FRASER BASIN COUNCIL

Thompson River Watershed Base Level Flood Hazard Mapping

FINAL
April 30, 2020

Project No.:
0511003

Prepared by BGC Engineering Inc. for:
Fraser Basin Council

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April 30, 2020
Project No.: 0511003

Mike Simpson
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Via email: msimpson@fraserbasin.bc.ca

Dear Mike,

Re: Thompson River Watershed Base Level Flood Hazard Mapping – FINAL

Please find attached the above referenced report for your review. The web application accompanying this report can be accessed at www.cambiocommunities.ca.

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

Yours sincerely,

BGC ENGINEERING INC.
per:

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

TABLE OF REVISIONS

ISSUE	DATE	REV	REMARKS
DRAFT	April 1, 2020		Original issue of Discussion Draft
FINAL	April 30, 2020		Original issue

CREDITS AND ACKNOWLEDGEMENTS

BGC Engineering would like to express gratitude to Fraser Basin Council for providing background information, guidance and support throughout this project.

The following personnel provided input and guidance as the direct recipients of project deliverables:

- Mike Simpson (Regional Manager, Fraser Basin Council); Stuart Larson (Manager of Protective Services, Cariboo Regional District); Ron Storie (Director of Community Services, Thompson-Nicola Regional District)

The following personnel provided input and guidance as part of the Thompson River Watershed Advisory Committee:

- Tom Hansen (Emergency Program Coordinator, Columbia Shuswap Regional District); Charlie Henderson (Superintendent of Public Works, City of Merritt); Bill Kershaw (Vice Chair/Director, Electoral Area O, Thompson-Nicola Regional District); Tom Kneale (Geotechnical Engineer, Ministry of Transportation and Infrastructure); Stuart Larson (Manager of Protective Services, Cariboo Regional District); David Major (IT/GIS Coordinator, Columbia Shuswap Regional District); Al Richmond (Director, Electoral Area G, Cariboo Regional District); Steve Schell (Senior Project Manager, South Region, Ministry of Forests, Lands, Natural Resource Operations and Rural Development); Graeme Schimpf (Operations Manager, MOTI); Gerald Smith (Provincial Planning Officer, Emergency Management BC); Ron Storie (Director of Community Services, Thompson-Nicola Regional District)

The following BGC personnel were part of the study team:

- Kris Holm (Project Manager); Sarah Kimball (Assistant Project Manager); Patrick Grover (Technical Reviewer, Modelling); Kenneth Lockwood (Lead Hydraulic Modeller); Marc Trottier (Support Hydraulic Modeller), Alistair Beck (software); Elisa Scordo (hydrology); Melissa Hairabedian (hydrology and climate change); Matthew Buchanan (GIS); Philip LeSueur (Cambio); Hamish Weatherly (Technical Reviewer); Michael Porter (Reviewer).

LIMITATIONS

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EXECUTIVE SUMMARY

Fraser Basin Council retained BGC Engineering Inc. (BGC) to carry out flood hazard mapping in 12 areas of Thompson Nicola Regional District (TNRD) and Cariboo Regional District (CRD), encompassing a total of 480 km^2.

The work continues a geohazard risk management initiative for the entire Thompson River watershed (TRW[1]), which was launched in February 2018 at a Community-to-Community Forum in Kamloops, British Columbia (BC). The initiative is coordinated by Fraser Basin Council (FBC) with participation of local governments and First Nations. BGC completed the first step of this initiative ("Stream 1 study") in March 2019, with a clear-water flood, steep creek, and landslide-dam flood risk identification and prioritization study for the entire TRW.

The current project focuses on riverine flood hazards in areas identified as high priority during the Stream 1 study. The following objectives were set for each study area:

- Prepare 200-year flood hazard maps at a "base" level of detail, which is defined as an intermediate step between screening level flood hazard identification and more costly, detailed flood hazard mapping.
- Deliver hazard maps in digital formats amenable to incorporation into systems maintained by TNRD and CSRD (i.e., web- based flood hazard maps) and Cambio™ web application.
- Provide documentation (this report) describing the application of study results to planning, policy, regulation, and emergency management.

This report is best read with access to Cambio, which displays the results of both the Stream 1 and this study. The application can be accessed at www.cambiocommunities.ca, using either Chrome or Firefox web browsers.

This report expands on the following points for local and First Nations governments to consider when applying the study results in decision making:

- **Regional Geohazard Risk Management:** Adopt the geohazard areas prioritized in the Stream 1 study and those assessed further in this study as a preliminary 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[2]" principle when developing and implementing geohazard risk management plans.
- **Further Assessments:** Build on the existing work to implement next steps in a regional geohazard risk management process.
- **Geohazard Monitoring and Warning:** Combine hazard mapping with precipitation and streamflow monitoring and forecasts to develop alerts to support emergency management, and re-apply the hydraulic models developed for this study to support real-time emergency response.

[1] See www.thompsonflood.ca
[2] 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.

- **Policy Integration:** Review and update land-use designations, bylaws and policies, including Zoning Bylaws and Development Permit Areas (DPAs) where existing, with consideration of the hazard areas defined in Stream 1 and this study.
- **Training and Stakeholder Engagement:** Provide training to local and First Nations government staff who may rely on study results, tools and data services, and apply the study results to strengthen flood resiliency at a local community level. 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 TRW to share information, methods, and resources about pro-active geohazard risk and emergency management.
- **Multiple Stakeholder Resource Sharing**: Connect private and public resources for geohazard and risk management that amplify their effectiveness to reduce risk beyond what can be accomplished in isolation.
- **Responsibility and Liability:** Clarify roles and responsibilities for provincial and local authorities 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). Strengthen the role of the Province in funding and coordinating geohazard risk management in BC.

BGC emphasizes one recommendation to be implemented as soon as feasible. The timing of delivery for this study coincides with the issue of detailed lidar topography for the mapping areas. The availability of high resolution topography for hydraulic modelling was a key limitation for this study, with the exception of the Nicola/Coldwater Rivers (from Nicola Lake to Spences Bridge) where lidar data is already available.

BGC recommends re-running the hydraulic models with inclusion of the newly available lidar data, which would improve all mapping results at low cost in relation to benefit. This task was included in the 2020 Union of BC Emergency Preparedness Fund application; notice of funding is expected for June 2020. If additional budget can be made available, this task could be added to the current project prior to issuing Final deliverables, or it could be completed as part of a subsequent scope of work. BGC would be happy to provide a work plan and cost estimate on request.

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1. INTRODUCTION

1.1. Objective

Fraser Basin Council (FBC) retained BGC Engineering Inc. (BGC) to carry out base level flood hazard mapping in 12 areas of the Thompson Nicola Regional District (TNRD) and Cariboo Regional District (CRD) (Section 1.2). The base level flood mapping encompasses a total distance of approximately 560 km along the main watercourses for these 12 areas. Funding was provided through the Union of BC Municipalities Emergency Preparedness Fund. This work is being carried out under the terms of a contract between FBC and BGC dated May 27, 2019, administered by FBC in a contribution agreement between FBC, TNRD, and CRD.

This study represents a continuation of a geohazard risk management initiative for the entire Thompson River watershed (TRW[3]), which was launched in February 2018 at a Community-to-Community Forum in Kamloops, British Columbia (BC). The initiative is coordinated by the FBC with participation of local governments and First Nations, with the work being carried out by BGC. BGC completed the first step of this initiative in March 2019, with a clear-water flood, steep creek, and landslide-dam flood risk prioritization study for the entire TRW (BGC, March 31, 2019). The March 2019 study is referred to herein as the "Stream 1" study. Due to the integrated nature of the work, both the Stream 1 study and the current work are referred to throughout this document.

This study focuses on clear-water riverine flood hazards. The project objectives were developed with input from an advisory committee convened by FBC at the outset of the 2018 geohazard risk management initiative. The committee includes staff and elected representatives from the CRD, TNRD, Regional District of North Okanagan (RDNO), Columbia Shuswap Regional District (CSRD), and staff from the Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD), Emergency Management BC (EMBC), Ministry of Transportation and Infrastructure (MoTI), and First Nations.

This study has the following objectives for each study area:

- Complete the steps of flood hazard mapping at a "base" level of detail (defined in Section 2), including hydrologic analyses and hydraulic modelling.
- Prepare hazard maps in digital formats amenable to incorporation into systems maintained by the TNRD and CSRD (i.e., web maps).
- Present digital mapping via access to Cambio™ web application.
- Provide documentation (this report) describing the application of study results to planning, policy, regulation, and emergency management.

This report is best read with access to Cambio, which displays the results of both the Stream 1 and this study (Figure 1-1). The application can be accessed at www.cambiocommunities.ca, using either Chrome or Firefox web browsers. Appendix A provides a Cambio user guide. Appendix D provides terminology definitions.

[3] See www.thompsonflood.ca

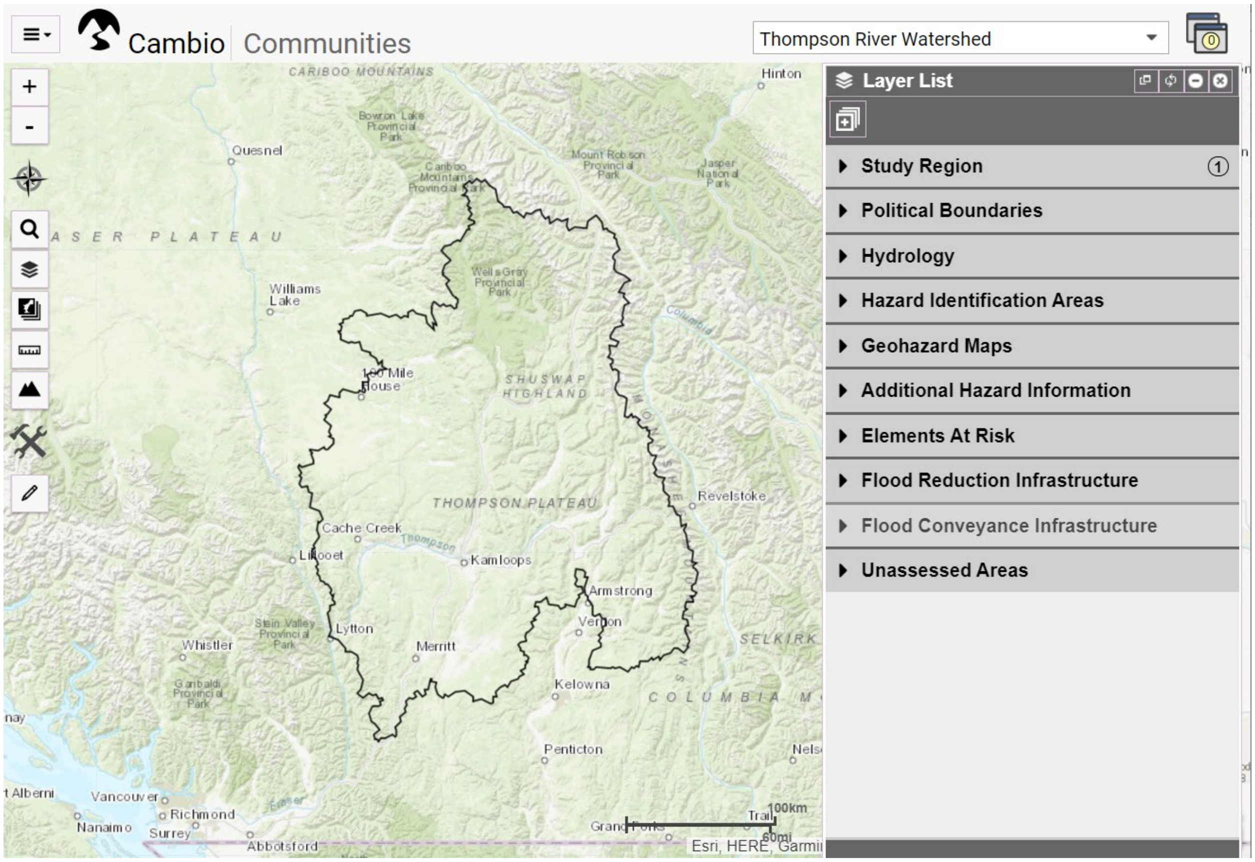

Figure 1-1. Example of *Cambio* web application.

This study 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.).

1.2. Why This Study?

A flood map is used to identify the boundaries of a potential flood event based on type and likelihood (e.g., 200-year return period), and can be used to identify potential impacts of a flood event to protect human life and minimize property damage.

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

Areas with historical floodplain mapping within the TRW are on average 30 years old and do not:

- Reflect the full data record available for hydrometric stations within the watershed
- Reflect potential changes in channel planform and bathymetry (e.g., aggradation, channel alterations such as bank erosion or avulsion)
- Reflect the technological advances in hydraulic modelling software, topographic mapping (e.g., LiDAR) and other technologies (e.g., GIS).
- Consider land use changes (e.g., wild fire)
- Consider climate change impacts on flooding.

The proposed work helps fill a gap identified by the Stream 1, namely the lack of the most basic floodplain mapping in many areas. Through the provision of flood hazard maps and information, this study supports subsequent work related to planning, policy, bylaws, and emergency management.

1.3. Study Area

Figure 1-2 and Table 1-1 show the 12 mapping areas selected for flood hazard mapping, which in total encompass approximately 560 km of the main watercourses. These areas were selected in collaboration with the TRW Advisory Committee based on hazard, consequence and priority ratings assigned in the Stream 1 study; records of previous events; reference to previous reports; and available funding.

Further information on physiography and hydroclimate throughout the TRW, including the areas assessed in this study, was previously provided as part of the Stream 1 study (BGC, March 31, 2019). The sites chosen are not necessarily the locations where the “next” damaging geohazards event will occur in the TRW, which is not known. Within the TRW, the sites encompass areas within the TNRD and CRD, but not the CSRD and RDNO, and do not include all high priority sites identified in the Stream 1 study.

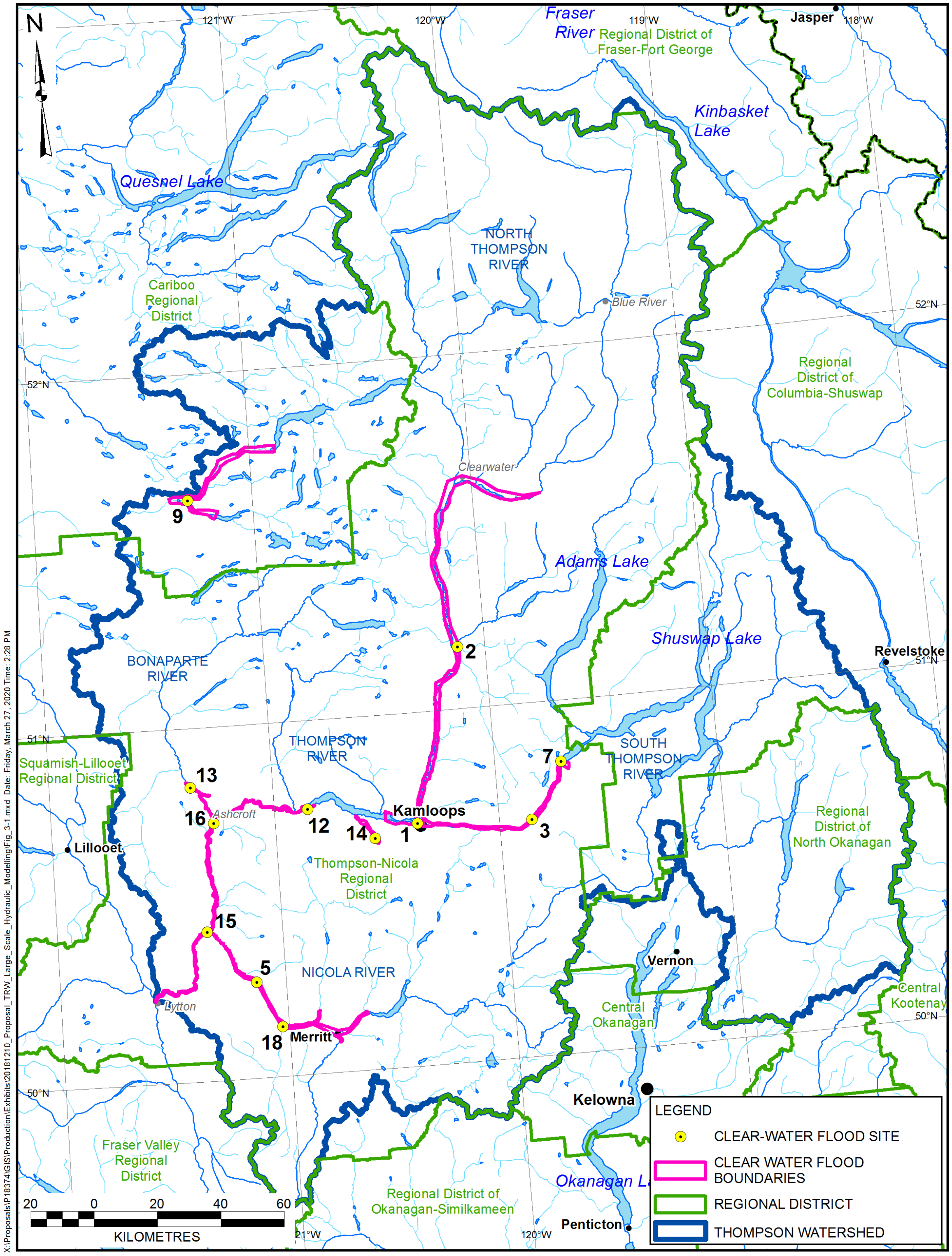

Figure 1-2. Study area boundaries (pink). Sites are numbered according to Table 1-1.

1.4. Scope of Work

Table 1-2 lists the activities and tasks included in the scope of work.

Table 1-2. Clear-water flood mapping work plan.

Activities	Tasks	Deliverables/Products	Resources
Project Management	Meetings, project management and administration	Presentations and updates	• BGC team • District team • Project stakeholders
Data Compilation and Review	1. Base Data Collection	Base inputs for hazard analyses and study integration such as historical air photographs, regional geology maps and land use coverage maps	• LiDAR (as available) • BGC team • District team • Project stakeholders
	2. Asset Inventory Update	Base inputs for model setup and study integration.	• BGC team • District team • Project stakeholders
Analysis	3. Hydrology Assessment	Hydrologic inputs for hydraulic modelling	• BGC team
	4. Base Level Hydraulic Modelling	Model outputs showing flood extent, flow depth and velocity.	• BGC team
Final Deliverables	5. Hazard Map Production (via Web Map)	Clear-water flood hazard maps showing the areas and depths of 200-year flood inundation	• BGC team
	6. Reporting and Data Services	Description of methods, results, and limitations, and data and web services for dissemination of study results	• District team • Project stakeholders

2. METHODS

Appendix B provides a full description of the study methodology, including data compilation, hydrologic analyses and hydraulic modelling. This section summarizes the major steps of analysis listed in Table 1-2 (Section 1.4).

2.1. Introduction

While flood mapping studies are an important tool for developing safe and resilient communities, detailed studies are expensive and time consuming and therefore undertaken only when there are recognized hazards.

Recognizing the cost of detailed flood mapping, organizations responsible for flood management in the USA have begun to consider less costly flood mapping at a screening level of detail. The US Federal Emergency Management Agency (FEMA) refers to this level of assessment as “Base Level Engineering” (BLE) (FEMA, 2018) and it is referred to as Base Level hazard mapping in this study.

Base level hazard mapping improves flood hazard assessment compared to the Stream 1 study through more detailed flood frequency analyses that considers climate change and hydraulic modelling for a specified 200-year flood discharge (Appendix B). While not as accurate as detailed flood studies, Base Level flood hazard maps can be completed at far lower cost per area assessed (factor of 10 lower). A key aspect of Base Level flood hazard maps is that the topographic data used for hydraulic modelling are based on available digital elevation models that generally do not account for the full river bathymetry[4]. As such, it is possible to complete mapping over much larger areas to support decision making.

Where required, Base Level flood hazard maps can also be applied to serve as a basis for more detailed mapping in the future, given it is more efficient to refine the models than prepare detailed flood maps from scratch. Section 3.3 provides further context on different levels of mapping detail and their applicability to decision making.

