mapped areas susceptible to debris floods and debris flows using topographic susceptibility modelling. These areas are shown as “RDCK Debris Flood Susceptibility” and “RDCK Debris Flow Susceptibility” on Cambio under the “Additional Hazard Information” dropdown in the layer list. BGC recommends the RDCK consider the application of these results to defining steep creek DPAs for areas potentially prone to steep creek hazards but are not included in the fan inventory. BGC notes that hazard extents identified by susceptibility modelling are highly uncertain until at least a screening level assessment has been completed (i.e., fan boundary delineation). As such, BGC suggests that topographic susceptibility modelling inform, but not define, the preparation of DPAs.

Steep Creek Hazards – Detailed (Stream 2) Study

The composite hazard rating maps prepared during this study can be used to prepare steep creek DPAs at a higher level of detail than for the Stream 1 assessment, including sub-zones with different requirements according to the level of hazard. The detailed mapping should supersede previous regional scale assessment (i.e., the Stream 1 study) and previous studies such as NHC and Thurber (1990) for preparation of DPAs, including delineation of the hazard boundary.

BGC anticipates that discussions about hazard map application in policy and bylaws will extend beyond final report delivery. As a preliminary step, Table 4-2 provides a template to consider when developing DPA requirements based on the composite hazard rating maps. While the current work focuses on steep creek and clear-water flood hazards, the template has been designed for consistent use across multiple hazard types (i.e., also with fall-, slide- or flow-type landslides). BGC notes the following points of consideration:

- The granularity of hazard rating categories (e.g. low, moderate, high) should reflect RDCK's land-use and policy objectives.
- DPAs which are defined within a hazard boundary may need to be accompanied by objectives of the designation, and guidelines for how proposed development can address those objectives. Such policies and bylaws should be developed by considering the potential impacts which are posed by the hazard and are reflected within the composite hazard map rating categories.
- As shown, Table 4-2 focuses on rapid geohazards. It does not currently address designation of hazard levels for low velocity flooding where different factors control vulnerability, such as depth and rate of rising water.
- The composite maps provided with all site assessment reports are subject to further review with RDCK from the perspective of policy application. Even where the underlying hazard scenarios do not change, cartographic choices (i.e., map colours and category selection and definition) can influence interpretation of the maps. BGC also notes that the hazard ratings shown on Table 4-2 are based on so-called impact force-frequency (IFF) ranges (see the Steep Creek Assessment Methodology Report, Doc. No. RDCK2-SC-011D). The choice of ranges used to define each category should also be considered preliminary.

Table 4-2. Template to consider composite hazard ratings in the preparation of geohazard DPAs.

<table>
<tr><th rowspan="2">Composite Hazard Rating</th><th rowspan="2">IIF (kN/m/yr)</th><th rowspan="2">Hazard and Consequence Description Given Impact to Standard (Wood Frame) Building</th><th rowspan="2" colspan="3">Typical Process Type Range</th><th colspan="2">Permit Application Requirements</th></tr>
<tr><th>Existing Development</th><th>Proposed Development</th></tr>
<tr><td>Very Low</td><td>n/a</td><td>Area not affected by any modelled hazard scenarios in the current Stream 2 study but that are not considered entirely free from hazard.</td><td rowspan="3">Floods/Debris Floods</td><td rowspan="5">Debris Flows</td><td rowspan="6">Landslides</td><td rowspan="6" colspan="2">Criteria to be established separately for existing and proposed development. Potential options:
- Yes; without restriction and without necessity of QP report
- Conditional; QP report required, hazard reduction required according to RDCK evaluation criteria.
- Conditional; Quantitative Risk Assessment (QRA) desirable or required; risk reduction required according to RDCK evaluation criteria to meet ALARP conditions.
- Not approved.</td></tr>
<tr><td>Low</td><td>< 0.01</td><td>Hazard is very rare or of minor intensity and does not constitute a credible life loss risk, but can still potentially cause water damage to buildings without elevated foundations.</td></tr>
<tr><td>Moderate</td><td>0.01 to 0.1</td><td>Hazard is rare or of moderate intensity and is unlikely to lead to loss of life, but will cause substantial building damage</td></tr>
<tr><td>High</td><td>0.1 to 1</td><td>Hazard likely occurs within a person's lifetime or of substantial intensity and may lead to loss of life and considerable building damage</td><td rowspan="3"></td></tr>
<tr><td>Very High</td><td>1 to 10</td><td>Hazard occurs frequently or with very high intensity and is likely to lead to loss of life and requires building reconstruction</td></tr>
<tr><td>Extreme</td><td>>1</td><td>Hazard occurs very frequently or with extreme intensity and is very likely to lead to loss of life and total building destruction</td><td></td></tr>
</table>

Clear-water Hazards (Stream 1 Study)

For clear-water hazards, the mapped floodplain boundaries can be used for defining the outer boundary of DPAs. Further assessment (hazard mapping and site-specific assessment) will be required by a Qualified Professional (QP) in permitting approvals.

Clear-water Hazards (Stream 2 Study)

As noted in Section 3.5.2, BGC generated 20- and 200-year FCL maps, where FCL polygons define upper (upstream) and lower (downstream) bounds for flood construction levels within each polygon. The choice to define FCLs as polygons (as opposed to isolines) was based on anticipated needs to spatially query FCLs against other information, such as parcel boundaries, as part of a digital approach to apply land use and development policy.