2.2. Hydrology Assessment

Peak discharges for the 200-year flood (Annual Exceedance Probability of 0.005) used as inputs to the hydraulic models were determined through statistical analysis of historical streamflow records (e.g., streamflow discharges collected at Water Survey of Canada hydrometric stations[1]). All of the creeks and rivers in this study were gauged in that historical streamflow monitoring has been performed on the watercourses. The creeks and rivers fell into two categories:

- Gauged rivers and creeks with enough historical streamflow records to provide a reasonably accurate estimate of the 200-year flood.
- Gauged rivers and creeks without enough historical streamflow records to provide a reasonably accurate estimate of the 200-year flood.

[4] In cases, where lidar data are available, a significant component of the river bathymetry can be captured if the data were acquired during a period of low flow.

For the first case a single-station flood frequency analysis was performed using the historical streamflow records. For the second case, a regional flood frequency analysis (Regional FFA) was performed using streamflow observations from hydrologically similar catchments to supplement the at-site observations. The estimated peak instantaneous discharges for the 200-year flood event were then pro-rated to appropriate locations within the study areas. Appendix B provides additional details on the hydrological analysis used to determine the 200-year peak discharges.

Climate change is expected to have an impact on the magnitudes of the peak flows. The EGBC (2018) guidelines provide guidance for adjustment of peak flows to be used in detailed floodplain assessments. BGC recently completed detailed flood mapping for a number of rivers in the Regional District of Central Kootenay (RDCK). For those studies, BGC performed an assessment of climate change using both statistical and process-based methodologies as per the EGBC (2018) guidelines, as well as quantitative consideration of climate change variables in the Regional FFA. This quantitative analysis, while not conclusive, supported a 20% upwards adjustment of flood quantiles. Therefore, the peak discharges estimated for the Nicola River and Spius Creek were adjusted upwards by 20%.

Climate change considerations were not accounted for at the other sites, as a lower resolution DEM was used which limits the overall accuracy of the results. It was felt that accounting for the changes in peak discharges due to climate change would have limited meaning relative to the uncertainty and resolution of the coarse DEM used at the other sites. Peak discharges were adjusted for the Nicola River study area, as a high-resolution DEM was available for hydraulic modelling.

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 to hybrid or hybrid to rainfall-dominated systems are all intertwined and non-linear. We have entered a climate with characteristics outside the recorded human experience. Changes will likely be profound, and the understanding of the trajectory and magnitude of change will evolve rapidly in the coming decade. All climate change assumptions applied in this study warrant periodic review as climate science evolves in the future.

2.3. Hydraulic Modelling

BGC developed a two-dimensional (2D) hydraulic model from the DEM and FFA generated for each site to develop inundation extents, flood depths and peak flow velocities for 200-year return period clear-water floods events. The flood depths at steady state were estimated using HEC-RAS version 5.0.7 hydraulic model. HEC-RAS is a public domain hydraulic modelling program developed and supported by the United States Army Corps of Engineers (Brunner & CEIWR-HEC, 2016). This version of HEC-RAS supports both one-dimensional (1D) and two-dimensional (2D) hydraulic modelling.

For this study, a 2D hydraulic model was selected. The 2D model provides more detailed information on the flow depths and velocities than a 1D model. A 2D model also removes some of the subjective modelling techniques which are involved in the development of 1D models such as defining ineffective flow areas, levee markers and cross-section orientation.

The models used the topographic data from Canadian Digital Elevation Model (CDEM) except for the Nicola/Coldwater Rivers and Spius Creek where airborne lidar was available. The base resolution of the CDEM is 0.75 arc second along a profile in the south-north direction and varies from 0.75 to 3 arc seconds in the east-west direction, depending on location. For TRW this yields approximately to a 20 m grid cell resolution (Government of Canada, 2016).

The HEC-RAS 2D model has limitations that BGC considered when modelling steeper watercourses (Spius Creek) and when using coarse DEMs with relatively smaller flows (i.e. Cherry Creek, and Chase Creek). The approach that the HEC-RAS 2D model uses to calculate the flows and water levels is computationally efficient but can result in fragmented inundation (Figure 2-1). BGC minimized the fragmentation by adding breaklines to prevent “leakage” within computational cells (applies to areas with lidar DEMS) and reducing the cell size to limit the interpolation of the hydraulic gradient between adjacent computational cells. The fragmentation is greatest for the creeks modeled using the coarse DEM. Using a lidar based DEM will improve the results for these sites (see Section 4.3.1). The current Base Level mapping using Table 2-1 lists additional modelling limitations and uncertainties, and implications for decision making.

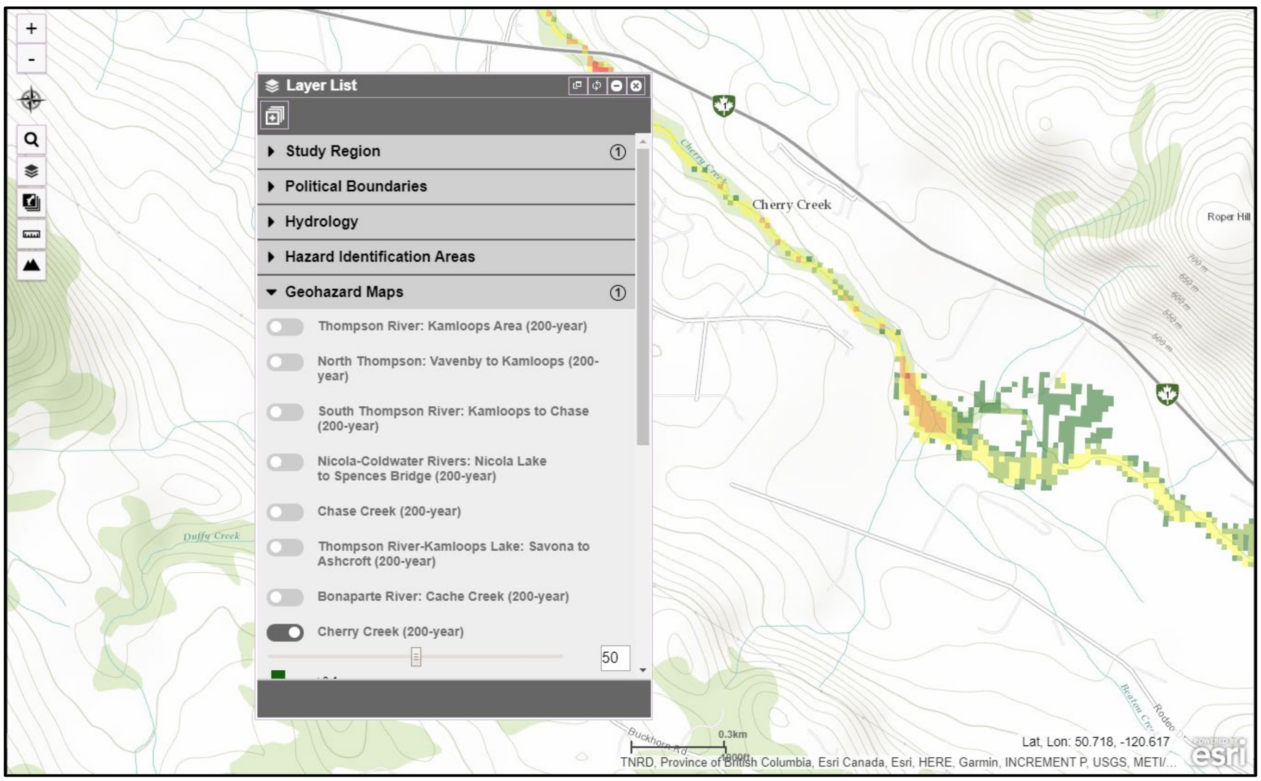

Figure 2-1. Example of fragmented inundation along Cherry Creek.

Table 2-1. Modelling limitations and uncertainties.

Description	Technical Implications	Implications for Decision Making
Flow conveyance infrastructure (i.e., bridges and culverts) were not incorporated into hydraulic models, nor was the topography of the built environments considered. Structural flood protection (i.e., dikes) was also not incorporated into models except as it may be represented in the topography. The CDEM DEM used for most areas is not sufficient resolution to distinguish dikes.	Flooding extents around flow conveyance infrastructure and structural flood protection may differ from what was modelled. Backwater effects from water backing up behind a bridge will not be modelled. Because the resolution of the CDEM DEM is not sufficient resolution to detect dikes, flows may extend into areas with flood protection.	Although the hazard mapping approach will generally yield conservative results (higher flood depth and extent) compared to detailed flood hazard mapping, the mapping in the vicinity of conveyance infrastructure may not be conservative. There is insufficient detail to define Flood Construction Levels (FCLs), although the mapping may be used to trigger requirements for FCL mapping and to highlight locations where historical mapping may be out of date.
Break lines were used only to delineate river centerlines and increase resolution in that region. They were not used elsewhere (such as at the top of banks) to delineate abrupt changes slope.	Flows that would be contained by the banks of rivers or other abrupt changes to elevation such as dikes may extend beyond those points in the model.	Hazard mapping may be more conservative (higher flood depth and extent) compared to detailed flood hazard mapping.
The elevation model uses only surficial topographic data, the bathymetry of lakes and rivers is not accounted for.	Over-estimation of the level of overland flow.	Hazard mapping likely to be more conservative (higher flood depth and extent) compared to detailed flood hazard mapping.
Watercourse modeling using the CDEM DEM are limited in their vertical and horizontal accuracy due to the coarseness of the topographic model (20 m cell resolution).	Limitation in confidence level and accuracy of model results.	Hazard mapping suitable for planning, policy, emergency planning, and regional risk assessment, but not for mitigation design or quantitative prescriptions in bylaws (i.e., FCLs).
Models were not calibrated against field evidence of recorded floods, and the topography is assumed to be static (i.e., no consideration of channel changes).	Limitation in confidence level of model results; hazard mapping should be considered a snapshot in time.	Periodic review and updates will be required.
Peak discharges were only modelled for the main watercourses. Peak flows from tributaries were not modelled.	200-year peak discharges for tributaries which discharge into the main watercourses for each study were not modelled. Typically, this requires separate model runs to achieve.	Hazard mapping along the main tributaries to the main water courses considered in this study will likely be under-estimated.

3. RESULTS

3.1. Summary

The results of this study include:

- Documentation (this report)
- Hazard model scenario maps provided in digital format (GIS files) for each study area
- Hazard model scenario maps added to Stream 1 study results accessed via Cambio web application, which can be accessed at www.cambiocommunities.ca.

The Base Level hazard maps display modelled extent and depth of inundated areas for an estimated 200-year flood discharge. Figure 3-1 provides an example screen-capture from Site 5, at Merritt. Table 3-1 defines the inundation depth thresholds displayed on the maps. The flood depths and extents estimated in this study are advanced over those provided by the Stream 1 assessment, but should still be considered approximate (see Section 2.3 for limitations and uncertainties).

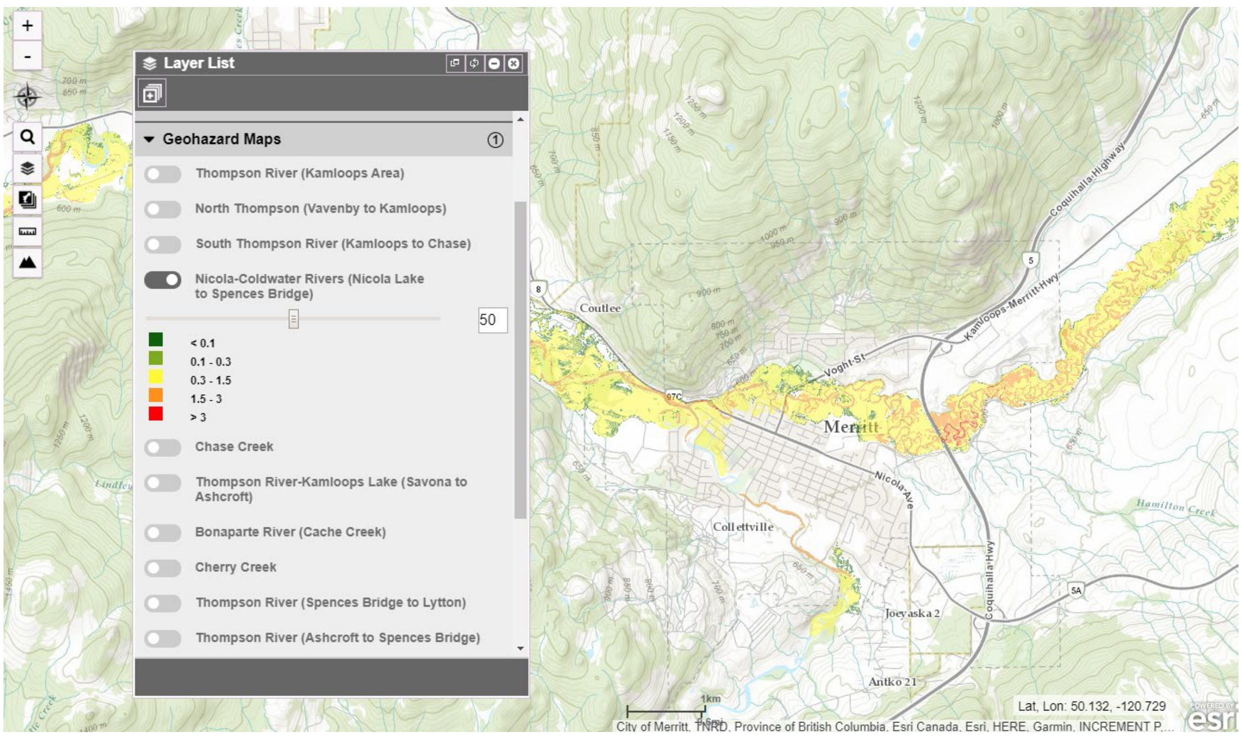

Figure 3-1. Flood depth for Site 5 – Nicola/Clearwater Rivers at Merritt, in Cambio Communities.

Table 3-1. Flood inundation depth thresholds displayed on the hazard maps.

Peak Flood Depth above Ground Surface (m)	Symbology in Cambio Communities
< 0.1	(dark green)
0.1 – 0.3	(light green)
0.3 - 1.5	(yellow)
1.5 – 3	(orange)
> 3	(red)

3.2. Users and Use-Cases

BGC anticipates that a wide range of parties will use the results of both the Stream 1 study and this project. Table 3-2 provides examples of potential use cases. Both the Stream 1 and this study are considered in the table, which reflects an integrated approach to advance geohazards understanding in the TRW. The table is written from the perspective of accessing results in Cambio, but it applies broadly to viewing study results via digital platforms.

Table 3-2. Intended users of the Stream 1 geohazard risk prioritization and the hazard mapping results generated by this study.

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 current Base Level hazard mapping, users can: • View and apply base level flood hazard maps showing estimated flood extents and depths for a 200-year flood scenario.
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, or consequence ratings across multiple areas. For areas additionally encompassed by the current Base Level hazard mapping, users can: • View 200-year flood hazard maps across multiple areas, 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., Fraser Basin Council	"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.

3.3. Level of Detail

The hazard maps prepared by this study are at a level of detail between the Stream 1 study and more costly detailed mapping. Table 3-3 compares the level of detail of mapping approaches and highlights implications for decision making.

A key constraint on mapping resolution was the availability of high resolution lidar topography. Although not available in time for the current work, Terra Remote Sensing (2020) has now completed lidar acquisition and processing for all areas mapped in this study. Re-running the hydraulic models with the inclusion of lidar data would greatly improve the resolution of mapping.

Table 3-3. Hazard assessment levels of detail.

Points of Comparison	Hazard Identification Maps (Stream 1)	Flood Hazard Assessment & Maps	
		Base Level (This Study)	Detailed[1] (Future Study)
Applicability for decision making	Suitable for prioritization and definition of the outer boundary of hazard areas subject to subdivision regulation in Official Community Plans (OCPs)	Suitable for limited[2] application in planning, policies, and bylaws at individual parcel (property boundary) level of detail, and emergency response & mitigation planning.	Suitable for parcel scale risk management, including risk assessment & bylaw enforcement, hazard monitoring, and detailed emergency response & mitigation planning
Level of detail	Hazard boundary (hazard extent and attributes, but not mapped flow characteristics)	Hazard characteristics (flow depth) displayed within the hazard boundary	Hazard characteristics displayed within the hazard boundary
Relative level of effort for a given study area	$	$$	$$$$
Examples of existing projects in the study region	TRW, CRD and CSRD geohazard risk prioritization studies: BGC (2019, 2020b, 2020c)	Base level flood mapping (BGC 2020a)	Proposed in this study
Inputs	Desktop analyses	Desktop analyses, limited fieldwork	Desktop analyses, hydrometric surveys, and fieldwork
Hazard return periods considered	Single (to compare sites)	200-year Peak Instantaneous Discharge	Multiple return periods & scenarios
Qualitative/Quantitative	Relative, qualitative	Quantitative	Quantitative
Map Deliverables	Hazard boundaries	Hazard maps	Hazard maps
Applicable Guidelines	NRCAN (2017)	NRCAN (2017); FEMA (2018)	EGBC (2017, 2018)

Notes:

1. Multiple levels of effort are possible for detailed assessment (EGBC, 2017, 2018).
2. e.g., lower precision and confidence than detailed hazard assessment for site-specific application at individual parcels.

For clarity, BGC emphasizes that the results provided by this study do not replace detailed floodplain maps, where existing, and are not comparable to Flood Construction Level (FCL) maps. FCLs are developed from detailed flood hazard mapping and define a flood level that typically adds freeboard to modelled water surface elevations. Freeboard was not added to modelled water depths provided in this study. In areas containing flood protection, FCL map preparation also requires assumptions about the potential for dike failure, which may result in flood depths and extents that are greater than if the dike was not present. The results of this study should not be used to determine FCLs. However, they do provide flood characteristics in advance of more detailed mapping and can help identify areas where FCL maps may be required. Both the hydrologic and hydraulic analyses completed in this study can be refined to develop FCL maps at lower cost than developing such maps from scratch.

4. ADDITIONAL CONSIDERATIONS

This section highlights ways that this assessment and the Stream 1 study may be considered in geohazards risk management decision making within the TRW.

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 local governments in the TRW 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, avoiding 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 in updates and include recommendations for next steps in the risk management cycle.

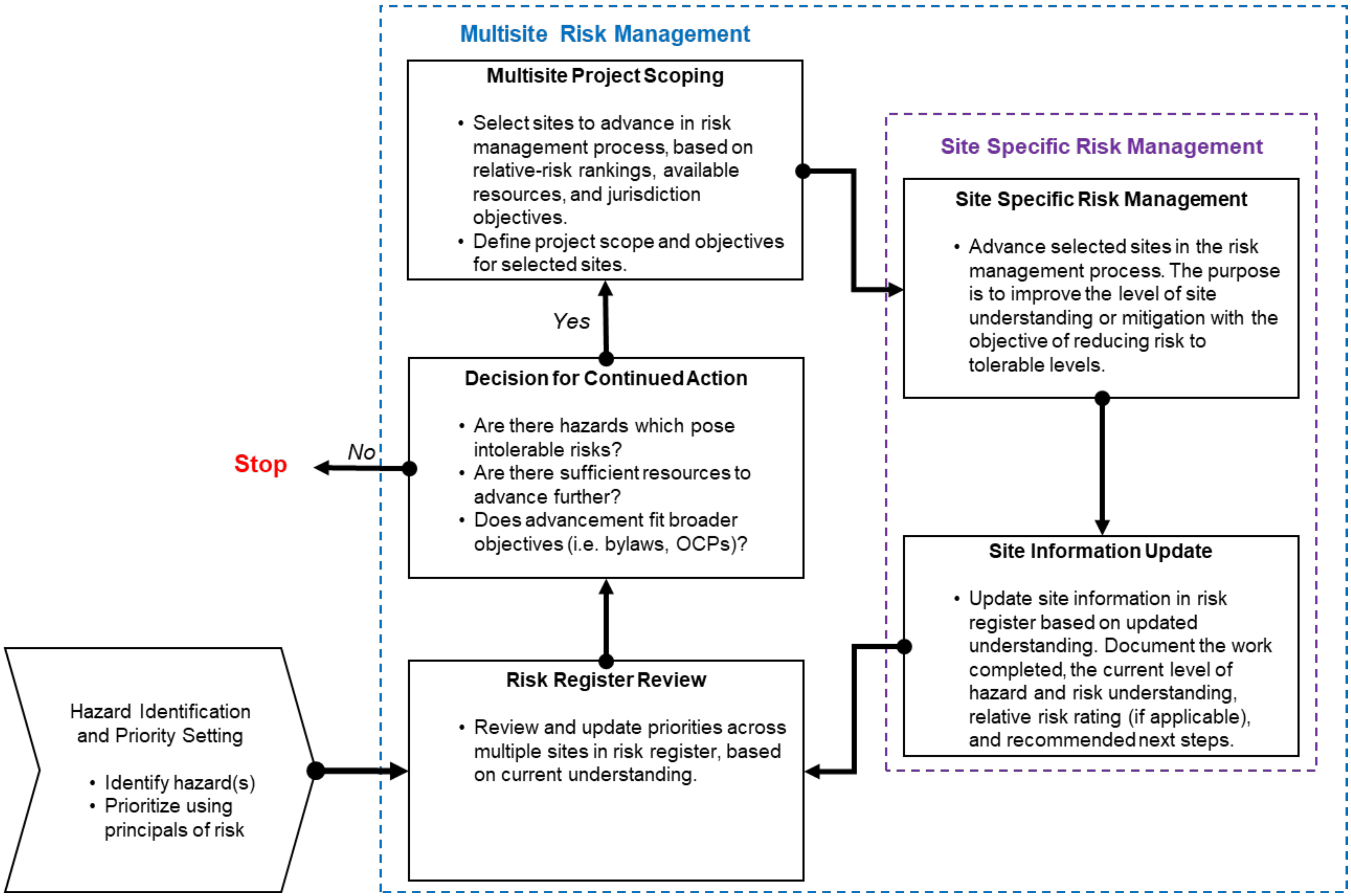

Figure 4-1. Schematic of multi-site risk management approach.