BGC notes that the FCL maps do not assume that structural flood protection performs as intended and are generally conservative. Direct application of FCLs as part of a hazard-based policy may result in costly requirements for new development, such as requirements for raised foundations. RDCK may wish to consider the assessment of geotechnical stability for structural flood protection, followed by risk assessment, to support risk policy and bylaw implementation in areas with FCLs. Such an approach could compare the probability of losses against the costs of bylaw implementation.

4.5.2. Land Use Review

BGC suggests that RDCK and member municipalities review land-use designations against Stream 1 geohazard areas and areas mapped in detail by this Stream 2 study. The objective would be to identify areas that were previously unknown as prone to flood or steep creek hazards and compare them to current land-use.

4.5.3. Policy and Bylaw Review

The RDCK and member municipalities within the RDCK administer policies and bylaws that govern development in flood and steep creek hazard areas. BGC suggests RDCK review policies and bylaws from the perspective of:

- Developing policies and bylaws that support integration of this studies results into flood and steep creek governance in RDCK.
- Developing an approach that aligns with current flood and steep creek risk management best-practice.
- Achieving consistency between jurisdictions within the RDCK and, ideally, other jurisdictions in British Columbia or at least within the Columbia River Watershed.
- Developing a risk-informed approach to geohazards management.

Table 4-3 summarizes key considerations for review of flood and steep creek related policies and bylaws within the RDCK. To support consistent policy and bylaw review and updates, BGC suggests that RDCK form an advisory committee that could include local government staff, provincial ministries responsible for subdivision approval or the assessment of hazardous lands

(MOTI, FLRNORD) and, if feasible, BGC to advise on topics related to geohazard risk identification, analysis, evaluation or control.

Table 4-3. Summary of key considerations for review of flood and steep creek related policies and bylaws.

No.	Recommendation
1	Review the classification of hazardous lands DPA categories. This would allow RDCK to develop bylaws and policies for hazardous lands that recognize differing requirements for hazard management depending on the hazard type (e.g., flood vs. steep creek).
2	Consider developing policies and bylaws that integrate the results of this study into flood and steep creek governance across RDCK.
3	Developing guidelines for how developments, or high intensity land-use types, are discouraged in hazardous lands.
4	Writing bylaws in Official Community Plans (OCPs) that establish Hazardous Lands DPAs in a way that allows on-going updates to DPA boundaries.
5	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, and criteria to make risk reduction decisions that can maximize the level of risk reduction with the available financial resources).

4.6. Training and Stakeholder Engagement

Consideration:

- *Provide training to government staff and other parties 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 and public engagement.*

The information collected for both the Stream 1 and Stream 2 assessments will have a broad range of applications for geohazard risk management within the RDCK. BGC suggests that RDCK identify potential end-users and develop an engagement plan.

At a staff level, potential participants could include planners, building permit officers, geomatics/GIS support staff, and emergency response workers. An initial workshop could include the following:

- Overview of steps to identify, assess, and manage the types of geohazards considered in this and the Stream 1 study, in the context of planning, policy, and emergency response.
- Discussion of the use of information (flood hazard maps) provided in this study
- Information sharing between local jurisdictions and provincial staff.

Such a workshop will help maximize the degree to which investments by local governments, the Province of BC, and the Government of Canada in the current work are incorporated into long-term decision making.

For broader public engagement, the study results can provide a resource to:

- Support conversations to strengthen flood resiliency that can bridge analytical, local and traditional sources of knowledge.

- Listen and respond to concerns raised by communities becoming more aware of geohazards potentially affecting areas where they live and work.

4.7. Digital Information Sharing

Recommendation:

- *Collaborate with private and public sector agencies within and outside the RDCK to share information, methods, and resources about pro-active geohazard risk and emergency management.*

The following comments apply to information sharing and liability in the context of geohazard risk management within the RDCK and more broadly across BC:

As a rough analogy, approaches to geohazards information management in BC have historically been akin to a musical record collection. Some local governments have greater resources to maintain larger collections. Some collections are up to date, and others are older and hard to access. Duplicates and conflicting versions exist. The Province asks local governments to send them copies but is resource-constrained to curate a master set. For this analogy, an alternative is music sharing services such as Spotify™, where everyone shares the cost to access a larger dataset than anyone could maintain independently. BGC envisions a similar approach to geohazards information management, as has already occurred for other types of media and other industries.

For example, EMBC and GeoBC have initiated a data management portal (BC Emergency Management Common Operating Picture), where study results are integrated with other data and made accessible to government ministries and external stakeholders. BGC is delivering the results of Stream 1 and Stream 2 studies via a web application, Cambio, and via a data export for RDCK and the Province. While valuable information, static data export is akin to the "record collection" analogy described above. Irrespective of the platform visible to the user, dynamically linking the underlying datasets is a more powerful way to share information and manage change over time.

Where capacity exists, we suggest that RDCK make the management of spatial data (data services) a key priority when considering investments in information management, including systems for identifying revisions and tracking evolving data versions. Being able to consume and deliver "living" data in forms that can readily be incorporated into web applications will increase their utility for decision making, especially when adapting to change (e.g., changing climate, watershed conditions and land use). For parties without the capacity to consume data into their own internal systems, Cambio can provide access to all study information via a standard web browser.

All vulnerability and risk assessments require spatial data about assets (e.g., buildings and infrastructure). BGC's Stream 1 required an asset inventory that was resource intensive to compile and will require continued resources to be kept up to date. We suggest that, with increased provincial support, the Integrated Cadastral Information (ICI) Society could collect and disseminate a comprehensive inventory of asset data suitable for vulnerability and risk assessment.

4.8. Multiple Stakeholder Resource Sharing

Consideration:

- *Connect geohazards management activities in the private and public sector through the sharing of information and resources.*
- *Encourage provincial leadership for resource coordination while recognizing that much leadership can occur from a local government level within the existing governmental divisions of responsibility.*

Different branches and levels of government, non-governmental organizations, and owner-operators of major assets (e.g., transportation and energy generation and transmission) in a given hazard area will commonly have shared requirements to understand and manage geohazard risk, and decisions by any single owner may have downstream implications (e.g., potential risk transfer). Moreover, hazards commonly cross jurisdictional boundaries, or require different levels of government to plan land use, approve subdivisions, pay for structural mitigation, and plan and pay for emergency response.

BGC suggests that the RDCK develop a value proposition based on shared objectives for hazard and risk management not only with public stakeholders, but with the private sector. BGC suggests the following for consideration:

- Consider approaches that leverage public-private information sharing without necessarily requiring any changes to existing organizational structures, responsibilities, or funding mechanisms.
- When addressing confidentiality, recognize that valuable input data may be shareable even where its application by a third party is confidential. For example, it would be valuable to share baseline terrain, hydrologic and hazard information even where the use of that information (e.g. to assess specific assets) is kept confidential.
- Consider the different strengths contributed by each stakeholder in terms of sharing both information and processes. For example, dynamically (semi-continuously) managed approaches to geohazard risk and asset management, including software-supported hazard monitoring and field inspection programs, are well established for linear infrastructure in ways that readily transfer to community applications with long-term maintenance supported through cost-sharing. Conversely, a spatial understanding of hazards (e.g., hazard maps) are rare along linear corridors in BC and contain attributes readily transferable to risk management for linear assets.
- Consider the assessment and management of service disruption as an intersection of needs between communities and the owners/regulators of lifelines (transportation and utility networks).

BGC currently works with several operators of major utilities and transportation infrastructure and can help identify areas where the study results could be applied in stakeholder collaborations, on request.

4.9. Responsibility and Liability

Recommendations:

- *Clarify roles and responsibilities for government in geohazard and risk management.*
- *Clarify how to consider issues of professional responsibility and liability in the context of digital data and changing conditions (changing climate, landscape and land use).*
- *Advocate for a strengthened Provincial Government role in funding and coordinating geohazard risk management in BC.*

Currently, responsibilities for geohazard risk management are spread across multiple levels and branches of government in British Columbia. However, local governments may lack control or authority over parts of the land base upon which geohazards exist. These issues create challenges when defining roles, responsibilities and liabilities related to geohazard risk management in British Columbia. For example, hazards could cross jurisdictional boundaries, or the same geographic area could require different levels or branches of government to plan land use, approve subdivisions, pay for structural mitigation, and plan and pay for emergency response. These issues can potentially foster decision paralysis or create conflicting interests, such as a desire to densify development in a hazard area to create tax revenue required for mitigation planning.

Professional responsibility and liability issues need to be explicitly addressed as part of the professional reliance model applied by local governments for most geohazards-related work. Relying on geohazards maps and related knowledge in the context of climate change and landscape-altering events (e.g., wildfires or geohazard occurrence) raises additional questions related to professional responsibility and liability.

The dynamic delivery of online digital information under a changing climate and changing land use provides both an opportunity (to address change) and a challenge (given it is an ever-evolving area of practice). A distinction ought to be made between disseminating data and information, compared to the interpreted knowledge relied upon to make risk management decisions. A government data hub may disseminate information without necessarily taking on the responsibilities of a Qualified Professional. BGC has proposed to establish a working group with EGBC to address this topic and we suggest local governments obtain advice from a law firm with related subject-matter expertise. BGC is happy to discuss further on request.

As part of BC's currently ongoing updates to the Emergency Management Act, BGC suggests strengthening the role of the Province in funding and coordinating geohazard risk management in BC. This would help clarify divisions of responsibility and could establish a more consistent level of service across local and First Nations governments, particularly for rural areas. While decisions about the role of the Province are not controlled by local government, BGC's experience is that multi-District coordination is a constructive way to define and advance priorities. BGC suggests RDCK explore avenues for collaboration between Regional Districts at the scale of the Columbia River Basin in Canada, perhaps with the involvement of Columbia Basin Trust as a coordinating body.

5. CONCLUSION

This study provides the RDCK with detailed assessments and mapping of six floodplains and ten steep creeks within the District. Within the ten steep creek hazard areas, seven are prone to debris floods, two are hybrids subject to debris floods at lower- and debris flows at higher return periods, and one creek is subject to debris flows. It focuses on high priority areas identified during BGC's 2018-2019 flood and steep creek risk prioritization and builds on the regional study to advance geohazard risk management goals for the District.

The deliverables of this study include reports and hazard maps for each assessment area, as well as hazard maps provided for digital download and via Cambio web application. BGC provides site-specific considerations for hazards management in the individual assessment reports and strategic recommendations in this summary report.

BGC anticipates this study will be considered in the development of RDCK's geohazards management strategy, which will continue to evolve over time. BGC emphasizes that such work is iterative, and that the current assessments are one step in a continual and long-term process to reduce risk and increase benefits to communities within the District.

6. 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,

BGC ENGINEERING INC.
per:

Final stamp and signature version to follow once COVID-19 restrictions are lifted.

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KH/MJ/mp/mm

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APPENDIX A
CAMBIO COMMUNITIES USER GUIDE

A.1. INTRODUCTION

This appendix describes the purpose and use of *Cambio*^{TM} web application to deliver maps and supporting information for the Stream 1 and Stream 2 studies.