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 TRW 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 pro-active 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).

Assessment Type	Risk Communication and Consultation	Steps	Monitoring and Review
Geohazard Assessment; Geohazard Risk Identification; Geohazard Risk Estimation; Geohazard Risk Assessment; Geohazard Risk Management	Informing stakeholders about the risk management process	**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	Ongoing review of risk scenarios and risk management process
Geohazard Assessment; Geohazard Risk Identification; Geohazard Risk Estimation; Geohazard Risk Assessment; Geohazard Risk Management		**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.	
Geohazard Risk Identification; Geohazard Risk Estimation; Geohazard Risk Assessment; Geohazard Risk Management		**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.	
Geohazard Risk Estimation; Geohazard Risk Assessment; Geohazard Risk Management		**4. Risk Analysis** a. Develop geohazard risk scenarios b. Determine geohazard risk parameters c. Estimate geohazard risk	
Geohazard Risk Assessment; Geohazard Risk Management		**5. Risk Evaluation** a. Compare the estimated risk against tolerance criteria b. Prioritize risks for risk control and monitoring	
Geohazard Risk Management		**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)	
Geohazard Risk Management		**7. Risk Control Implementation and Monitoring** a. Implement chosen risk control options b. Define and document ongoing monitoring and maintenance	

Where local and First Nations governments 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 local and First Nations governments in the TRW 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, and qualitative. 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 applies 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[5]. A concept called a "Disproportionality Ratio" can be used to define thresholds beyond which there '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. 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

4.3.1. Fiscal 2020 Proposed Assessments

Consideration:

- *Complete assessments proposed in a January 2020 applications to the Union of BC Municipalities Emergency Preparedness Fund (UBCM CEPF) (BGC, 2020).*

As noted in Section 1, this study continues a geohazard risk management initiative for the entire TRW, coordinated by the FBC with participation of local governments and First Nations. The work advances the regional geohazard risk management process summarized in Section 4.1.

As a next step, Fraser Basin Council and BGC assisted eight local governments within the TRW in the preparation of their January 2020 applications to the Union of BC Municipalities Emergency Preparedness Fund (UBCM CEPF) (BGC, 2020). Applicants included CRD, TNRD, CSRD, Merritt, Sicamous, Barriere, Clearwater and Clinton. Funding confirmation has not been received at the date of issue of this document but is anticipated for June 2020.

Figure 4-2 shows the location of the proposed assessments, which encompasses all areas considered in this current study plus additional locations in the TNRD, CRD and CSRD.

[5] 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!").

Appendix C lists the assessment areas, and Table 4-2 summarizes the assessments according to their objectives. The objectives differ by area because not all regions are at the same stage or level of detail of assessment, and include the following:

1. *Hazard Identification:*
    a. Leverage newly available floodplain modelling to increase the mapping accuracy of all floodplains identified throughout the region by the Stream 1 study.
    b. Increase the areal coverage of floodplain mapping.
2. *Base Level Hazard Assessment Update:*
    a. Extend mapping areas and incorporate newly available lidar to increase the accuracy of ‘Base Level’ clear-water flood hazard maps prepared by this current study.
3. *Detailed Hazard Assessment:*
    a. Develop detailed (parcel scale) steep creek and floodplain hazard maps at the highest priority areas, based on both desktop study and fieldwork.
    b. Increase the level of detail of assessment, including consideration of climate change.
4. *Risk Assessment Inputs:*
    a. Gap analysis and refinement of hazard exposure and vulnerability data at a parcel scale level of detail, as would be typically be required for quantitative risk assessment and input to flood management strategy.

Of the above objectives, “Base Level Hazard Assessment Update” and “Risk Assessment Inputs” are proposed for the areas assessed in this current study. Detailed flood hazard mapping is also proposed for the City of Merritt, based on a refinement of the hydraulic models prepared for this study.

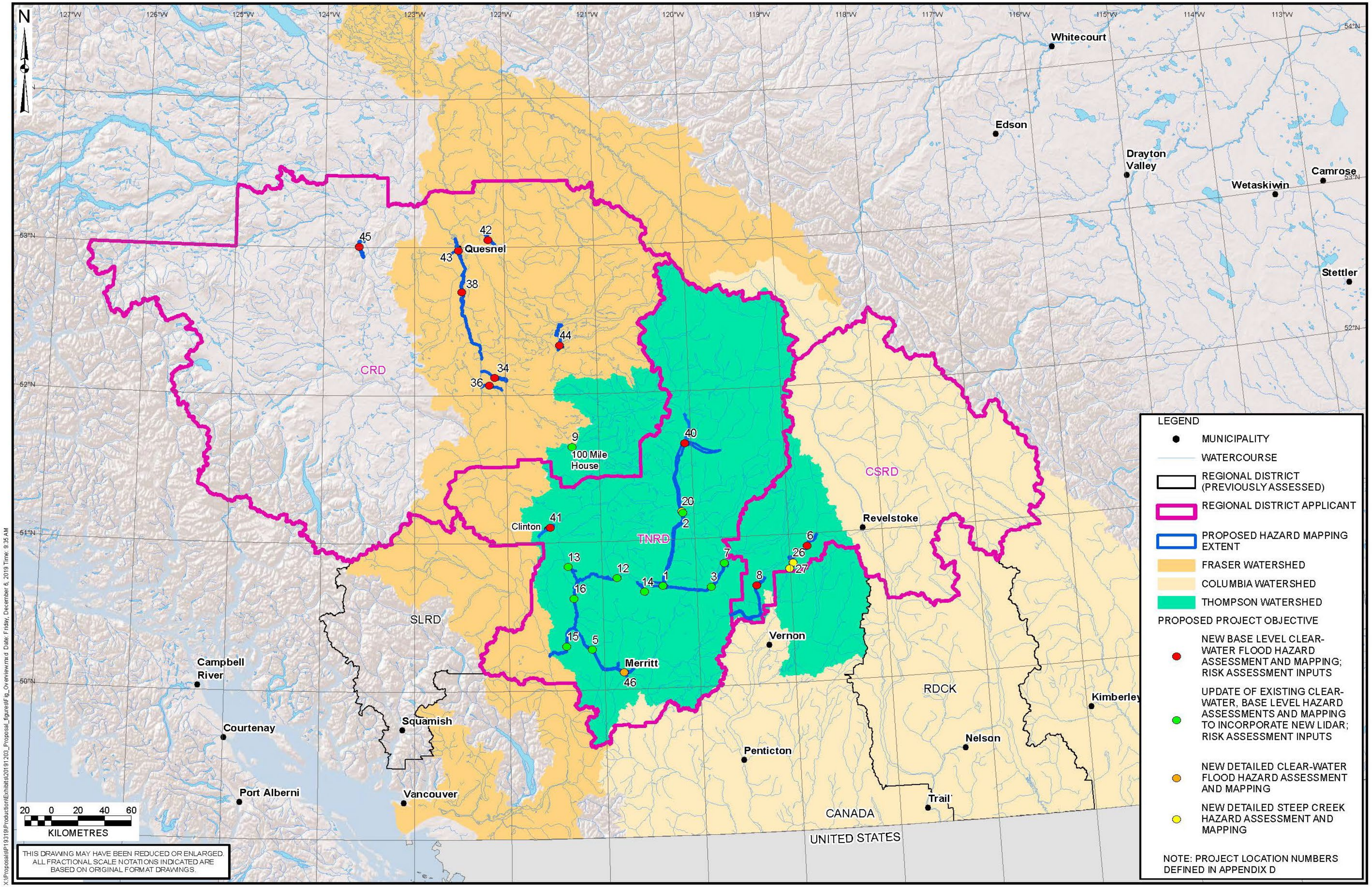

Figure 4-2. Proposed assessment areas. The numbers listed on the figure correspond to the study area numbers in Appendix C.

Table 4-2. Project objectives, January 2020 UBCM CEPF Applications. Those shown in bold are directly applicable to the study areas described in this document.

Study Areas	Site Classification (Assessment Stage per Figure 1-6)			Description of Project Objective	Number of Project Sites by Applicant (Administrative Area)								Total
	Current Stage	Proposed Project Objective			CRD	TNRD	CSRD	Merritt	Sicamous	Barriere	Clearwater	Clinton	
Watercourse hazard areas prioritized by BGC (2019)	Hazard identification & priority setting completed	1	Update of clear-water flood hazard identification	Refine regional floodplain identification with new provincial scale floodplain identification analysis completed by BGC (2019 internal, unpublished).	>100	~4,000	-[1]	-	-	-	-		many
		2	New base level clear-water flood hazard assessment and mapping Risk assessment inputs	Complete new, base level floodplain hazard mapping for high priority floodplains in CRD, CSRD, (BGC 2020a,b), using lidar topography available March 2020 where applicable, and prepare risk assessment inputs.	7	-	2	-	-	-	1	1	11
TRW study areas with base level floodplain mapping completed by BGC (2020a)	**Base level floodplain mapping completed**	**3**	**Update of existing clear-water, base level hazard assessments and mapping to incorporate new lidar.** **Risk assessment inputs**	**Update of existing base level floodplain mapping in TNRD and CRD based on lidar topography available March 2020, and prepare risk assessment inputs.**	**1**	**10**	**-**	**-**	**-**	**-**	**-**		**11**
		4	**New detailed clear-water flood hazard assessment and mapping.**	**Complete field surveys and detailed flood hazard mapping (City of Merritt).**	**-**	**-**	**-**	**1**	**-**	**-**	**-**		**1**
Selected steep creek hazard areas (fans) in District of Sicamous, District of Barriere and CSRD	Hazard identification & priority setting ongoing	5	New detailed steep creek hazard assessment and mapping	Complete detailed (desktop and field-based) steep creek geohazard assessments and mapping for selected high priority areas; building level hazard exposure modelling.	-	-	1	-	1	1	-		3

Note:

1. Floodplain identification update for CSRD is being undertaken as part of current work by BGC, supported by NDMP Stream 1 funding.

4.3.2. Additional Detailed Assessments

Consideration:

- *Prepare detailed flood hazard maps for areas subject to existing or proposed Development Permit Areas (DPA)s and zoning bylaws.*

BGC suggests local and First Nations governments build on the results of this study to prepare detailed flood hazard maps for areas subject to existing or proposed DPAs and zoning bylaws. Detailed flood hazard mapping has already been proposed for the City of Merritt (Section 4.3.1).

Where existing, historical floodplain maps are the primary source of flood information used to regulate land development in flood-prone areas, including some of the most populated areas of the TRW[6]. As noted in Section 1.2, these maps are largely out of date. The results of this study are an advancement over historical floodplain mapping, where existing, in that the results are based on current information and use more advanced hydrologic and hydraulic modelling approaches. At the same time, the current work is not considered detailed mapping and does not include the preparation of Flood Construction Level maps (Section 3.3). As such, BGC does not suggest that the current work be formally referenced in bylaws to define flood elevations.

Table 4-3 compares the results of this study against historical flood hazard maps. Discrepancies can be used to identify areas warranting more detailed review and updates. BGC notes the following two areas in particular:

- Sites 1, 2 and 3 (Kamloops area): The current work predicts a smaller 200-year flood extent than historical mapping. BGC believes the discrepancy is related to Kamloops Lake water levels assumed by the historical floodplain maps, which were higher than can be supported by current information. This result is subject to confirmation by detailed study, which would also consider the effects of structural flood protection on flood characteristics, consider climate change, and provide updated FCL estimates.
- Site 13 (Bonaparte River): The coarse DEM used in this study was not as exact as the DEM used in the 1996 study or the 2019 detailed flood hazard mapping at Cache Creek, which is based on lidar acquired within the city boundary. The base level mapping for the Bonaparte River would be significantly improved using a lidar based DEM, as has been included in the work proposed for the January 2020 UBCM CEPF application (Section 4.3.1).

[6] Cache Creek also completed detailed floodplain mapping in 2019, although it could not be made available for reference in this study (awarded 2017; MoTI March 27, 2017, completed Spring 2019)

Table 4-3. Comparison of current work to historical floodplain maps.

Site	Date of Study	Report Available?	Comments
Site 1: Thompson River (Kamloops Area)	1976	No	Historical floodplain extents performed in 1976 are larger than the Base Level mapping in the current study. The 1976 study appears to have used a very high-water level in Kamloops Lake (346.19 + 0.61 m of freeboard). Analysis of the historical water levels in Kamloops Lake at gauges (08LF046 and 08LF085) does not support this water elevation and a lower water elevation was used in the present modelling (344.96 m). The flooding extent in Kamloops as well as upstream along the North and South Thompson River appear to be sensitive to the water level in Kamloops Lake.
Site 2: North Thompson River	1982	No	Historical floodplain extents performed in 1982 match the Base Level extents in the current study for most of the North Thompson River. Between Westsyde and Kamloops the extents of the historical mapping are large and likely due to the backwater effects from the assumed water level in Kamloops Lake which may be unrealistic.
Site 3: South Thompson River	1976	No	Historical floodplain extents from the 1976 study match the current study extents most of the length of the watercourse. Historical mapping extents are much greater near Kamloops due to backwater effects from Kamloops Lake elevations which may be unrealistic.
Site 13: Bonaparte River	1996	Yes	Some disagreement between historical floodplain mapping and current mapping upstream of Cache Creek. Historical mapping shows greater flooding extents than current mapping. The coarse DEM used in this study did not compare well to the higher-resolution elevation contours used in the 1996 study.
Site 5: Nicola/Clearwater River	1989	Yes	Historical floodplain extents from the 1989 study generally match the Base Level mapping extents in the current study.
Site 18: Spius Creek	1989	Yes	The historical floodplain mapping extents from 1989 were based on the limits of the Spius Creek debris fan.

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 TRW. 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 TRW. 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™ (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 TRW (e.g., Figure 4-3).

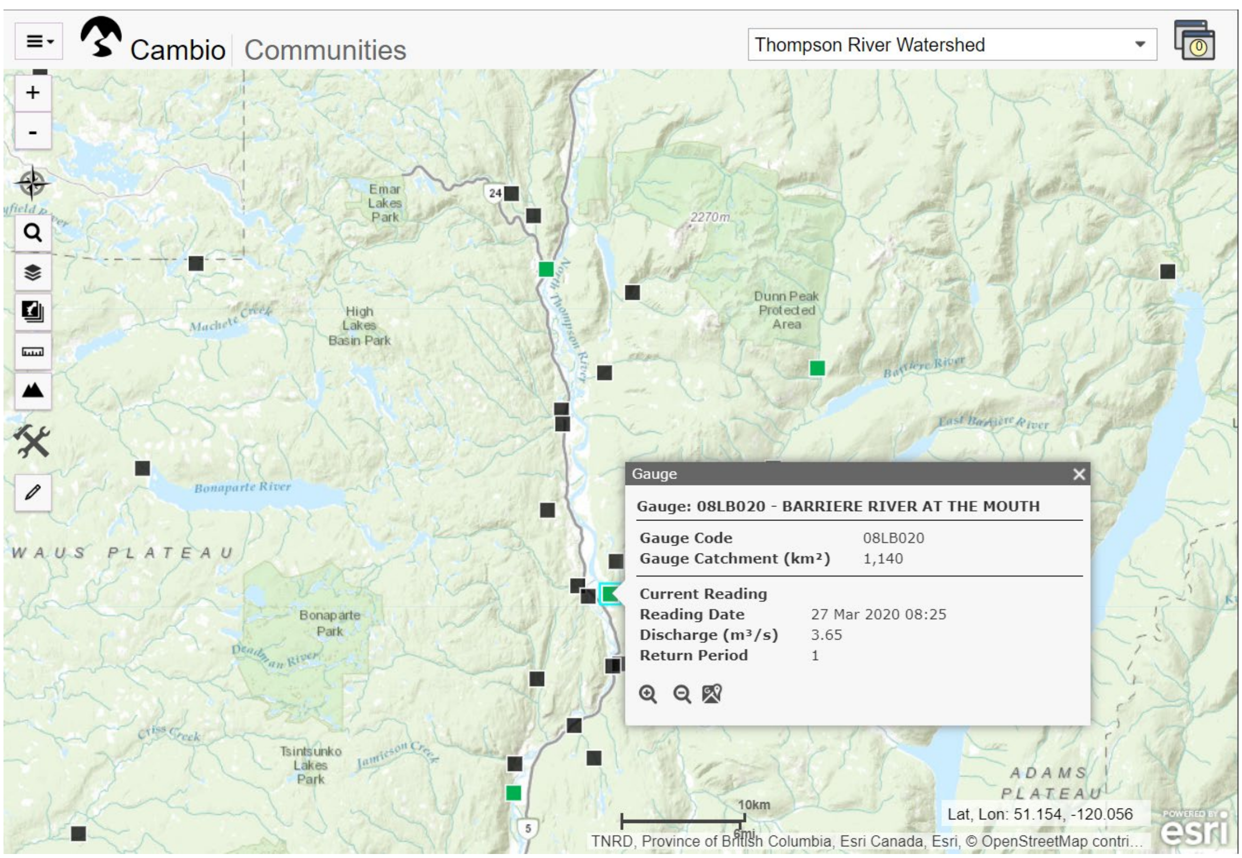

Figure 4-3. Example of a real-time streamflow gauge on the North Thompson River at Barrierre.

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[7].

ECCC also provides the Regional Deterministic Prediction System (RDPS)[8], 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.