A.1.1. Purpose

Cambio is an ecosystem of web applications that support regional scale, geohazard risk-informed decision making by government and stakeholders. It is intended to support community planning, policy, and bylaw implementation, and provides a way to maintain an organized, accessible knowledge base of information about geohazards and elements at risk.

The version of *Cambio* used to provide Stream 1 and 2 study results is called *Cambio Communities*. Other versions exist for other use-cases such as geohazard risk management for linear infrastructure (pipelines, roads and railways). *Cambio* also provides access to dynamic and real-time information sources (e.g., streamflow monitoring).

The application combines map-based information about geohazard areas and elements at risk with evaluation tools based on the principles of risk assessment. *Cambio* 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?

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

<u>Hazard information:</u>

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

<u>Exposure information:</u>

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

<u>Analysis tools:</u>

- Identification of assets in geohazard areas (elements at risk).
- Prioritization of geohazard areas based on ratings for geohazards and consequences.
- Access to data downloads and reports for geohazard areas[1].

[1] The ability to download available reports at a given geohazard area is only available for study areas where government has worked with BGC to define report location metadata.

This user guide describes how users can navigate map controls, view site features, and obtain additional information about geohazard identification areas and maps. It should be read with the main report, which describes methodologies, limitations, and gaps in the data presented on the application.

A.1.2. Site Access

Cambio can be viewed at www.cambiocommunities.ca. Username and password information is available on request. The application should be viewed using Chrome or Firefox web browsers and is not designed for Internet Explorer or Edge.

Two levels of access are provided:

- Local/Regional Government users: Access to a single study area of interest (e.g., administrative or watershed area of interest for the user).
- Provincial/Federal Government users: Access to multiple study areas[2].

The remainder of this guide is best read after the user has logged into *Cambio*. This guide describes information displayed across multiple administrative areas within British Columbia. Footnotes indicate cases where information is specific to certain regions.

A.2. NAVIGATION

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

[2] 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.

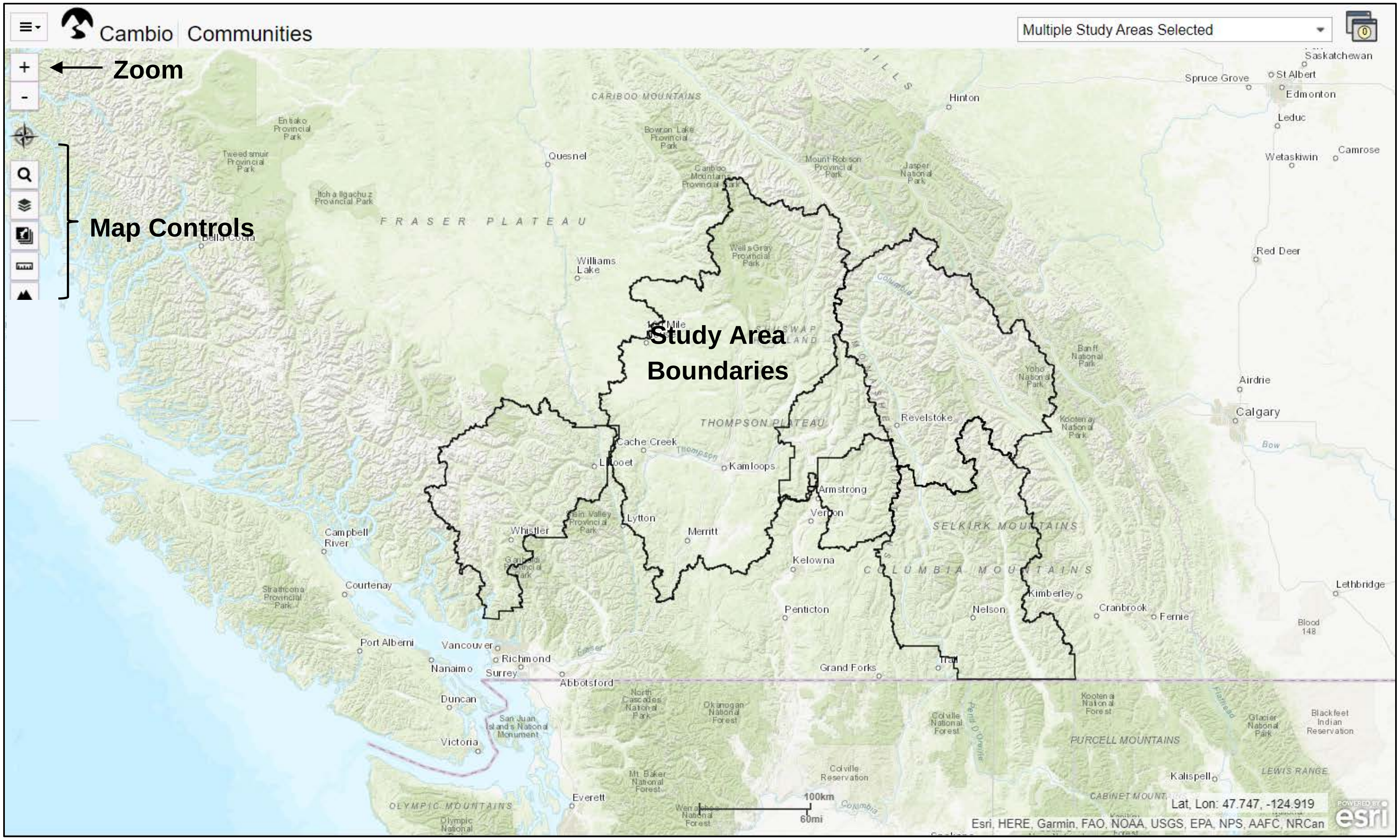

Figure A-1. Online map overview.