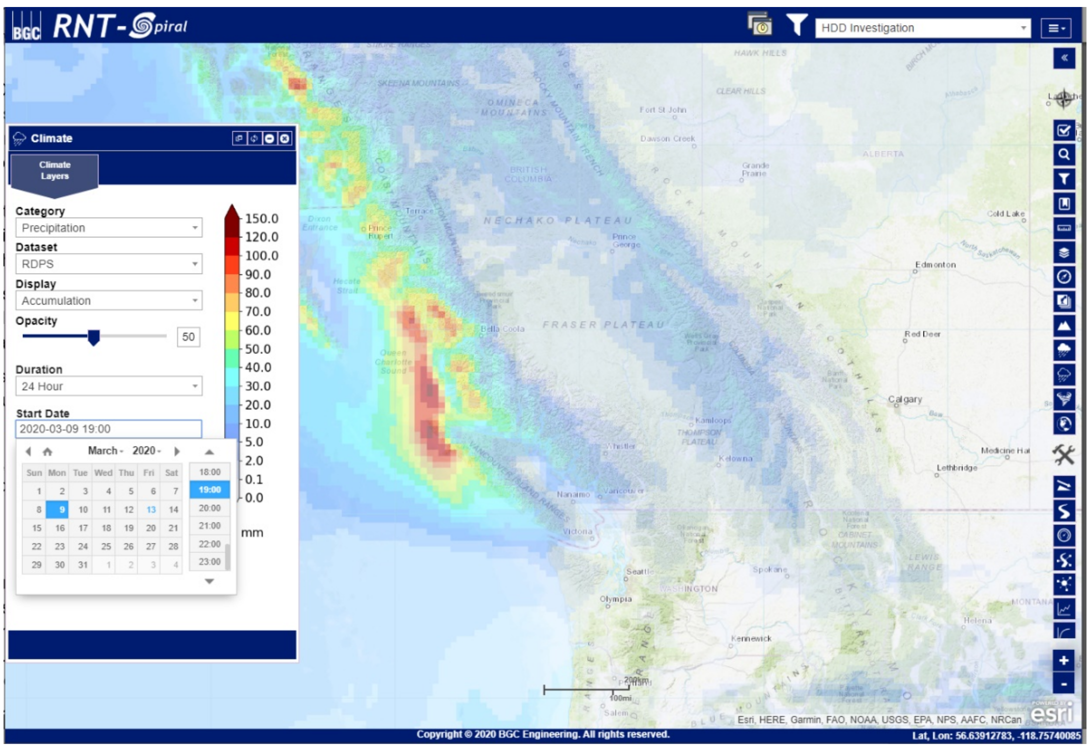

Figure 4-4. Example of 24-hour accumulated precipitation in southern British Columbia on March 9, 2020. Source: RDPA-CaPA (2020, BGC's River Network Tool™).

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

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

4.4.3. Automated Stream Flow Alerts

The 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 BGC, 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 and more detailed hazard mapping 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 4-5. 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 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)
- 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, areas of TRW are potentially well-positioned to participate in such an initiative. BGC suggests that FBC, local and First Nations governments consider their level of interest in applying storm alerts to emergency management as part of such an initiative.

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 Centers (EOC) to more efficiently allocate materials and resources where it is needed most. Re-running could also incorporate newly available lidar (Terra Remote Sensing, 2020).

4.5. Policy Integration

Considerations:

- *Review and update land-use designations, bylaws and policies, including Zoning Bylaws and Development Permit Areas (DPAs) where existing, with consideration of the hazard areas defined in Stream 1 and this study.*

4.5.1. Land Use Review

BGC suggests that local and First Nations governments within the TRW compare their existing land-use designations or restrictions against the Stream 1 geohazard areas and areas mapped in more detail by this study. The objective would be to identify hazard areas that were previously unknown and compare them to current land use.

4.5.2. Development Permit Areas (DPAs) and Zoning Bylaws

DPAs and zoning bylaws, where existing, define 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 such as those outlined within applicable OCPs.

BGC suggests local and First Nations governments within the TRW consider a phased approach to update or create areas of land use regulation, where level of detail is aligned with the level of detail of hazard mapping. For example, the hazard inventory completed for the Stream 1 study can be considered in an initial phase to define the outer boundary of a hazardous land DPA. Areas subject to more detailed hazard mapping can then be further considered to refine the outer boundary and create further subdivisions within the boundary. Doing so will allow decision makers 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 Base Level hazard mapping (this study) through detailed mapping (in future) at selected sites, with a risk-informed process in place to explain why certain areas are prioritized over others.

4.5.3. Policy and Bylaw Review

Local and First Nations governments within the TRW administer policies and bylaws that govern development in flood and steep creek hazard areas. BGC suggests each government review policies and bylaws from the perspective of:

- Developing policies and bylaws that support integration of the results of this and the Stream 1 study into flood and steep creek governance.
- Developing an approach that aligns with current flood and steep creek risk management best-practice.
- Achieving consistency between jurisdictions within the TRW and, ideally, other jurisdictions in British Columbia.
- Developing a risk-informed approach to geohazards management.

Table 4-4 summarizes key considerations for review of flood and steep creek related policies and bylaws within the TRW. BGC suggests that the TRW Advisory Committee provide input to support consistent policy and bylaw implementation across the different jurisdictions within the TRW.

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

No.	Recommendation
1	Review existing areas of land use regulation against the Stream 1 geohazard areas and areas mapped in more detail by this study. This would help in the development of 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 TRW.
3	Developing guidelines for how developments, or high intensity land-use types, are discouraged in hazardous lands.
4	Where Official Community Plans (OCPs) exist or are planned, design the OCP in a way that minimizes administrative barriers to making regular updates to areas of land use regulation.
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

Considerations:

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

The information collected for both the Stream 1 and Stream 2 assessments will have a broad range of applications for local and First Nations governments within the TRW. BGC suggests that local and First Nations governments 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 TRW 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 CSRD and more broadly across BC:

- Increasingly, much of the data supporting different aspects of geohazard risk and emergency management is spatial, delivered digitally, and changes over time. For example, EMBC and GeoBC have initiated a data management portal (BC Emergency Management Common Operating Picture), and BGC is delivering the results of both Stream 1 and Stream 2 studies via a web application, Cambio. Such applications may be linked in future through online data services. Where capacity exists, we suggest that local and First Nations goverments 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 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 local and First Nations governments without the capacity to consume data into their own internal systems, Cambio can provide access to all study information via a standard web browser.
- Under a professional reliance model, hazard, vulnerability and risk assessments in British Columbia are mostly completed by Qualified Professionals (QPs) via short-term contracts to deliver a scope of work. The results tend to be delivered piecemeal and with inconsistent formats, which makes it costly for governments to manage hazard,

vulnerability, and risk information in a common knowledge base. As tools for data sharing improve, we anticipate that QPs may increasingly use digital (web) processes to obtain data from multiple sources, add value in their area of expertise, and then "serve" back knowledge in a more dynamic way (i.e., via licensed data services). Local governments may wish to consider these changes when allocating budgets to maintain geohazard risk management programs. Section 4.8 describes approaches to collaborate and share costs with other parties with shared objectives (i.e., private stakeholders; different levels and branches of government).

- 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

Considerations:

- *Connect private and public resources for geohazard and risk management that amplify their effectiveness to reduce risk beyond what can be accomplished in isolation.*
- *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 FBC develop a value proposition based on shared objectives for hazard and risk management not only with public stakeholders, but with the private sector. FBC is already a leader in multi-stakeholder collaboration, and 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.
- 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 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).*
- *Strengthen the role of the Province 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 also disseminate information without 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, the Thompson advisory committee convened by FBC at the outset of the 2018 geohazard risk management initiative is proving to be a constructive way to define and advance priorities. BGC suggests that advisory committee be maintained long-term to guide geohazard risk management strategy in the TRW.

5. 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 replace this page once COVID-19 restrictions are lifted.

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APPENDIX A
CAMBIO COMMUNITIES USER GUIDE

A.1. INTRODUCTION

This appendix describes the purpose and use of *Cambio*™ 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:

Hazard information:

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

Exposure information:

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

Analysis tools:

- 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.

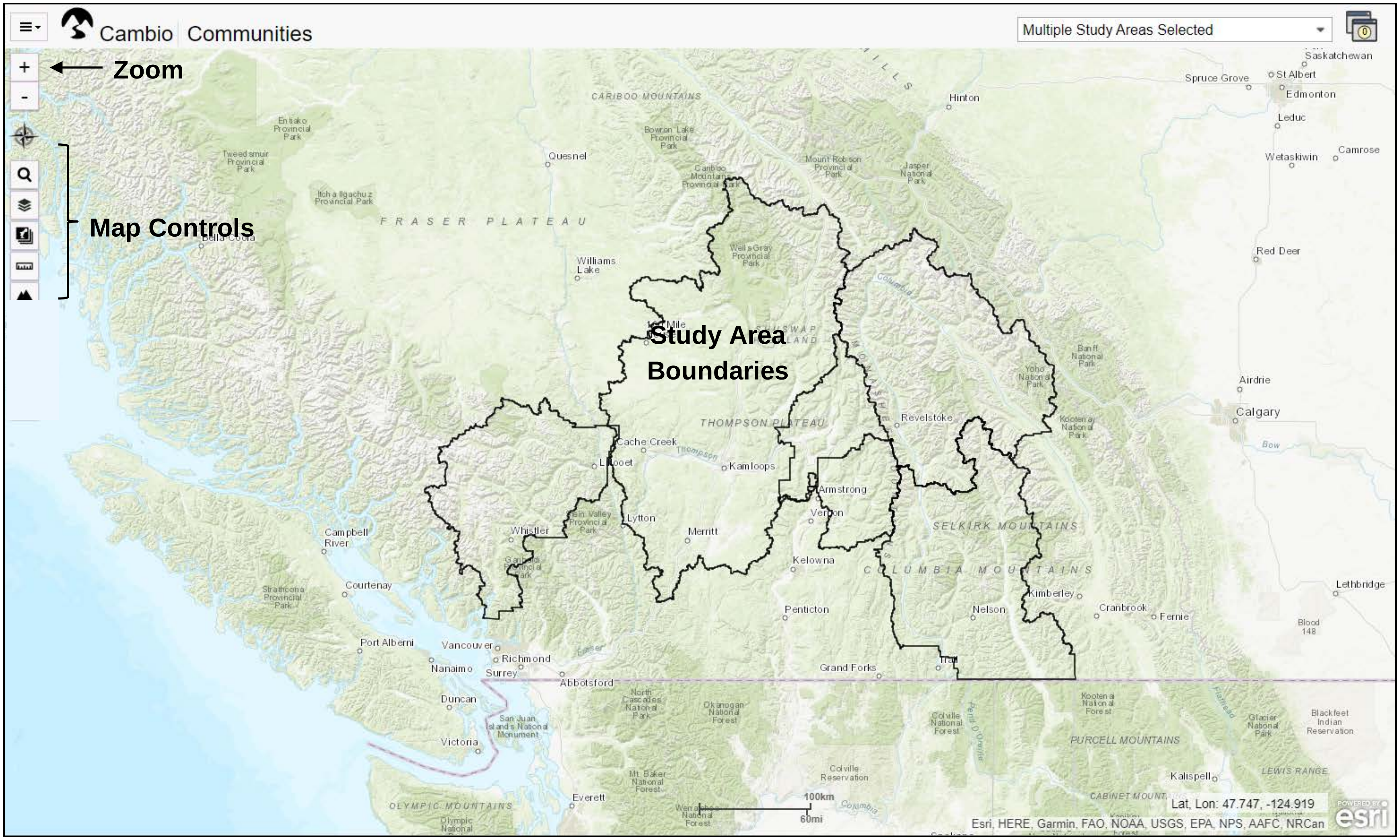

Figure A-1. Online map overview.

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.

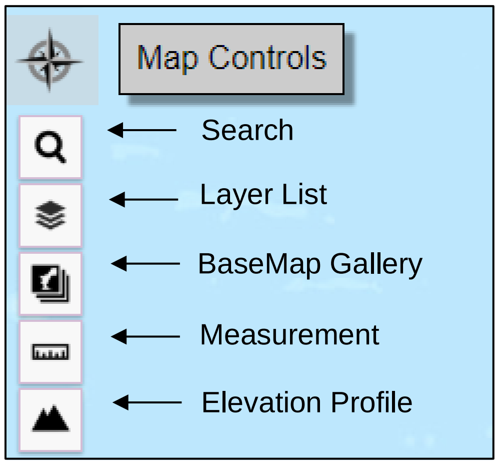

Figure A-2. Map controls and tools.

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).

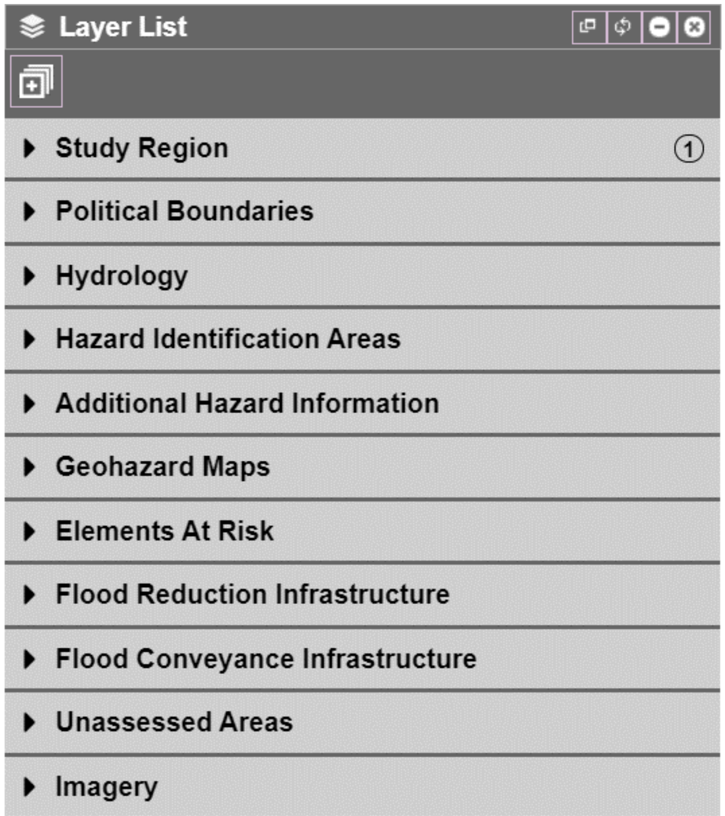

Figure A-3. Layers list.

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. Hazard Identification Areas

Hazard 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 hazard 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 hazard 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.

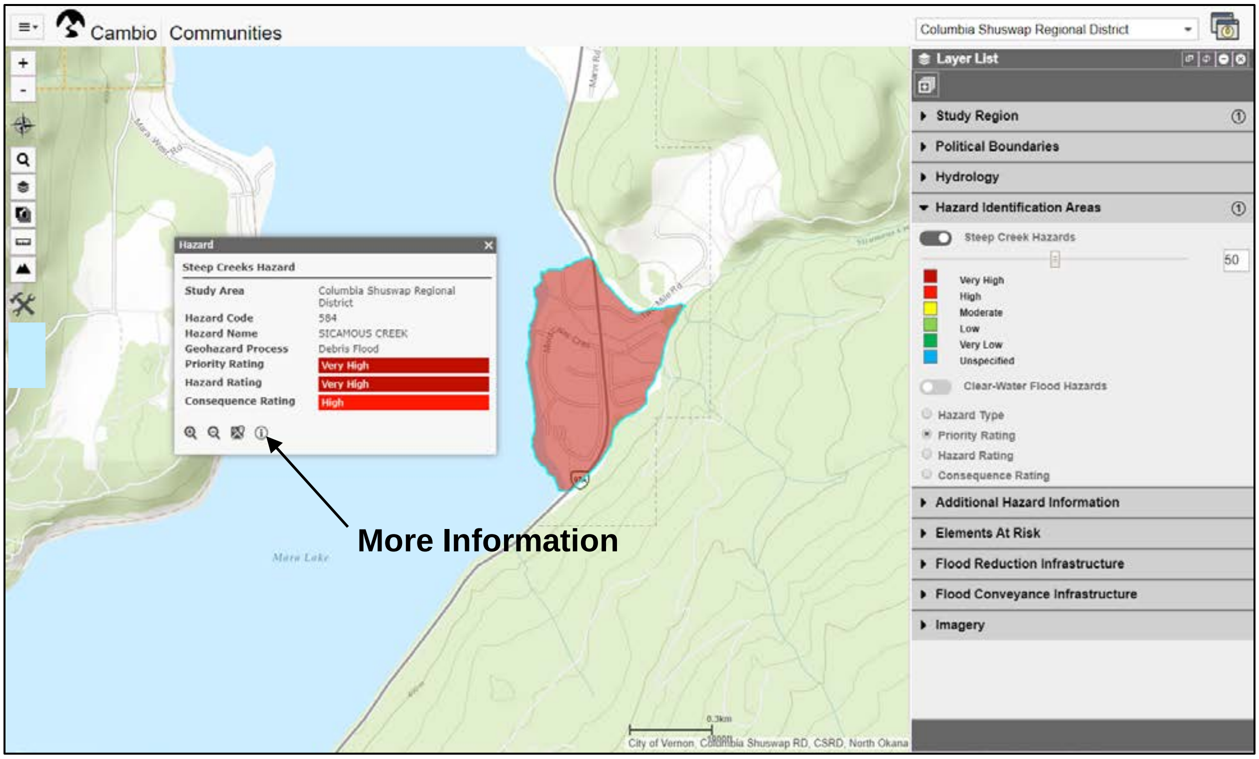

Figure A-4. Geohazard feature popup.

A.4.2. Hazard Maps

Geohazard maps are provided in Cambio for Base Level flood 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 “ℹ” open a sidebar with detailed information about the hazard identification area, as described in Section A.4.2.

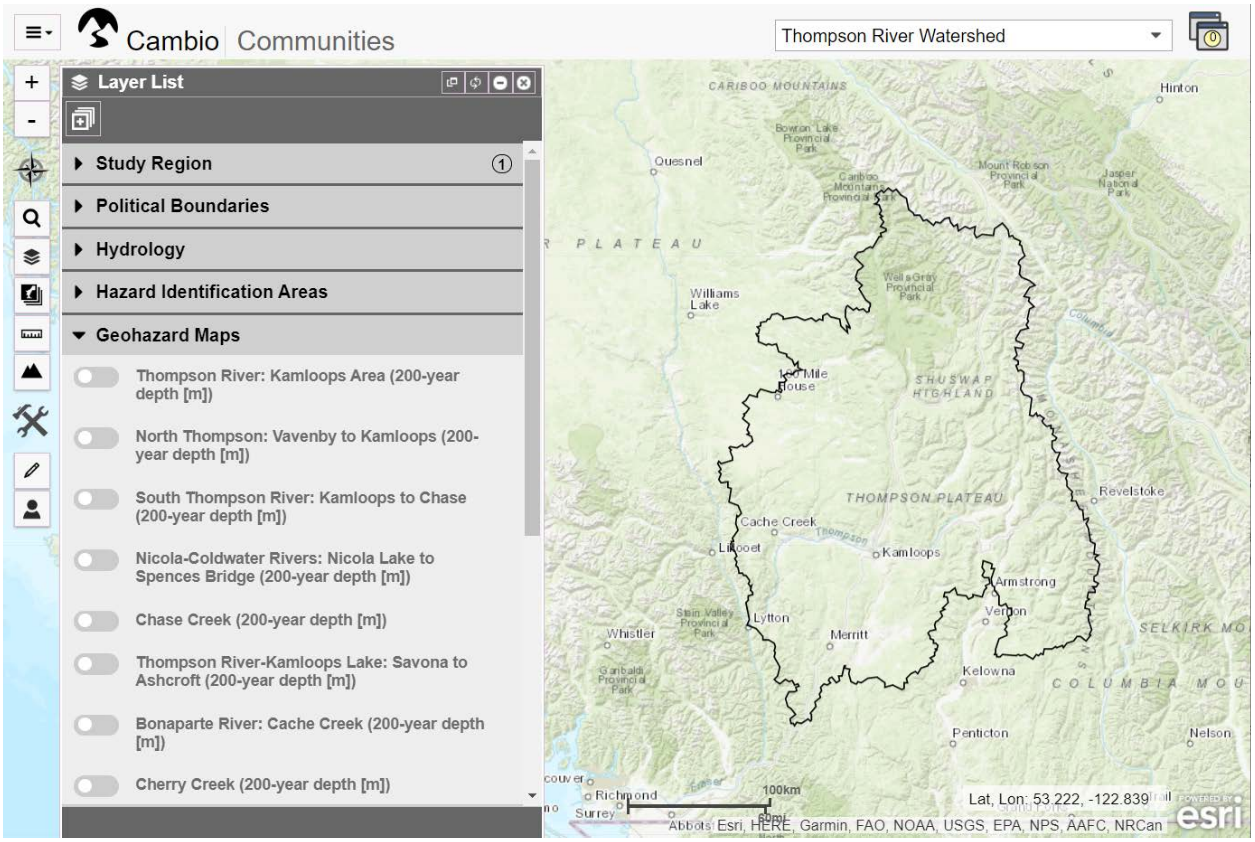

Figure A-5. Example hazard map layers

A.4.3. Hazard 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.