A.3. MAP CONTROLS

Figure A-1 showed the map controls icons on the top left side of the page. Map controls can be listed by clicking on the Compass Rose, then opened by clicking on each icon (Figure A-2). Sections A.3.1 to A.3.5 describe the tools in more detail.

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.

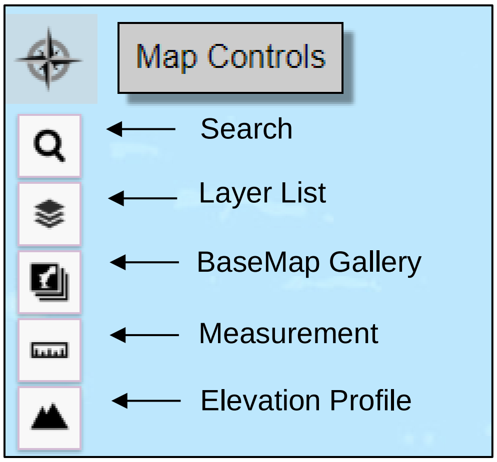

Figure A-2. Map controls and tools.

A.3.1. Search

Search is currently available for geohazard area names and street addresses. To search for hazards:

a. Select the hazard 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.

A.3.2. Layer List

This control (Figure A-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.

- Composite hazard rating map.
- Hazard model scenario maps (multiple maps at the range of return periods assessed).

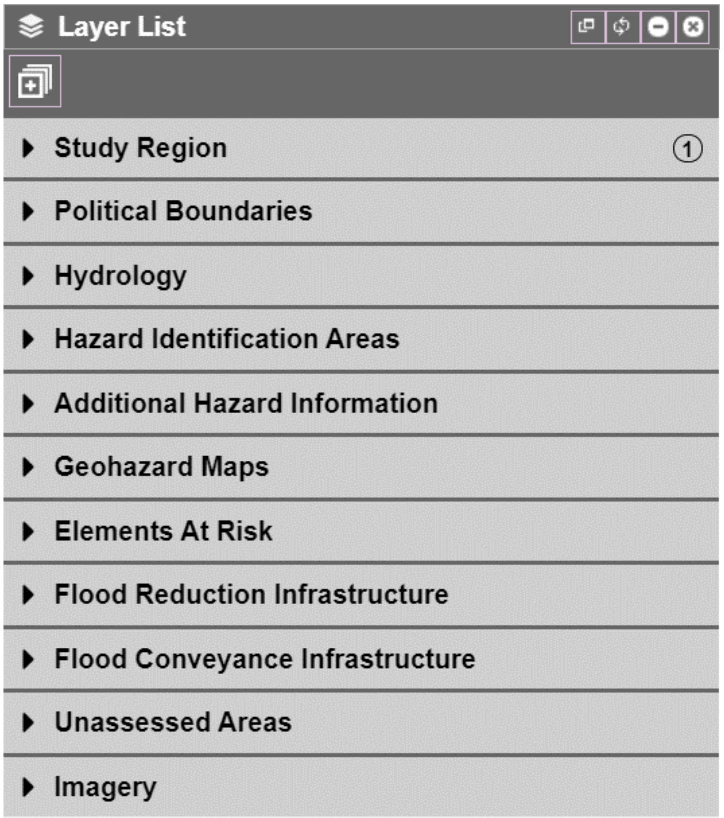

Figure A-3. Layers list.

A.3.3. Basemap Gallery

The basemap gallery allows the user to switch between eight different basemaps including street maps, a neutral canvas, and topographic hillshades. Map layers may display more clearly with some basemaps than others, depending on the color of the layer.

A.3.4. Measurements Tool

The measurements tool allows measurement of area and distance on the map, as well as location latitude and longitude. For example, a user may wish to describe the position of a development area in relation to a geohazard feature. To start a measurement, select the measurements tool icon from the options in the drop down.

A.3.5. Elevation Profile Tool

The elevation profile tool allows a profile to be displayed between points on the map. For example, a user may wish to determine the elevation of a development in relation to the floodplain. To start a profile, click “Draw a Profile Line”. Click the starting point, central points, and double click the end-point to finish. Moving the mouse across the profile will display the respective location on the map. The “🛈” in the upper right corner of the profile viewer screen displays elevation gain and loss statistics. The precision of the profile tool corresponds to the resolution of the digital elevation model (approximately 25 m DEM). As such, the profile tool should not be relied upon for design of engineering works or to make land use decisions reliant on high vertical resolution.

A.4. GEOHAZARD INFORMATION

Geohazard information is displayed in the layer list under two categories as follows:

- Geohazard Identification Areas: Areas prioritized as part of Stream 1 study.
- Geohazard Maps: Areas subject to detailed mapping as part of Stream 2 study.

A.4.1. Geohazard Identification Areas

Geohazard identification areas can be added to the map by selecting a given geohazard type under "Geohazard Identification 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).

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 A-4). Clicking the Google Maps icon opens Google Maps in a new browser window at the hazard site. This feature can be used to access Google Street View to quickly view ground level imagery where available. Clicking the "ℹ" opens a sidebar with detailed information about the individual feature, as described in Section A.4.2.

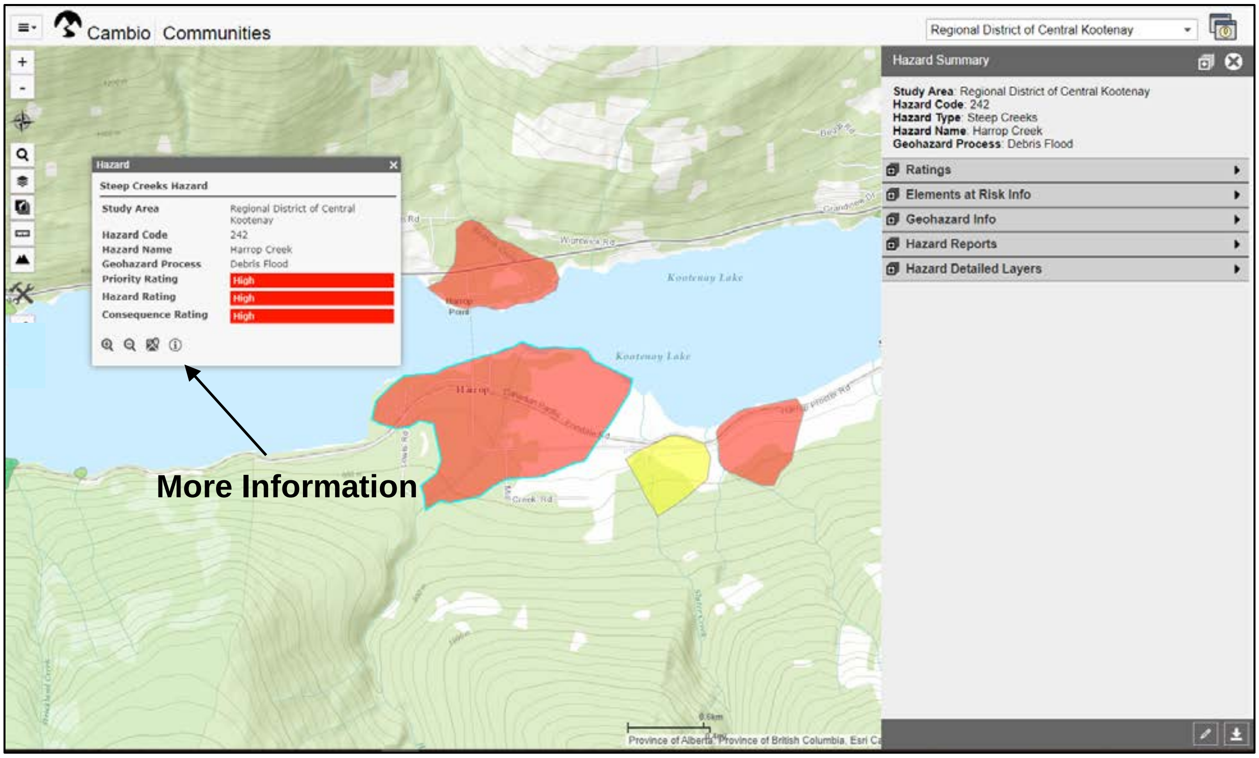

Figure A-4. Geohazard feature popup.

A.4.2. Geohazard Maps

Geohazard maps are provided in Cambio for detailed Stream 2 assessment areas (this study). These maps show spatial information about hazards within a geohazard identification area. They can be can added to the web map by selecting a given hazard layer in the layer list under, "Geohazard Maps".

Once selected, a drop-down list of each geohazard identification area where geohazard maps are available is displayed (Figure A-5). Clicking on the "⌖" will zoom to the associated hazard area. Clicking on the "🛈" open a sidebar with detailed information about the hazard identification area, as described in Section A.4.2.

Steep creek hazard areas include the following:

- Composite hazard rating map.
- Hazard model scenario maps (multiple maps at the range of return periods assessed).

Clear-water flood hazard areas include the following:

- Flood construction level map.
- Hazard model scenario maps (multiple maps at the range of return periods assessed).

Hazard map layers can be revealed by selecting the toggle-switch icon located left of the layer name (Figure A-5). Hazard map layers can also be accessed through the sidebar under 'Hazard Detailed Layers" (Figure A-6).