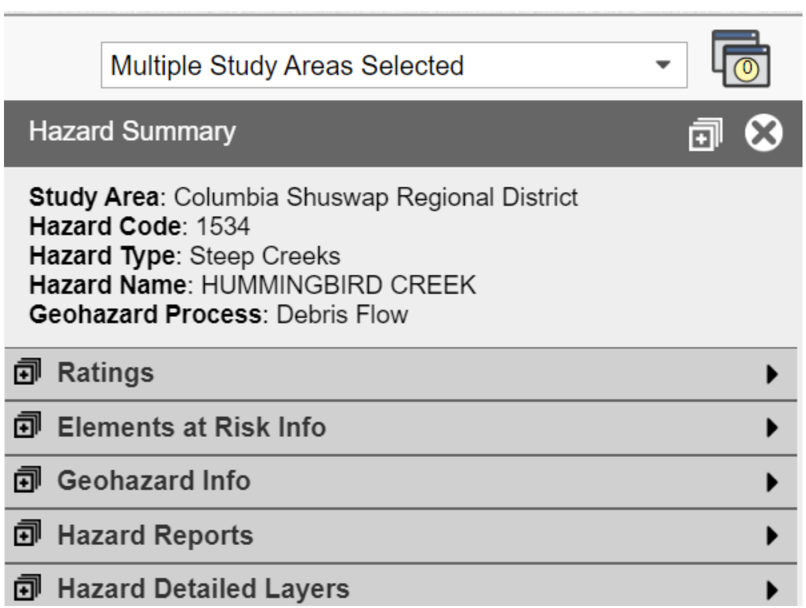

Figure A-6. Additional information sidebar.

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.

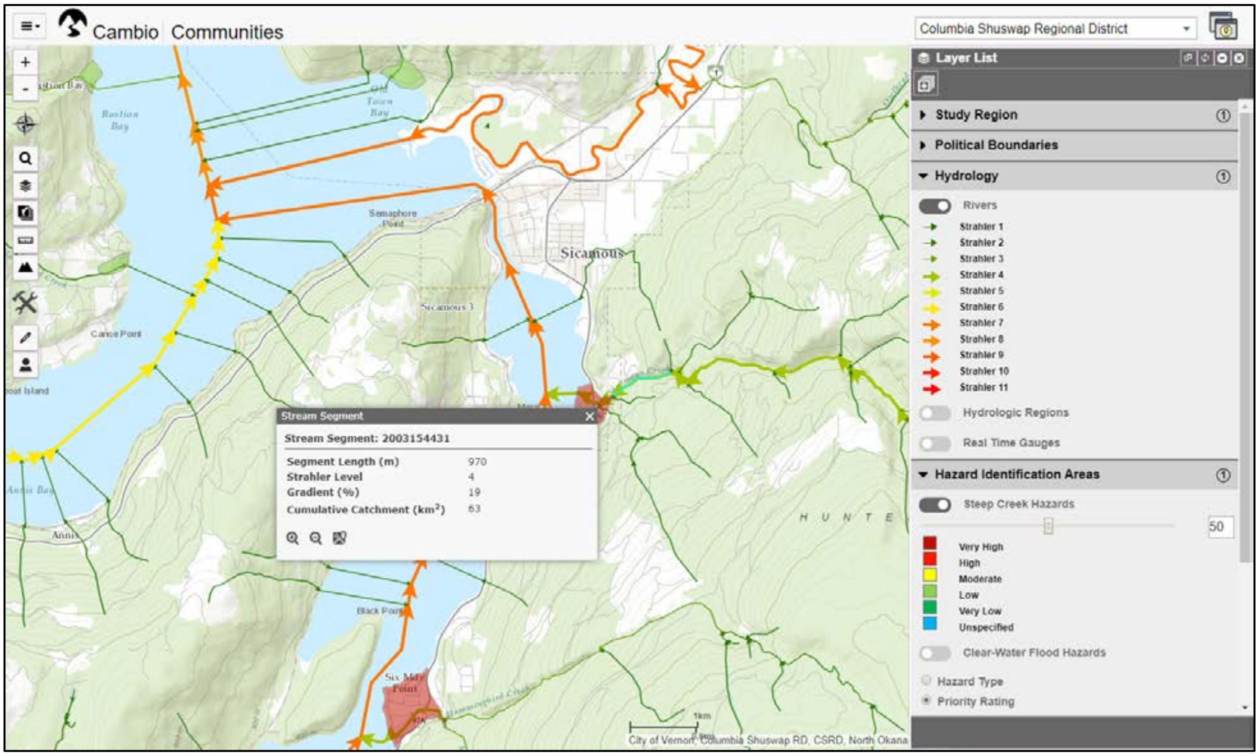

Figure A-7. Interactive Stream Network. The popup shows information for the stream segment highlighted in green.

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.

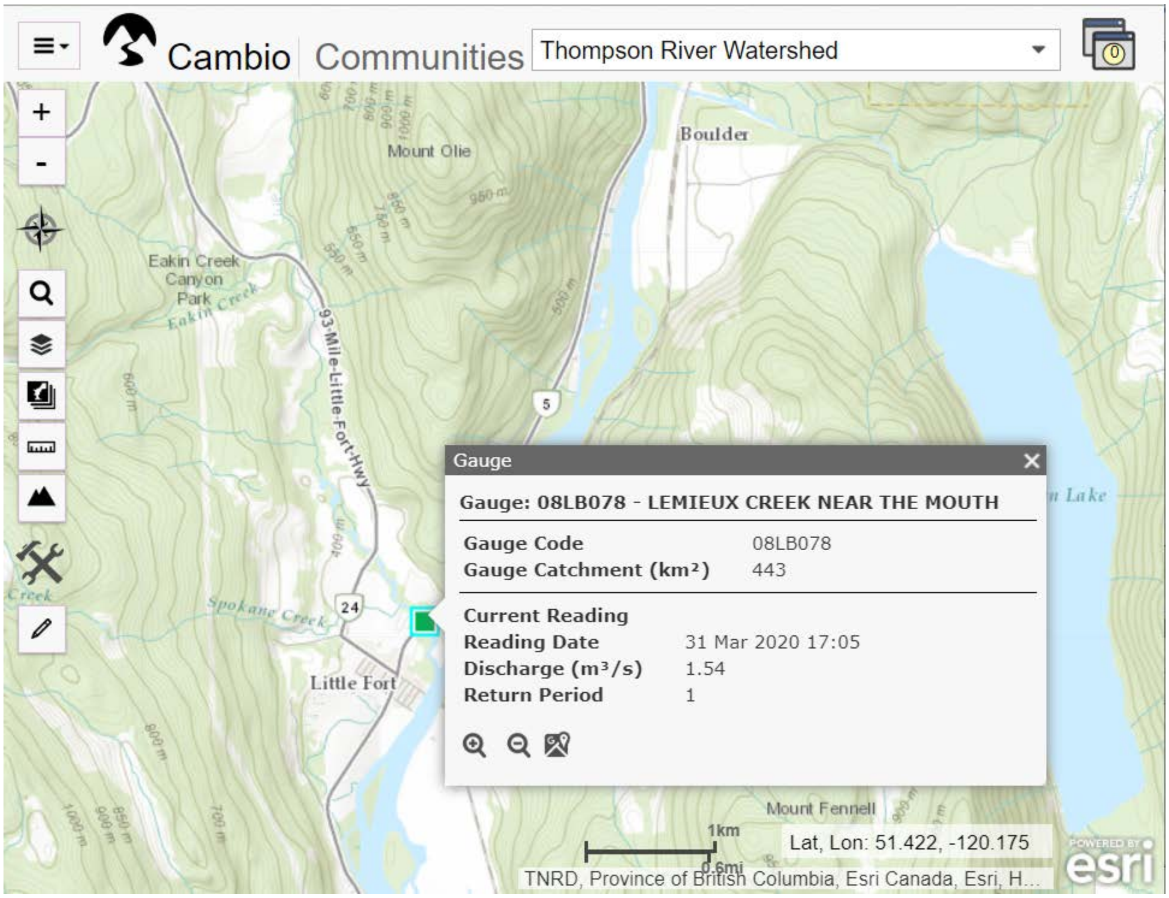

Figure A-8. Near real-time flow gauge. The popup shows gauge information including measured discharge and return period for a given reading date and time.

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.

APPENDIX B
STUDY METHODOLOGY

B.1. INTRODUCTION

This appendix provides an overview of the approach used by BGC to develop the hydrological and hydraulic models for the TRW Base Level Flood Hazard Mapping. This appendix is organized as follows:

- Section B.2 provides a summary of the hydrological methods and models used to determine the peak discharges used in the models.
- Section B.3 provides a summary of the hydraulic modelling used to determine the inundation extents and flow depths for each of the study areas based on the peak discharges.
- Section B.4 provides a summary of the hazard mapping developed from the hydrological and hydraulic modelling.

B.2. HYDROLOGICAL ANALYSIS AND MODELLING

B.2.1. Flood Frequency Analysis

Peak discharges for the 200-year flood (Annual Exceedance Probability of 0.005) used as inputs to the hydraulic models were determined through statistical analysis of historical streamflow records (e.g., streamflow discharges collected at Water Survey of Canada (WSC) hydrometric stations[1]). The hydrological analysis for the creeks and rivers in this study fell into one of three categories:

- Gauged rivers and creeks with enough historical streamflow records to provide a reasonably accurate estimate of the 200-year flood
- Gauged rivers and creeks without enough historical streamflow records to provide a reasonably accurate estimate of the 200-year flood.

For the first case a single-station flood frequency analysis was performed using the historical streamflow records. For the second and third cases, a regional flood frequency analysis was performed.

For the first case, a single station flood frequency analysis (single-station FFA) was performed using the streamflow data at the gauge to determine the 200-year peak instantaneous discharge (Q_{i200}). The single-station FFA was performed using the annual maximum series (AMS) using the maximum peak instantaneous discharges recorded at the station[2]. The Generalized Extreme Value (GEV) probability distribution function was fit to the AMS. The parameters of the distribution were calculated using the *L*-moments method of inference.

[1] Note that in the Regional Flood Frequency Analysis, streamflow data from USGS hydrometric stations were also used.

[2] For cases where there were missing instantaneous peak discharges from the AMS, but peak daily discharges were available, a model was built to interpolate the peak instantaneous discharge from the peak daily discharge.

For creeks and rivers for which the streamflow measurements are insufficient, a regional flood frequency analysis (Regional FFA) using the *L*-moments method and annual maximum series (AMS) of maximum peak instantaneous discharge was used. The Regional FFA was performed using the index-flood method. The index-flood method involves the development of a dimensionless regional growth curve assumed to be constant within a homogenous hydrological region. The index-flood method also requires the selection of an index-flood used to scale the regional growth curve for the specific watershed. The index flood can be the mean annual flood, the median annual flood, or another quantile of choice. In this study the mean annual flood was used for the index flood. To estimate the 200-year flood using the index flood method, the following relationship was used:

$$Q_{i200} = Q_{index}X_{200} \quad \text{[Eq. 1]}$$

Where Q_{i200} is the 200-year peak instantaneous discharge, Q_{index} is the index flood magnitude and X_{200} is the growth factor for the 200-year flood from the regional growth curve.

For each site where a Regional FFA was required, catchment descriptors used to describe the characteristics of the watershed were developed. These catchment descriptors were based on features thought likely to influence the magnitude of flood events such as the catchment area, slope, mean annual precipitation/temperature and landcover. The catchment descriptors were used to assign the sites in this study to specific hydrological regions.

The index flood (i.e., the mean annual flood) was determined using available streamflow records if the sites were gauged. If the site was ungauged, the index flood was estimated using a multiple linear regression model. Additional details on the regional-FFA are provided in Appendix C, while results of the hydrologic analysis are presented in Table B-1.

Table B-1. 200-year peak flow instantaneous flow estimates for study creeks.

Site	Watercourse (Area)	District	Method	Q_{i200} (m^3/s)
1	Thompson River (Kamloops Area)	TNRD	Single Station 08LF051	3840
2	North Thompson (Vavenby to Kamloops)	TNRD	Single Station 08LB064	2970
3	South Thompson River (Kamloops to Chase)	TNRD	Single Station 08LE031	1740
5	Nicola/Coldwater Rivers (Nicola Lake to Spences Bridge)	TNRD	Single Station 08LG006	420 (500)[1]
7	Chase Creek (Chase)	TNRD	Regional FFA with index flood based on 08LE112	72
12	Thompson River/Kamloops Lake (Savona to Ashcroft)	TNRD	Single Station 05LF051	3880
13	Bonaparte River (Cache Creek)	TNRD	Single Station 08LF002	110
14	Cherry Creek	TNRD	Regional FFA using quantile regression on 08LF009, 08LG056 and 08LF094[2]	13
15	Thompson River (Spences Bridge to Lytton)	TNRD	Single Station 05LF051	4370
16	Thompson River (Ashcroft to Spences Bridge)	TNRD	Single Station 05LF051	4140
18	Spius Creek	TNRD	Single Station 08LG008	270 (330)[1]
9	Bridge Creek (Camin Lake to 100 Mile House)	CRD	Single Station 08LA020	780

Notes:

1. Climate adjusted peak discharge with additional 20%.
2. The Qi200 was determined using quantile regression using the selected gauges reported in McElhanney (2019).Cherry Creek has a number of reservoirs in the watershed which decrease the mean annual flood but are not likely to impact the magnitude for larger return periods. For this reason the index flood method which requires an accurate estimate of the mean annual flood was not suited for estimating the peak discharges for this watershed.

B.2.2. Climate Change Considerations

Climate change is expected to have an impact on the magnitudes of the peak flows. The EGBC (2018) guidelines provide guidance for adjustment of peak flows to be used in detailed floodplain assessments. BGC recently completed detailed flood mapping several rivers in the Regional District of Central Kootenay (RDCK). For those studies, BGC performed an assessment of climate change using both statistical and process-based methodologies as per the EGBC (2018) guidelines, as well as quantitative consideration of climate change variables in the Regional FFA. This quantitative analysis, while not conclusive, supported a 20% upwards adjustment of flood quantiles. Therefore, the peak discharges estimated for the Nicola River and Spius Creek were adjusted upwards by 20%.

Climate change considerations were not accounted for at the other sites, as a lower resolution DEM was used which limits the overall accuracy of the results. It was felt that accounting for the changes in peak discharges due to climate change would have limited meaning relative to the uncertainty and resolution of the coarse DEM used at the other sites.

B.2.2.1. Peak Discharges at Model Boundaries

The results of the FFA were used to determine the peak discharges at the model boundaries. A majority of the FFA's completed for this study were single station assessments. As the location of these gauges are not necessarily at the location where the peak discharges need to be estimated, the peak discharges need to be adjusted. This was done by pro-rating the peak discharges based on the ratio of the catchment areas:

$$\frac{Q_{ungauged}}{Q_{gauged}} = \left(\frac{A_{ungauged}}{A_{gauged}}\right)^n \quad \text{[Eq. 2]}$$

where Q is the peak discharge, A is the watershed area for the gauged and ungauged watersheds, and n is an exponent whose value depends on the watershed area (Table B-2).

For sites where the peak discharges did not change significantly along the length of the model domain, the peak discharges were pro-rated to the outlet of the model. In cases where there was a significant contribution to the peak discharges along the model domain (e.g., a large tributary), the downstream peak discharge was pro-rated to specific locations along the domain where inflow boundaries to the model could be accommodated (e.g., at tributaries.).

Table B-2 Approximate watershed area exponents for transferring extreme flood data Transportation Association of Canada (2004).

Watershed Area (km^2)	Exponent, n
10 – 100	0.80
100 – 1000	0.65
1000 – 10,000	0.50
10,000 – 100,000	0.35
100,000 – 1,000,000	0.20

B.2.3. Hydraulic Modelling

B.2.3.1. Modelling Software

The HEC-RAS version 5.0.7 hydraulic modelling system was used to obtain the water surface elevations, depth of inundation, inundation extents and flow velocities. HEC-RAS is a public domain hydraulic modelling program developed and supported by the United States Army Corps of Engineers (Brunner & CEIWR-HEC, 2016). This version of HEC-RAS supports both one-dimensional (1D) and two-dimensional (2D) hydraulic modelling.

For this study, a 2D hydraulic model was selected. The 2D model is suited for the rivers and creeks in study areas which includes complex flow pathways. The 2D model also provides more detailed information on the flow depths and velocities than a 1D model. A 2D model also removes some of the subjective modelling techniques, which are involved in the development of 1D models.

A limitation of 2D models in HEC-RAS 5.0.7 is with the modelling of bridges. While the model can accommodate box culverts, the 2D module cannot model high flows at bridges (i.e., when the water surface elevation is greater than the low cord of the bridge). Incorporation of bridge piers can be accomplished within the 2D flow area using fine mesh elements, but it comes at a significant computational cost. Since bridges are not included within base-level flood hazard mapping, this model limitation was not an issue.

B.2.3.2. Modelling Development

Separate models were developed for all of the sites. A 2D HEC-RAS model consists of the following elements:

<u>Model Domain</u>

The model domain defines the outer perimeter or extent of the model. The domain was selected such that it covered the specified area for each site. Checks were made to ensure that the lateral extent of the domain covered the entire floodplain and the flow was not constrained by the sides of the model domain. For sections along the Thompson River, the model domain was specified such that there was overlap along adjacent modelling regions to accommodate the inflow and outflow boundary conditions.

<u>Model DEM and Terrain</u>

The models used the topographic data from Canadian Digital Elevation Model (CDEM) except for the Nicola/Coldwater Rivers where airborne lidar was available. The base resolution of the CDEM is 0.75 arc second along a profile in the south-north direction and varies from 0.75 to 3 arc seconds in the east-west direction, depending on location. For the TRW, this yields approximately a 20 m grid cell resolution (Government of Canada, 2016). For the Nicola/Coldwater Rivers, the lidar ground points were processed to create a DEM with a 1 m grid cell resolution. Bridges decks were removed from the DEM across the study area.

Additional processing of the CDEM was necessary for some of the study areas to remove artifacts from the model – most typically bridge decks. Other artifacts were observed in the CDEM topographic models, but these could not be removed.

Modelling Scenarios

For this project, only modelling of the Q_{i200} in the primary watercourse was considered. The 200-year peak discharges in tributary creeks and rivers were not modelled as this would require additional model runs and assimilation of the results.

Boundary Conditions

The model inflow and outflows were run using steady state hydrographs. The inflow boundary conditions for the model consisted of one or more inflow hydrographs determined as part of the hydrological analysis discussed in the previous section. When the outlet of the model was located on a large waterbody such as a lake, a constant stage or water elevation boundary was used. This was based on the maximum observed water level records for the waterbody in question based on WSC water level gauges. For sites ending along a river segment, a normal depth boundary condition based on the slope of the channel at the outlet was applied.

Computational Mesh

The HEC-RAS software for 2D modelling uses an irregular mesh to simulate the flow of water over the terrain. Irregular meshes are useful for development of numerically efficient 2D models to allow refinement of the model in locations where the flow is changing rapidly and/or where additional resolution is desired. With 2D models the objective is to define a model with sufficient accuracy and resolution that minimizes model runtime.

The default cell geometries created by HEC-RAS are rectangular but other geometries can be selected to suit the problem under consideration. Within HEC-RAS, a 2D mesh is generated based on the following inputs:

- The model perimeter (the model domain or extent of the model).
- Refinement areas to define sub-domains where the mesh properties (e.g., mesh resolution) is adjusted.
- Breaklines to align the mesh with terrain features which influence the flow such as dikes, ditches, terraces and embankments. HEC-RAS provides options to adjust the mesh resolution along breaklines if the modeler chooses.

From these inputs, HEC-RAS generates the mesh consisting of computational points, typically at the cell centroid, and the faces of the cells, for which hydraulic properties are computed prior to simulation runs. The meshing requirements for each site varied depending on the size of the domain, the steepness of the water course and the resolution of the DEM.

Manning's n Roughness

The resistance of the channel to the conveyance of flow through surface friction from the bed materials and form drag (e.g., vegetation, bedforms) is modelled in HEC-RAS using the Manning's n roughness coefficient. For detailed floodplain mapping, the Manning's n values are typically defined for the main channel and floodplains using available information regarding the channel bed materials and the landcover on the floodplains. These are then calibrated using known high-water events. For base-level floodplain mapping a simple Manning's n value was selected to be applied to both the channels and floodplains. A value of 0.06 was applied to all of the study areas to ensure that the results are generally conservative (the higher the Manning's n the higher the water surface). This value was adjusted upwards for some of the steeper sites to account for the additional frictional losses due to the higher velocities.

B.3. RESULTS

A summary of the models developed for each of the sites is presented in Table B-3. Water surface profiles and flow depths for each modelled area along with brief descriptions are presented in the following sections.

Table B-3. Summary of hydraulic models for each of the sites.

Site No.	Watercourse (Area)	Inflow Boundary	Outflow Boundary	Mesh Resolution
1	Thompson River (Kamloops Area)	North Thompson: 3100 m^3/s South Thompson: 740 m^3/s	Constant Stage: 344.96 m	10 m
2	North Thompson (Vavenby to Kamloops)	Inlet: 1380 m^3/s Raft River: 160 m^3/s Clearwater: 200 m^3/s Lemieux Creek: 100 m^3/s Barrriere River: 130 m^3/s Louis Creek: 41 m^3/s Jameson Creek: 56 m^3/s	Normal Depth	20 m
3	South Thompson River (Chase to Kamloops)	Inlet: 1740 m^3/s	Normal Depth	20 m general mesh, 10 m with 10 cell repeats over river
5	Nicola/Coldwater Rivers (Nicola Lake to Spences Bridge)	Nicola Lake (dam): 110 m^3/s Clapperton Creek: 120 m^3/s Coldwater Creek: 160 m^3/s Guichon Creek: 55 m^3/s Spius Creek: 35 m^3/s[1] Skuhum Creek: 23 m^3/s	Normal Depth on Thompson River 5 km downstream of the confluence with the Nicola River	15 m
7	Chase Creek (Chase)	Inlet: 72 m^3/s	Constant Stage: 348.84 m	20 m general mesh 5 m, 2m and 1m over urbanized areas

Site No.	Watercourse (Area)	Inflow Boundary	Outflow Boundary	Mesh Resolution
12	Thompson River/ Kamloops Lake (Savona to Ashcroft)	Inflow: 3883 m^3/s Tributary: 69 m^3/s	Normal Depth	20 m general mesh, 10 m with 6 cell repeats over river
13	Bonaparte River (Cache Creek)	Inlet 111 m^3/s Tributary 3 m^3/s	Normal Depth	10 m general mesh, 5 m in urbanized areas
14	Cherry Creek	Inlet: 13 m^3/s	Constant Stage: 342.7 m	20 m general mesh 5 m along channels
15	Thompson River (Spences Bridge to Lytton)	Inlet: 4144 m^3/s Tributary: 227 m^3/s	Normal Depth	20 m general mesh, 10 m with 5 cell repeats over river
16	Thompson River (Ashcroft to Spences Bridge)	Inlet: 4144 m^3/s	Normal Depth	20 m general mesh, 10 m with 3 cell repeats over river
18	Spius Creek	Inlet: 326 m^3/s	Constant Stage on Nicola River 3.5 km downstream of the confluence with Spius Creek: 498.29 m	15 m
9	Bridge Creek (Canim Lake to 100 Mile House)	Inlet: 23 m^3/s Buffalo Creek: 9 m^3/s	Constant Stage: 769.23 m	20 m general mesh, 10 m refinement area along river

Note:

1. Estimated using method presented in Section B.2.2.1. Does not correspond to a specific return period. See Site 18 for flood scenario on Spius Creek.

B.3.1. Site 1 – Thompson River (Kamloops Area)

The water surface elevation and the flood depth for Site 1 are shown in Figure B-1 and Figure B-2. The centreline of the model taken from the inlet at the North Thompson River is just over 16 km. The water surface elevation shows a significant change in the profile at station 4000 m. This change in the water surface was caused by a sudden change in the DEM profile along the Thompson River. It was not possible to remove the artifact from the DEM; however the overall impact on the inundation is not anticipated to be significant. The flooding is generally constrained to the immediate shoreline of the river except for downstream of Kamloops, where there is significant flooding of the agricultural areas and wastewater plants along both shores.

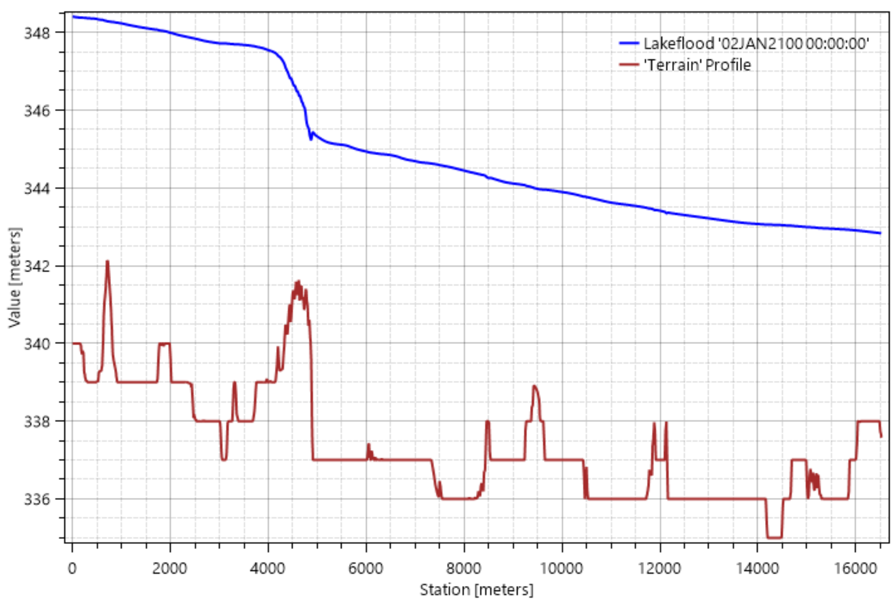

Figure B-1. Water surface elevation for Site 1 – Thompson River (Kamloops Area).

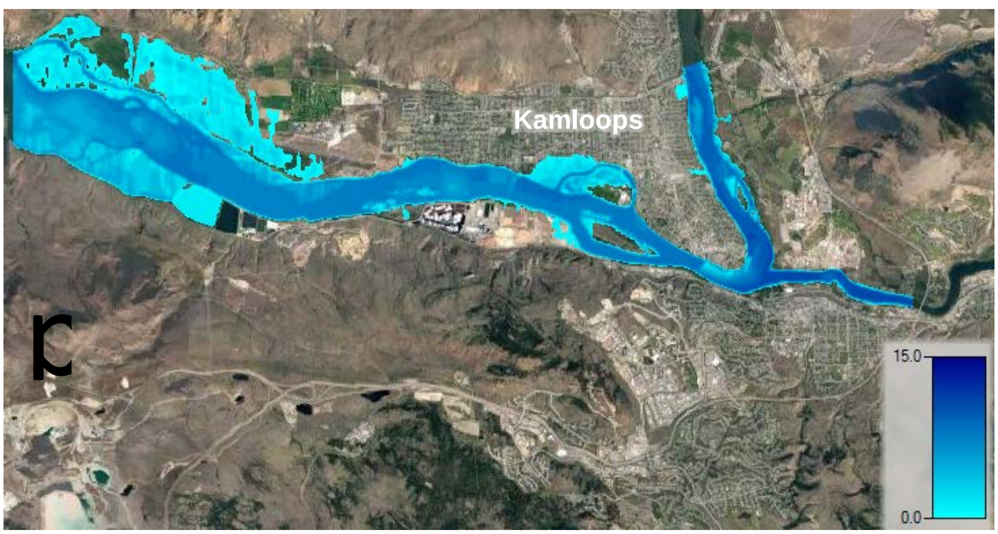

Figure B-2. Flood depth for Site 1 – Thompson River (Kamloops Area).

B.3.2. Site 2 – North Thompson - Vavenby to Kamloops

The water surface elevation and the flood depth for Site 2 are shown in Figure B-3 and Figure B-4. The centreline of the model covers approximately 160 km. The water profile is generally steeper in the upper reaches, then the slope decreases as it approaches the confluence with the South Thompson River. Extensive flooding along the floodplains was noted upstream of the town of Heffley Creek. Downstream from Heffley Creek, the flow becomes more confined within the shoreline of the river.

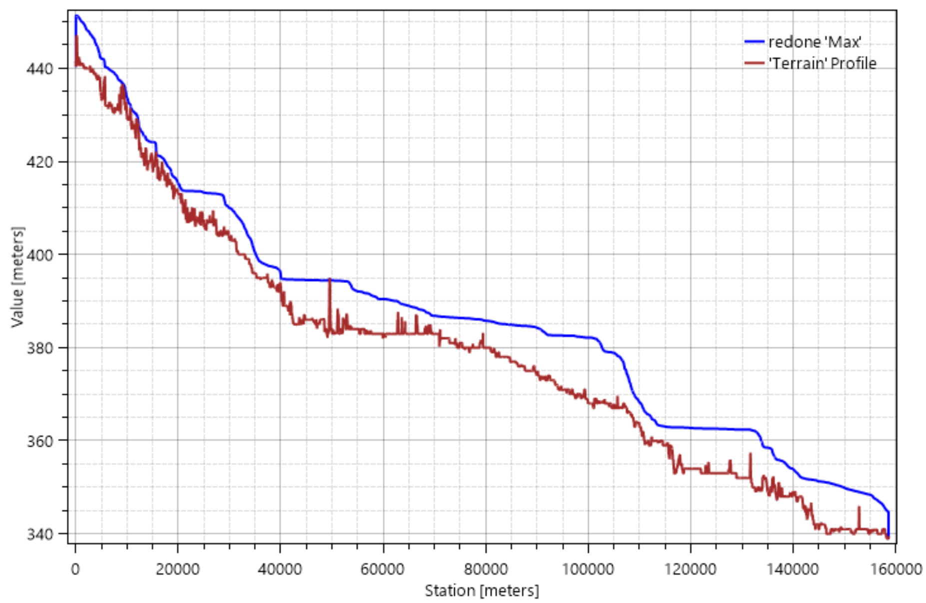

Figure B-3. Water surface elevation for Site 2 – North Thompson (Vavenby to Kamloops).

Figure B-4. Flood depth for Site 2 – North Thompson (Vavenby to Kamloops).

B.3.3. Site 3 – South Thompson River (Chase to Kamloops)

The water surface elevation and the flood depth for Site 3 are shown in Figure B-5 and Figure B-6. The centreline of the model covers approximately 60 km. The flow is generally well contained within the shoreline of the river with some flooding of rural areas south of Chase and west of Monte Creek. There is an initial drop in the water surface profile where the model transitions from Little Shuswap Lake into the South Thompson River at the town of Chase.

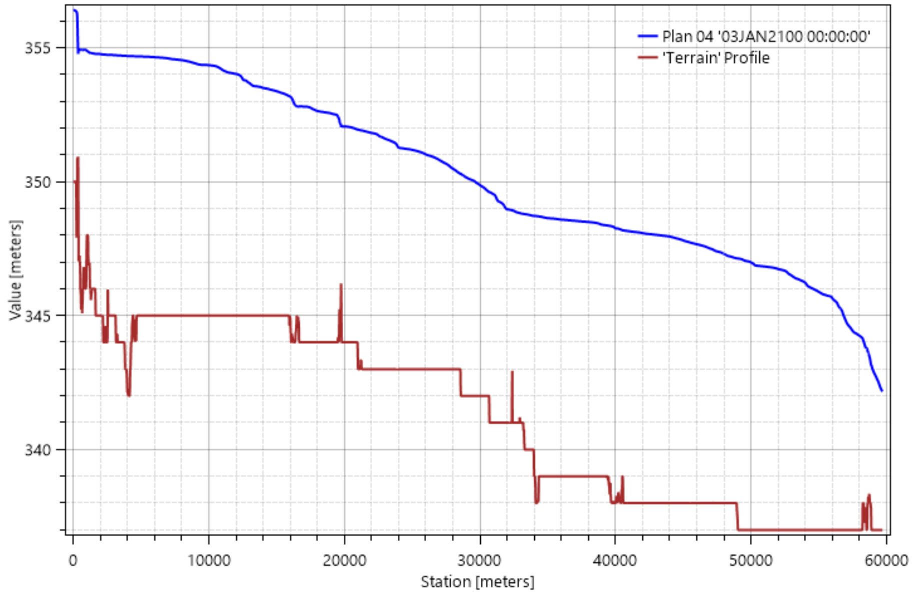

Figure B-5. Water surface elevation for Site 3 – South Thompson River (Chase to Kamloops).

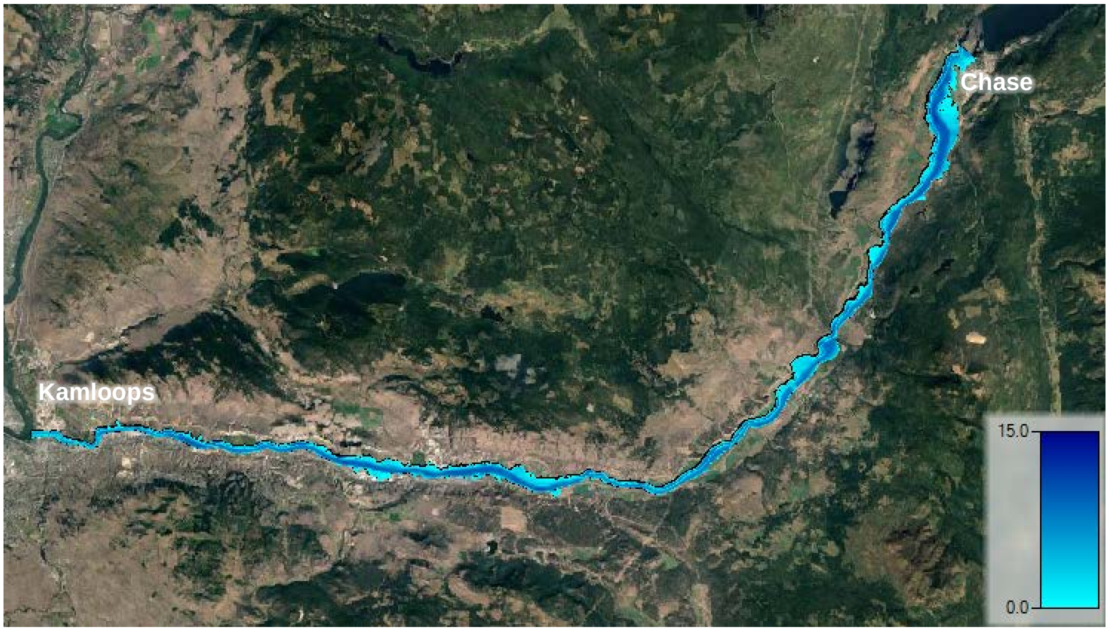

Figure B-6. Flood depth for Site 3 – South Thompson River (Chase to Kamloops).

B.3.4. Site 5 – Nicola/Coldwater Rivers (Nicola Lake to Spences Bridge)

The water surface elevation and the flood depth for Site 5 are shown in Figure B-7 and Figure B-8. The model terrain was built using lidar points and resampled to a 1 m grid resolution. The model mesh was created using a 15 m cell size and breaklines along important topographical features with the same mesh resolution. The centreline of the Nicola River is approximately 100 km along the thalweg.

The reach between Nicola Lake and Merritt is highly sinuous. The channel gradient increases along the centreline downstream of Merritt. The Coldwater River is located approximately at station 27 km and the channel gradient increases downstream of the confluence. Guichon Creek flows into the Nicola River approximately at station 36 km and there is a slight increase in the Nicola River channel gradient. Spius Creek flows into the Nicola River approximately at station 50 km and an increase in the gradient of the Nicola River is observed. Skuhum Creek flows into the Nicola River approximately at station 75 km and an increase in the gradient of the Nicola River is observed. The channel gradient between station 75 km and the mouth (station 100 km) is generally the same.

The 200-year flood is predicted to cause flooding between the Nicola Lake Dam and Merritt. The Nicola Cutoff Road is flooded at multiple locations along with agricultural lands at lower elevation near the river. The Coquihalla Highway in Merritt is not predicted to be impacted, although the bridge opening was not modelled and flooding upstream could be exacerbated if the flow exceeds the bridge capacity. In Merritt, flooding is predicted along the Nicola River and the Coldwater River. Highway 5A (Voght Street) and Highway 8 (Nicola Avenue) are both flooded around their bridge crossings of the Nicola River. The Coldwater River is predicted to flood the following areas but not limited to (enumerated from upstream to downstream):

- Moon Shadows RV Park and Campground
- Properties between the right bank (northeast) of the river and Pooley Avenue
- Sawmills on both sides of the river
- Garcia Street up to Coldwater Avenue
- Claybanks RV Park
- From the right bank to the corner of Quilchena and Cleasby Street
- Government Avenue
- Wastewater treatment plant (1298 Coldwater Avenue) and infiltration ponds (Pine Street).

The Nicola, Kamloops & Similkameen Railway is flooded at multiple location along the Nicola River.

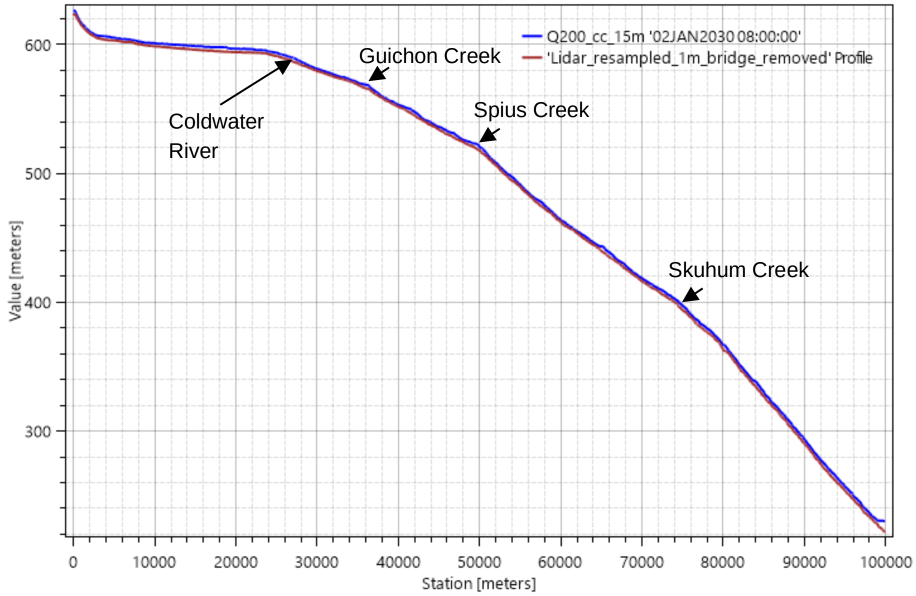

Figure B-7. Water surface elevation for Site 5 – Nicola/Coldwater Rivers.

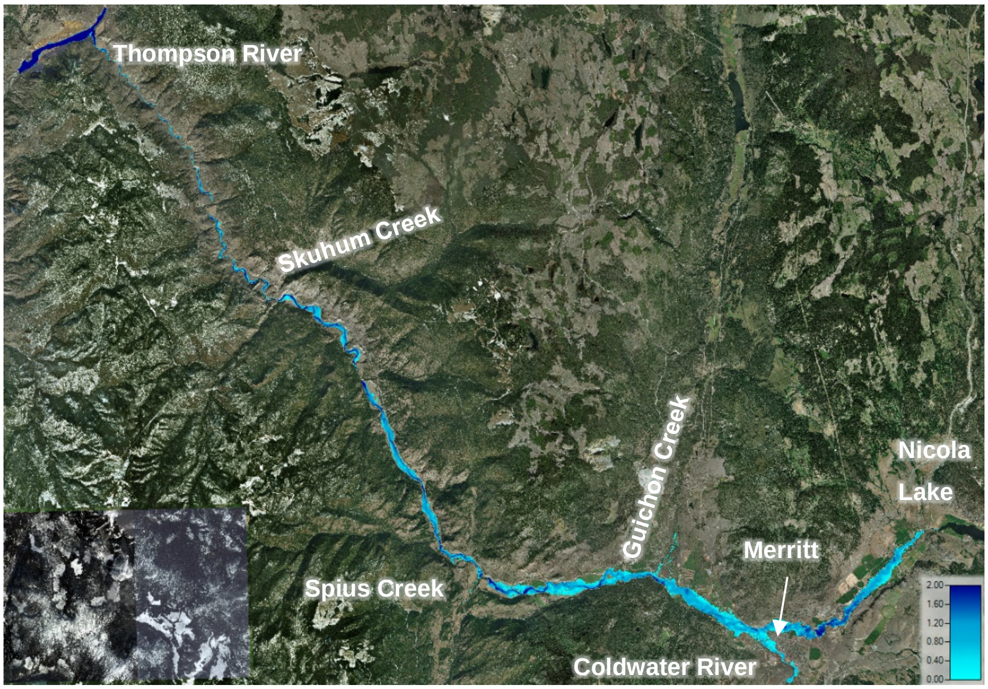

Figure B-8. Flood depth for Site 5 – Nicola/Coldwater Rivers.