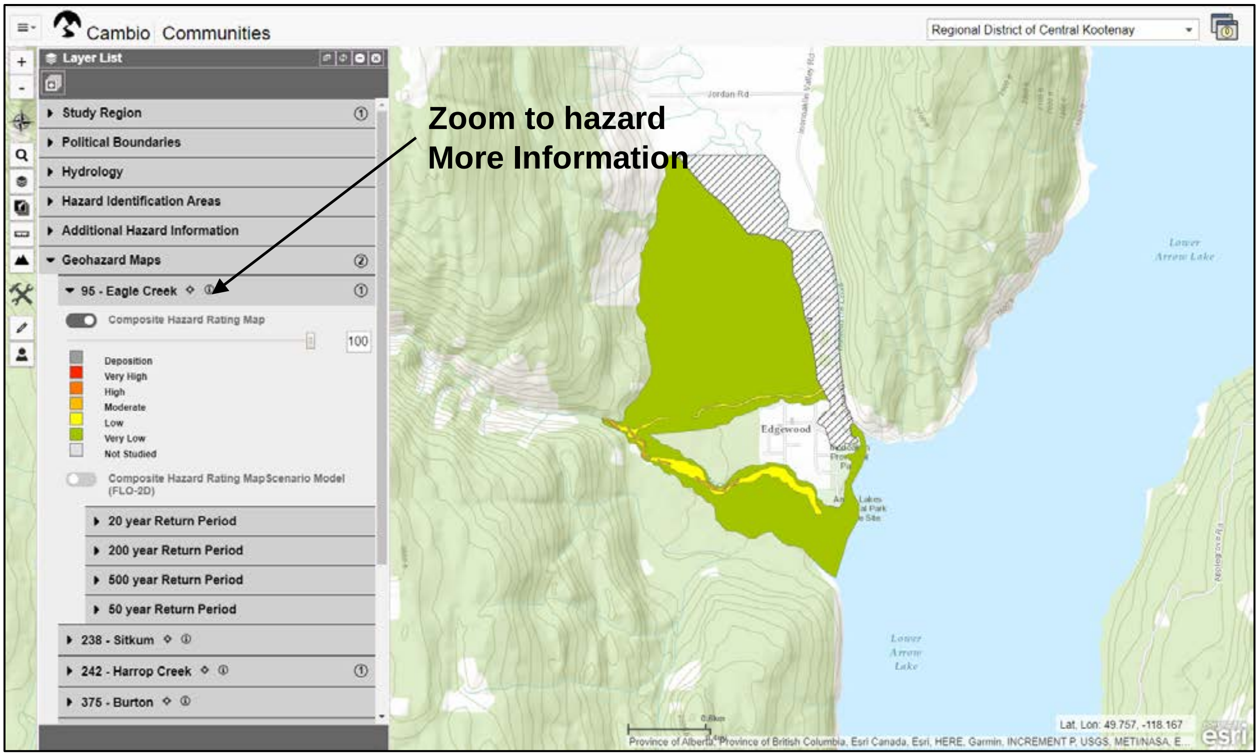

Figure A-5. Example hazard map layers

A.4.3. Geohazard Information Sidebars

Clicking a geohazard feature and then the "🛈" within the popup opens additional information in a sidebar on the right side of the screen (Figure A-6). Dropdown menus allow the user to view as much detail as required.

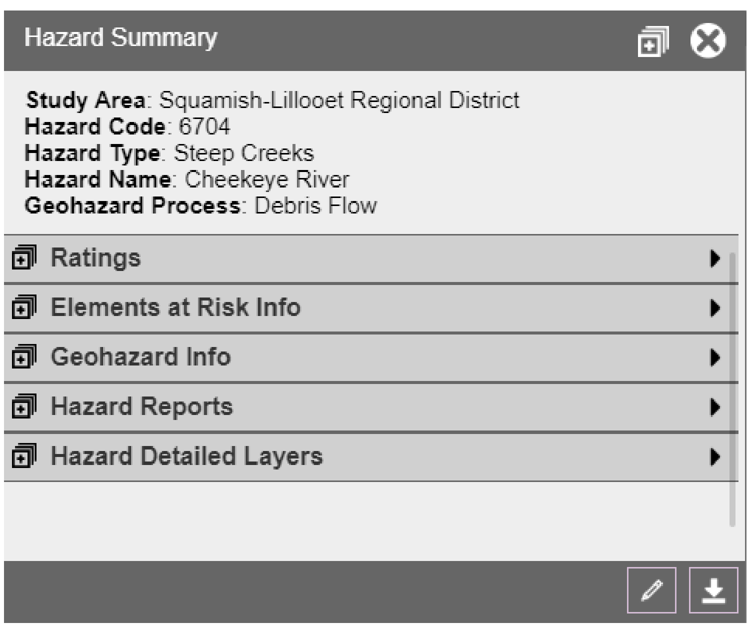

Figure A-6. Additional information sidebar.

Table A-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 A-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.
Reports	Links to download previous reports associated with the area (if any) in pdf format.

A.5. ASSET INFORMATION

Elements at risk, flood reduction, and flood conveyance infrastructure can be displayed 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 are not exhaustive, and much data are currently missing for some asset types (i.e., building footprints and stormwater drainage infrastructure).

A.6. ADDITIONAL GEOHAZARD INFORMATION

A.6.1. Additional Geohazard Layers

Additional geohazard-related layers can be displayed under "Additional Geohazard Information" in the layer list. These should be reviewed with reference to the main report document for context and limitations.

A.6.2. Imagery

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

A.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™ (RNT). 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 A-7). 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.