B.3.5. Site 7 – Chase Creek

The water surface elevation and the flood depth for Site 7 are shown in Figure B-9 and Figure B-10. The model is one of the smaller sites with the centreline of the model covering approximately 4 km. The upper 1 km of the model is very steep, and the flooding is constrained by the steep valley walls. As the creek passes the Trans-Canada Highway and flows through Chase, the flood width increases, and a separate branch avulses just downstream of 2nd Avenue.

The actual flow path through urban areas is often determined by small scale topographic elements (e.g., roadways, curbs, etc.), which are below the resolution of the DEM. Therefore, the actual flooding extent and path through this area is highly uncertain.

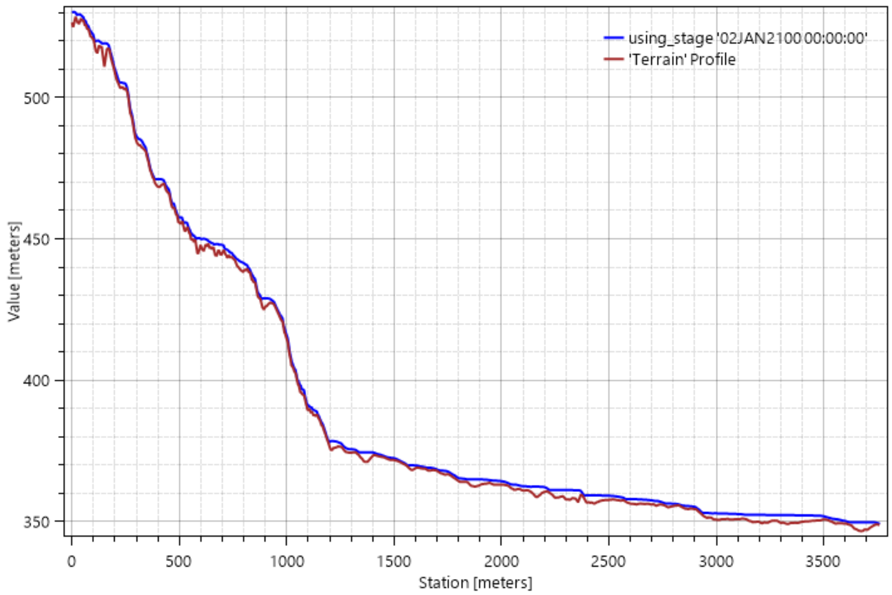

Figure B-9. Water surface elevation for Site 7 – Chase Creek.

Figure B-10. Flood depth for Site 7 – Chase Creek.

B.3.6. Site 12 – Thompson River / Kamloops Lake (Savona to Ashcroft)

The water surface elevation and the flood depth for Site 12 are shown in Figure B-11 and Figure B-12. The centreline of the model covers approximately 39 km. The water surface profile and the channel gradient are generally consistent throughout the model extent. Flooding of properties adjacent the river shoreline was noted. The flooding was generally limited to the shoreline of the river banks.

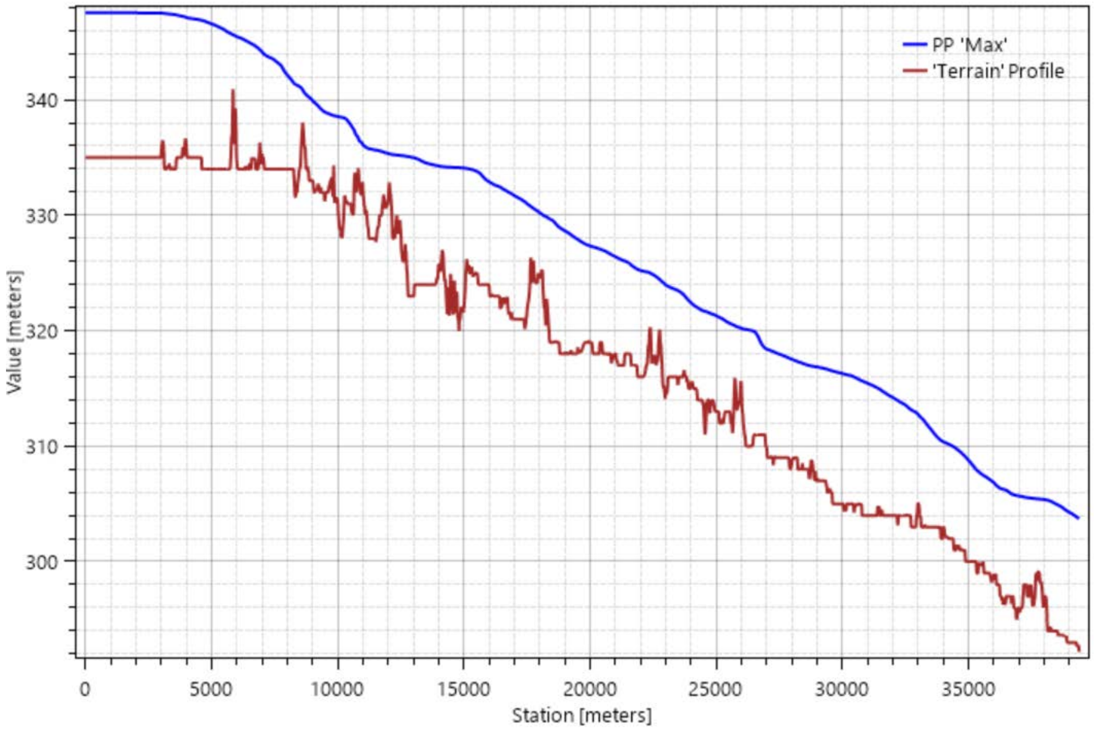

Figure B-11. Water surface elevation for Site 12 - Thompson River/Kamloops Lake (Savona to Ashcroft).

Figure B-12. Flood depth for Site 12 – Thompson River / Kamloops Lake (Savona to Ashcroft).

B.3.7. Site 13 – Bonaparte River (Cache Creek)

The water surface elevation and the flood depth for Site 13 are shown in Figure B-13 and Figure B-14. The centreline of the model covers approximately 17.5 km. The water surface profile and terrain have an initially shallow slope which becomes progressively steeper with a noticeable drop at station 12 km. Flooding of a significant portion of the properties adjacent to the river shoreline in the Village of Cache Creek was noted.

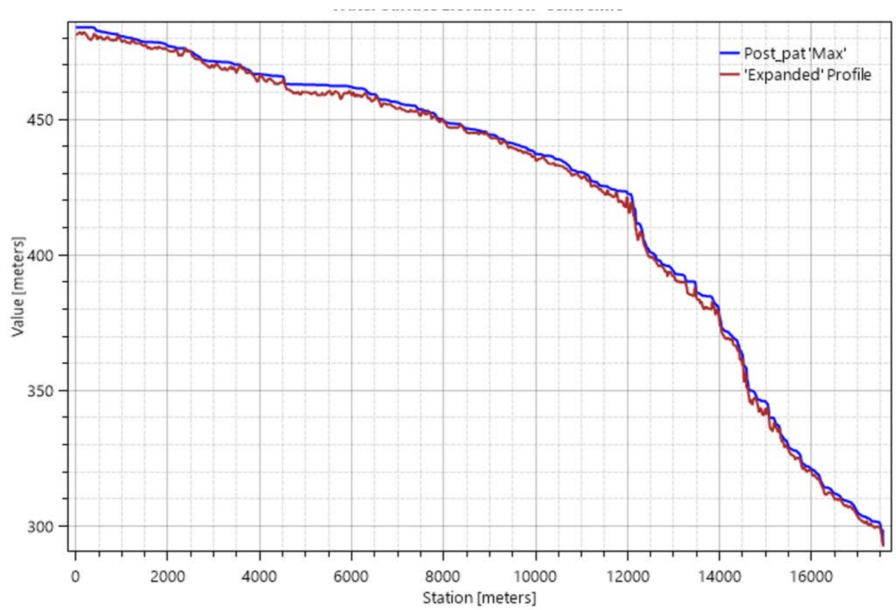

Figure B-13. Water surface elevation for Site 13 – Bonaparte River (Cache Creek).

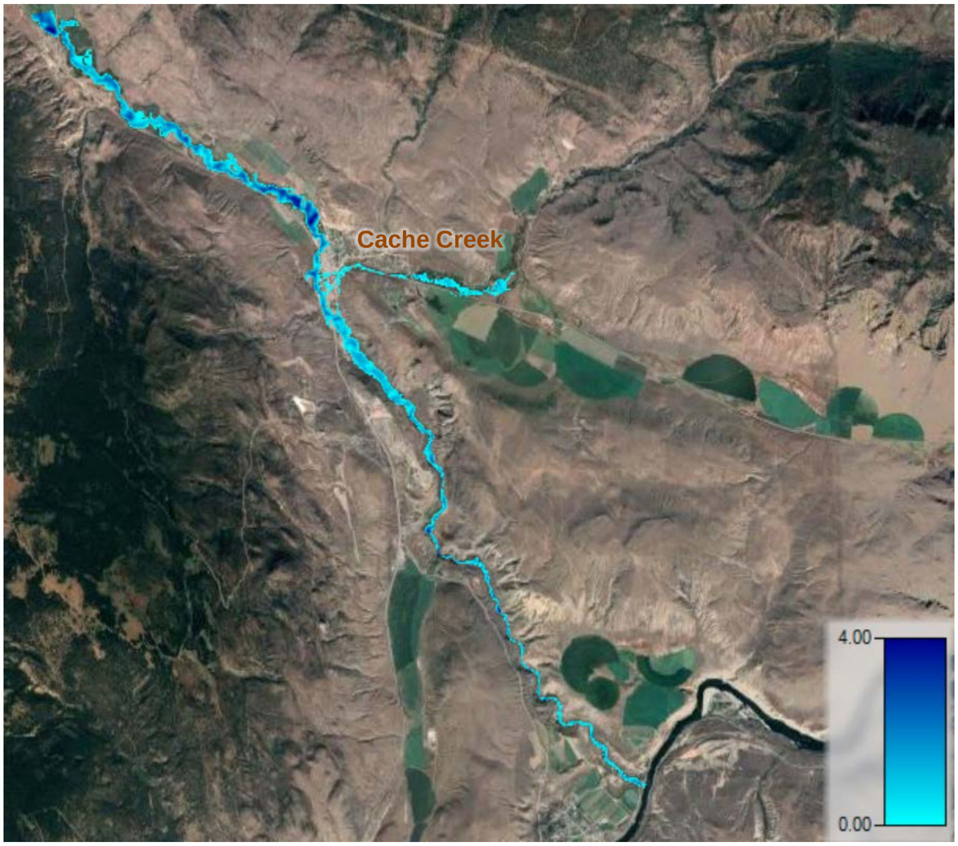

Figure B-14. Flood depth for Site 13 – Bonaparte River (Cache Creek). Note: approximately 6 km of the Cache Creek tributary was included in the model however the results are not included in the results as the resolution of the DEM is insufficient to properly resolve the flows properly.

B.3.8. Site 14 – Cherry Creek

The water surface elevation and the flood depth for Site 14 are shown in Figure B-15 and Figure B-16. The centreline of the model covers approximately 13 km. The water surface profile and terrain have an initially shallow slope with a sharp drop at station 12 km approaching the entrance to Kamloops lake. The flooding is generally constrained to the immediate shoreline of the river except for an agricultural area about 750 m south of the shore of Kamloops Lake where there is more extensive flooding.

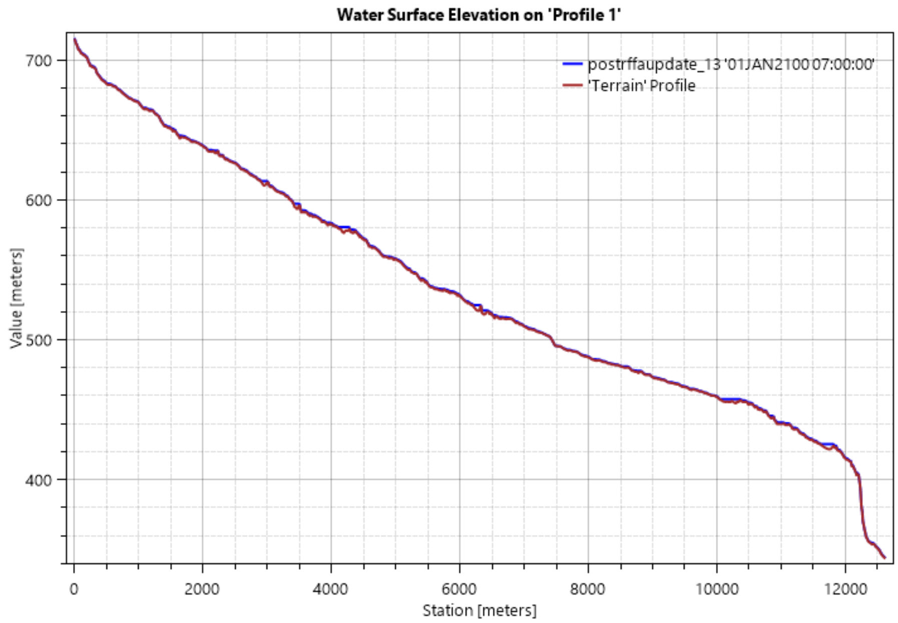

Figure B-15. Water surface elevation for Site 14 – Cherry Creek.

Figure B-16. Flood depth for Site 14 – Cherry Creek.

B.3.9. Site 15 – Thompson River (Spences Bridge to Lytton)

The water surface elevation and the flood depth for Site 15 are shown in Figure B-17 and Figure B-18. The centreline of the model covers approximately 41 km. The water surface profile and channel gradient are generally consistent throughout the model extent with the exception of plateaus from Station 6 km to 14 km and 32 km to 36 km. Flooding of properties adjacent the river shoreline was noted.

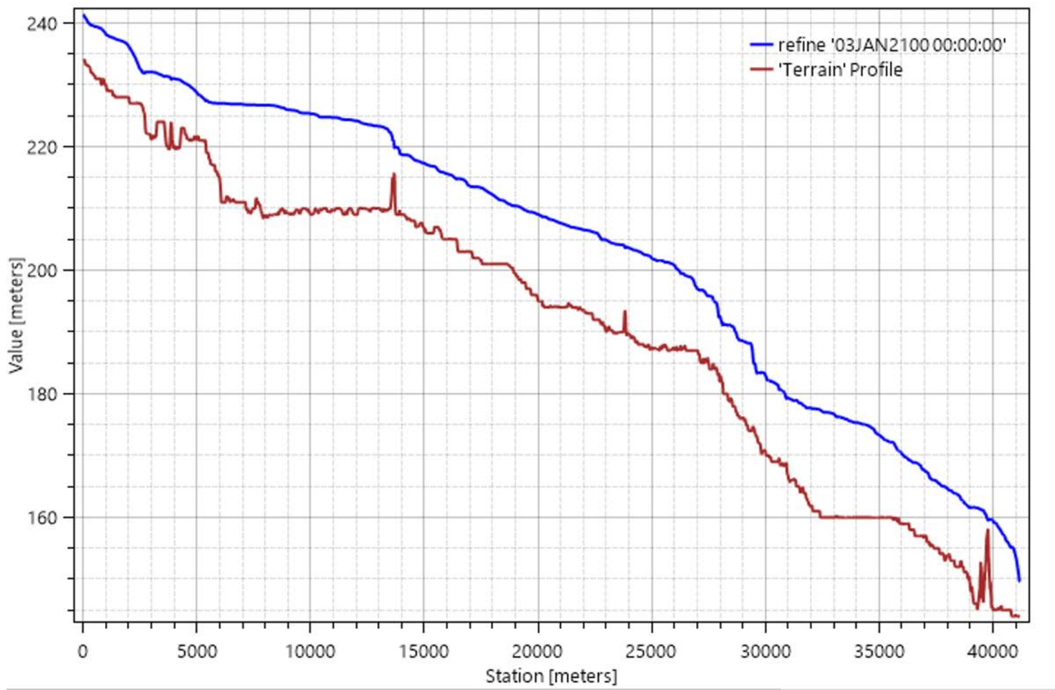

Figure B-17. Water surface elevation for Site 15 – Thompson River (Spences Bridge to Lytton).

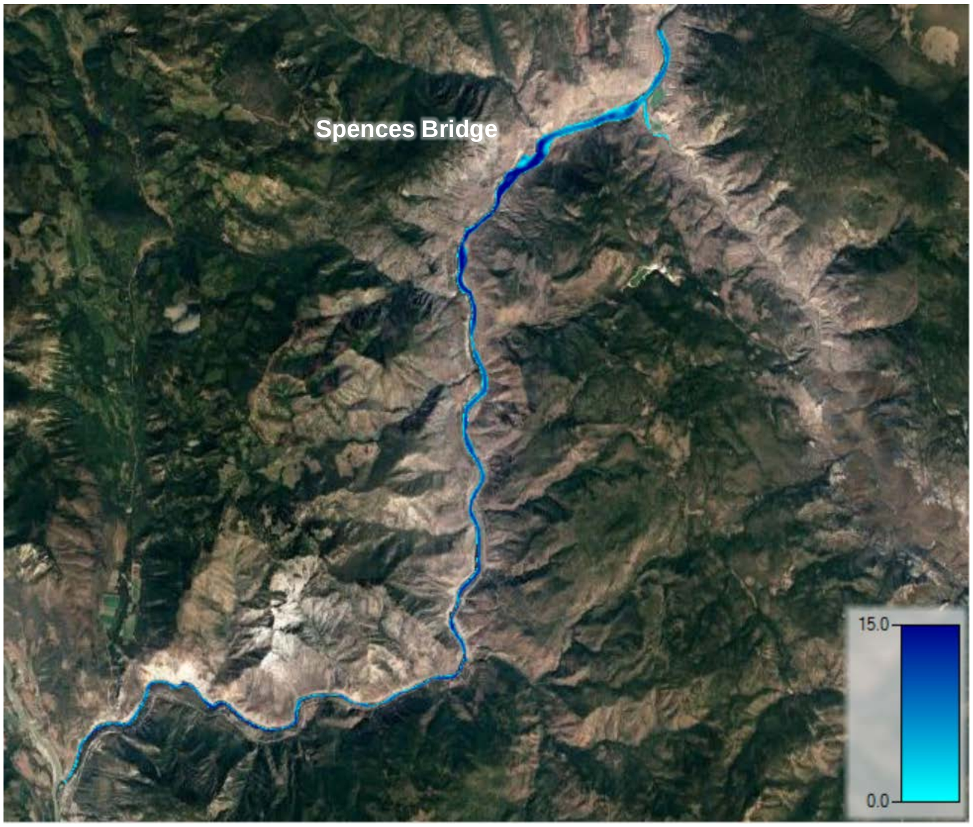

Figure B-18. Flood depth for Site 15 – Thompson River (Spences Bridge to Lytton).

B.3.10. Site 16 – Thompson River (Ashcroft to Spences Bridge)

The water surface elevation and the flood depth for Site 16 are shown in Figure B-19 and Figure B-20. The centreline of the model covers approximately 43 km. The water surface profile and channel gradient are generally consistent throughout the model extent with the exception of a plateau between stations 20 km to 30.1 km. Flooding of properties adjacent the river shoreline was noted.