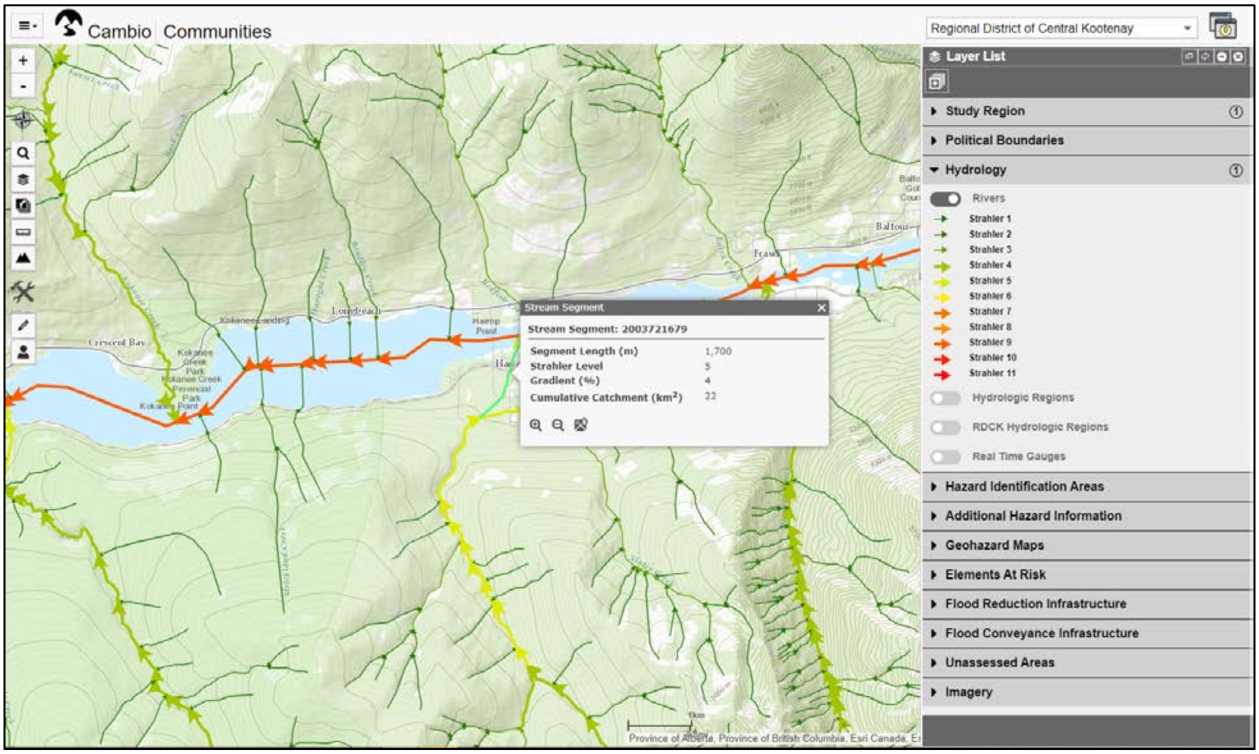

Figure A-7. Interactive Stream Network. The popup shows information for the stream segment highlighted in green.

A.6.4. Real-time Flow Gauges

Cambio also provides access to real-time[3] stream flow and lake level monitoring stations where existing. The data are sourced from the Water Survey of Canada (WSC) and published from RNT. Clicking any gauge will open a popup window with gauge data including measured discharge and flow return period for the current reading date (Figure A-8). The real time gauges are also colored on the map by their respective flow return period for the current reading date.

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

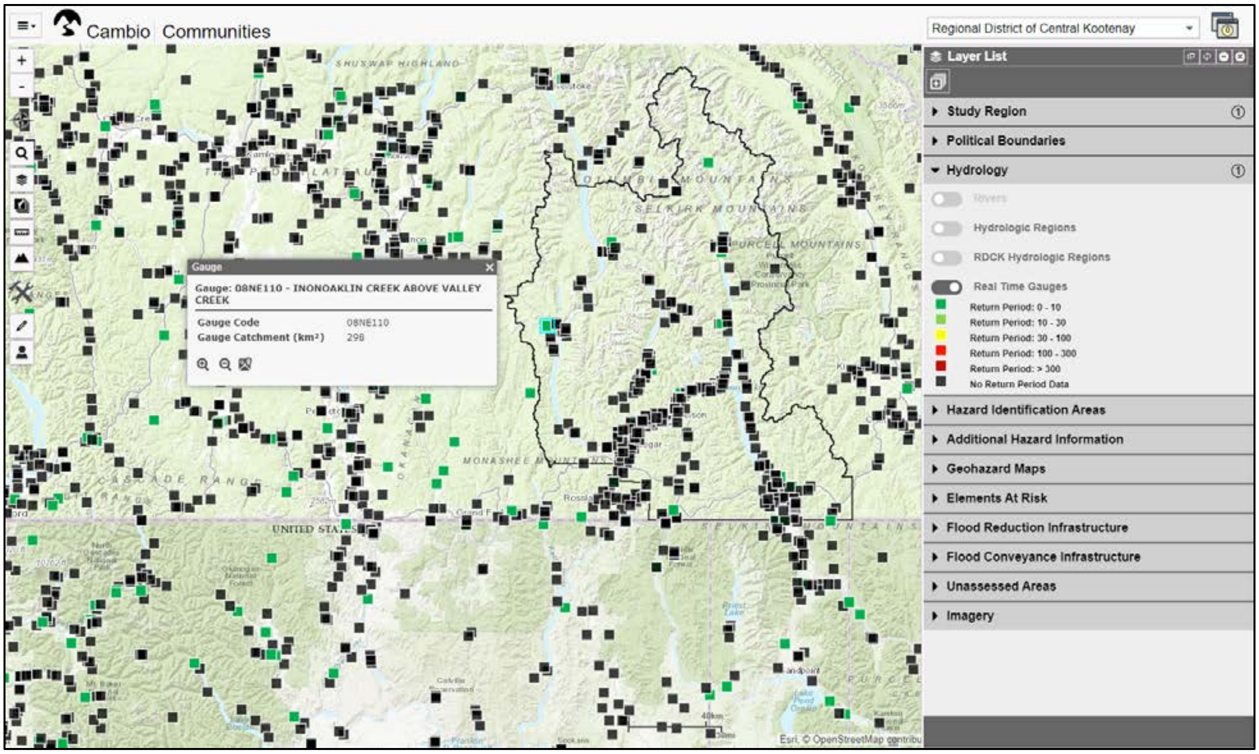

Figure A-8. Near real-time flow gauge. The popup shows gauge information including measured discharge and return period for a given reading date and time.

A.7. FUTURE DEVELOPMENT

The current version is the first release of *Cambio Communities*. BGC is working to 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
- Real-time[4] precipitation monitoring and forecasts, in addition to stream flow and lake level.
- Automated alerts for monitored data (i.e., stream flow or precipitation)
- Automated alerts for debris flow occurrence locations and characteristics.
- Inclusion of other types of geohazards (i.e., landslides and snow avalanches).
- Inclusion of functions implemented in other versions of Cambio, related to field inspections and reporting.

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

[4] i.e., information-refresh each time monitoring data are updated and provided by third parties.