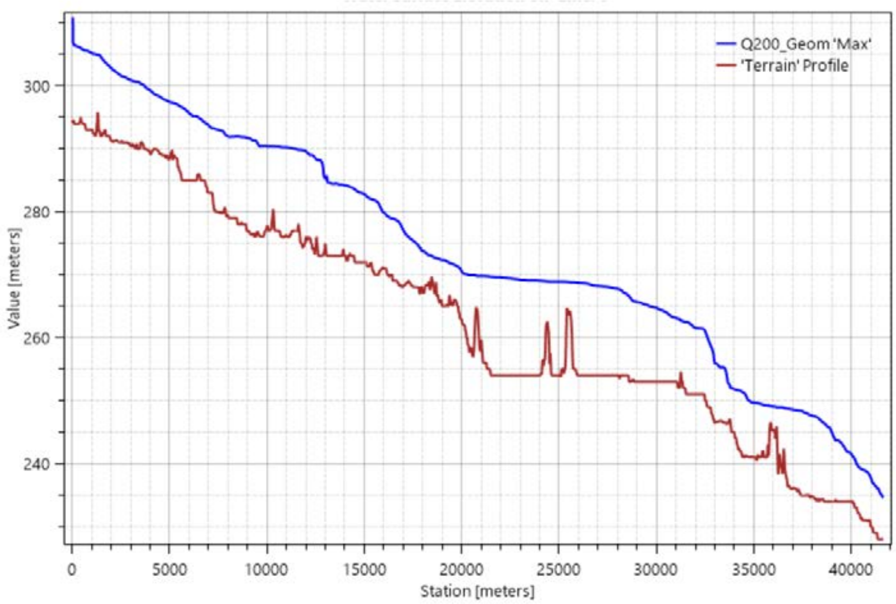

Figure B-19. Water surface elevation for Site 16 – Thompson River (Ashcroft to Spences Bridge).

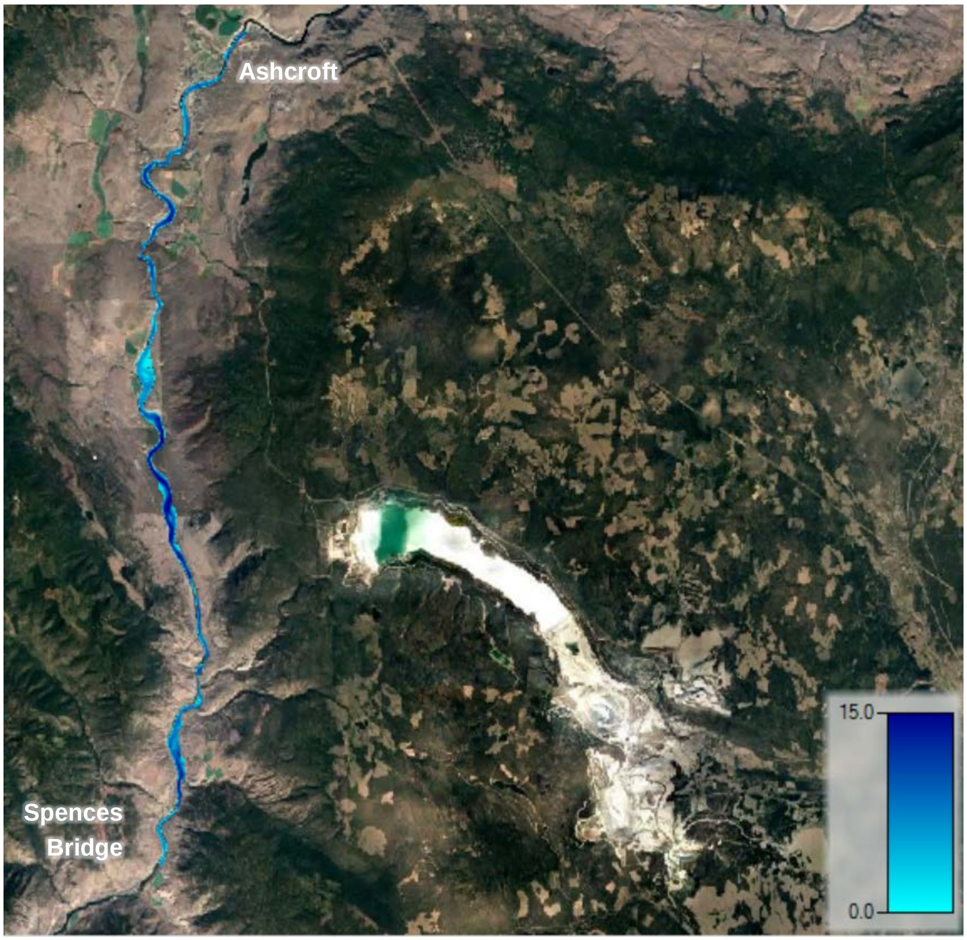

Figure B-20. Flood depth for Site 16 – Thompson River (Ashcroft to Spences Bridge).

B.3.11. Site 18 – Spius Creek

The water surface elevation and the flood depth for Site 18 are shown in Figure B-21 and Figure B-22. The centreline of the model covers approximately 2.5 km. The water surface profile and channel gradient are generally consistent throughout the model extent with the exception of the water surface profile at the mouth that experiences backwater from the flood level on the Nicola River. Flooding of agricultural properties on the left floodplain (northwest) the river shoreline was noted. The Nicola Kamloops & Similkameen Railway is flooded along with Petit Creek Road.

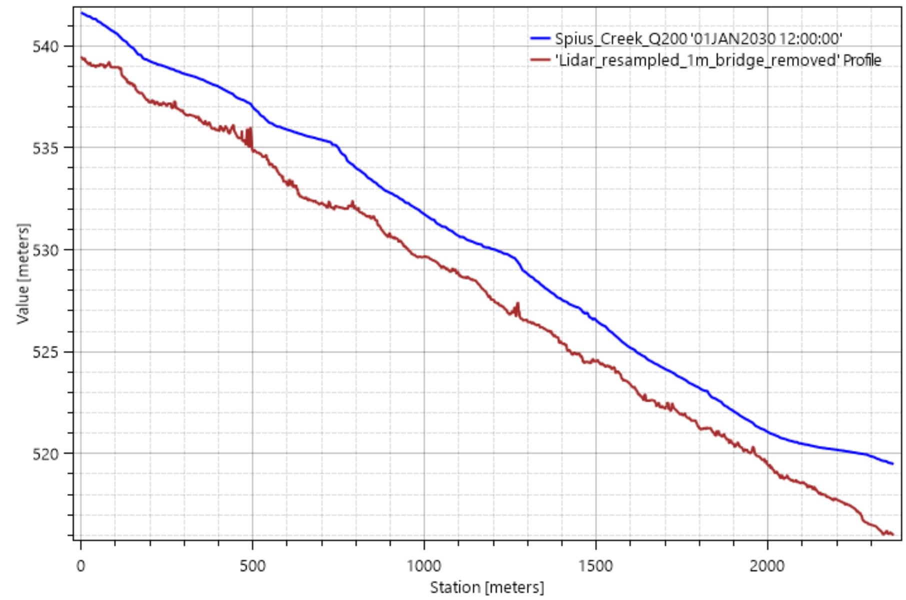

Figure B-21. Water surface elevation for Site 18 – Spius Creek.

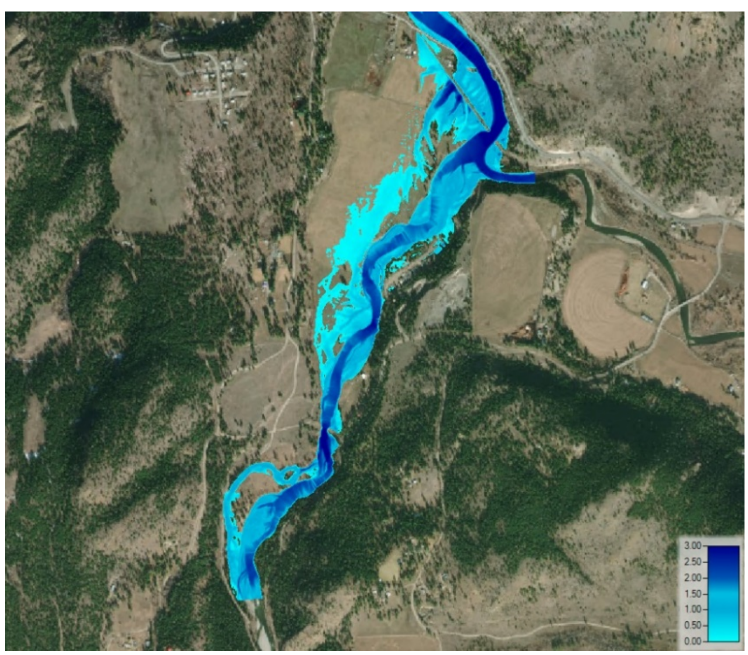

Figure B-22. Flood depth for Site 18 – Spius Creek.

B.3.12. Site 9 – Bridge Creek (Canim Lake to 100 Mile House)

The water surface elevation and the flood depth for Site 9 are shown in Figure B-23 and Figure B-24. The centreline of the model covers approximately 53 km. Between stations 5 km and 12 km the channel's gradient is extremely steep and becomes progressive shallower as it moves downstream. Flooding of properties adjacent the river shoreline was noted along with extensive flooding near the Canim Lake Indian Reserve.

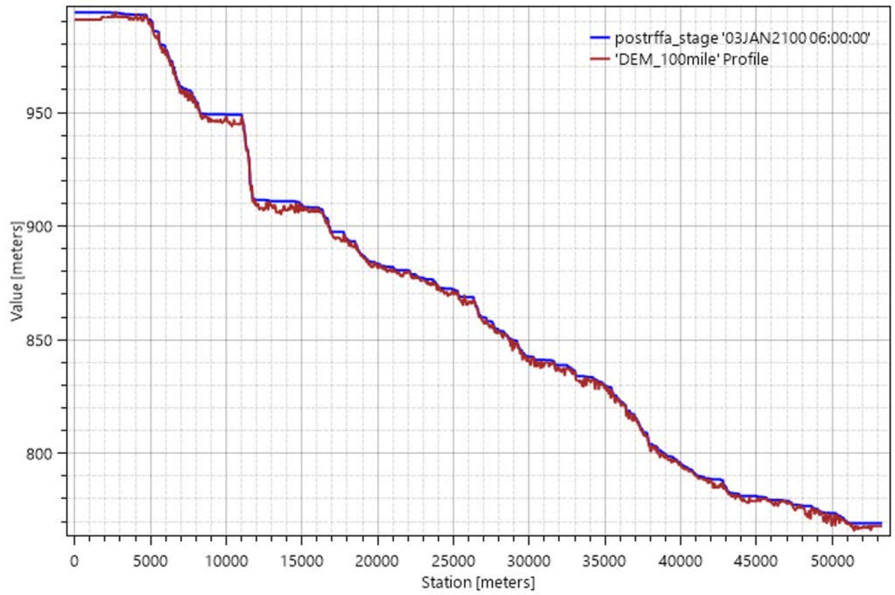

Figure B-23. Water surface elevation for Site 9 – Bridge Creek (Canim Lake to 100 Mile House).

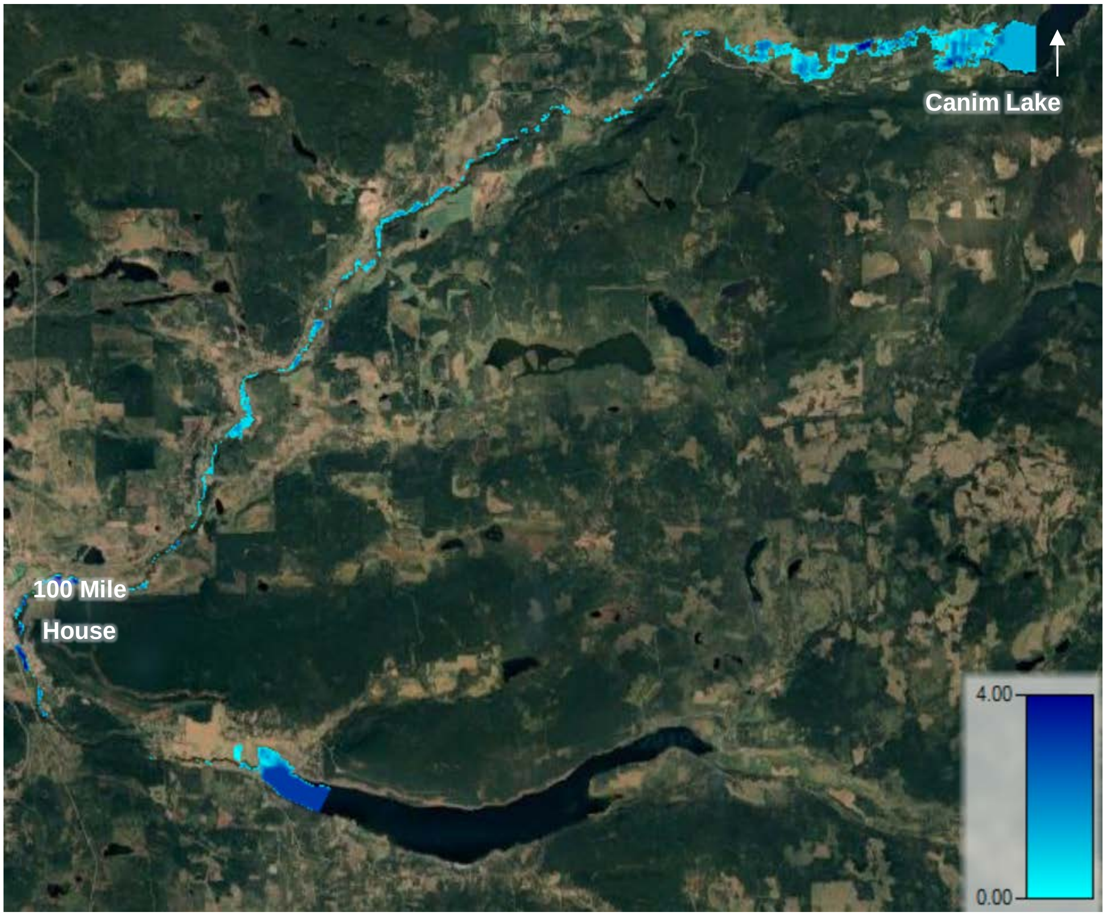

Figure B-24. Flood depth for Site 9 – Bridge Creek (Canim Lake to 100 Mile House).

B.4. HAZARD MAPPING LAYERS

The HEC-RAS models for each of the sites were run until they reached steady state (i.e., the outflow of the model was equal to the total inflows). The results of the models were reviewed and the flow depth at the final time step was exported as a GIS raster layer. The flow depth rasters were reviewed in a GIS and additional cleaning of the results was performed to remove artifacts from the model run. The processed rasters for each site were then classified into discrete peak flood depths (Table B-4) and converted to polygons and imported into Cambio Communities.

Table B-4. Discrete flood depths used for display in Cambio Communities.

Peak Flood Depth above Ground Surface (m)	Symbology in Cambio Communities
< 0.1	
0.1 – 0.3	
0.3 - 1.5	
1.5 – 3	
> 3	

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APPENDIX C
PROPOSED STUDY AREAS

Geohazard Process	Study Area Grouping	Current Assessment Stage	Strategic Project Objective (Future Assessment Stage)	Description of Project Objective	Site No.	Hazard ID (Cambio)	Watercourse (Area)	Project Applicant	Recorded Historical Flooding Events	Comments/Recommendations	Easting (UTM 10)	Northing (UTM 10)
Clear-water flood (watercourse)	Watercourse hazard areas prioritized by BGC (2019)	Hazard identification & priority setting completed	1. Update of clear-water flood hazard identification	Refine regional floodplain identification with new provincial scale floodplain identification analysis completed by BGC (2019 internal, unpublished).	Many (>6000 sites)	Multiple	All clear-water watercourses prioritized by BGC (2019)	CSRD, TNRD, CRD, Merritt, Clearwater, Clinton, Sicamous, Barrière	many (multiple sites)		372665.1381	5641967.9293
			2. New base level clear-water flood hazard assessment and mapping; Risk assessment inputs	Complete new, base level floodplain hazard mapping for high priority floodplains in CRD, CSRD, (BGC 2020a,b), using lidar topography available March 2020 where applicable, and prepare risk assessment inputs.	6	2472	Eagle River (Malakwa to Sicamous)	CSRD	1894, 1948, 1967, 1972, 1982, 2012	Flooding at the western extent of Eagle River is influenced by lake levels on Shuswap and Mara Lakes. Costs for flooding damage in Sicamous area (including steep creeks on Sicamous and Hummingbird Creeks) totalled approximately $3.8M (Public Safety Canada, n.d.). Sicamous completed a hydrological connectivity study and applied for flood mitigation funding for Sicamous Creek.	794390.8201	5648764.5140
					8	Multiple	Salmon River (Falkland to Salmon Arm)	CSRD	1894, 1972, 1999, 2018	Flooding at the northern extent of Salmon River is influenced by lake levels on Shuswap Lake. Adams Lake Indian Band is currently conducting climate modelling for Chase Creek, Salmon River, and others. Lower reaches around Salmon Arm have updated floodplain mapping (2011).	756458.6896	5619080.0570
					41	2434, 2438	Clinton Creek	Village of Clinton	1873	Village of Clinton experienced a debris flow event due to heavy rain in 1873. About 100 m of street was buried in up to 3 m of debris. Costs for flooding damage totalled $51,000 (Septer, 2007).	601439.0000	5662233.0000
					40	2208, 1876, 1769	Clearwater River	District of Clearwater	1928, 1972, 1980, 1997, 1999, 2005 (ice jam)	Past flood events have forced residents to be evacuated (1928 and 1972). Environmental impact due to flooding include loss of salmon spawning in 1980 due to a major flood. In 1991, the cost of flood damage due to road washouts totalled approximately $690,000 (Septer, 2007). In 2005, Community of Birch Island, approximately 12 km north of Clearwater, exereprienced flooding due to ice jams.	702653.1000	5725546.0000
					38	TBD	Fraser River (Quesnel to MacAlister)	CRD	Event compilation in-progress	Flood risk identification and prioritization in-progress	535210.0000	5838802.0000
					34	TBD	Williams Lake River	CRD	Event compilation in-progress	Flood risk identification and prioritization in-progress	559906.3227	5774617.4520
					36	TBD	Chimney Creek	CRD	Event compilation in-progress	Flood risk identification and prioritization in-progress	555915.2048	5768764.7600
					42	TBD	Cottonwood River	CRD	Event compilation in-progress	Flood risk identification and prioritization in-progress	554943.7068	5878205.6300
					43	TBD	Baker Creek	CRD	Event compilation in-progress	Flood risk identification and prioritization in-progress	532627.2923	5869958.5260
					44	TBD	Horsefly River	CRD	Event compilation in-progress	Flood risk identification and prioritization in-progress	608663.5172	5799022.8360
					45	TBD	Nazko River	CRD	Event compilation in-progress	Flood risk identification and prioritization in-progress.	458384.3254	5872812.3300
	TRW study areas with base level floodplain mapping completed by BGC (2020a)	Base level floodplain mapping completed	3. Update of existing clear-water, base level hazard assessments and mapping to incorporate new LiDAR; Risk assessment inputs	Update of existing base level floodplain mapping in TNRD and CRD based on lidar topography available March 2020, and prepare risk assessment inputs.	9	Multiple	Bridge Creek (Camin Lake to 100 Mile House)	CRD	1997, 1999	Flooding in 1999 caused approximately $400,000 in damage including bridge replacement. An ice jam on Bridge Creek near 100 Mile House created localized flooding in 1997. Wildfire near 100 Mile House in 2017 (Gustafsen Fire), mitigation planning underway.	617970.0000	5722817.0000
					1	Multiple	Thompson River (Kamloops Area)	TNRD	1894, 1928, 1936, 1948, 1972, 1974, 1990, 1995, 1997, 1999, 2012, 2014	City of Kamloops updated floodplain maps in 2004. Portion of Tk'emlups te Secwepemc reserve land had floodplain mapped as part of City of Kamloops in 2004. Elephant Hill wildfire burned a portion of the watershed near Ashcroft.	686186.9089	5618548.1090
					2	Multiple	North Thompson (Vavenby to Kamloops)	TNRD	1894, 1928, 1948, 1972, 1990, 1997, 1999, 2005 (ice jam), 2012	TNRD is currently undertaking an official community plan in North Thompson. River is prone to ice jams (2005). Areas with existing floodplain mapping could be considered (e.g., Lower Barriere River has existing floodplain mapping but could be extended to the upper reaches of Barriere River). Additional areas that could be considered for floodplain mapping include Clearwater, Little Fort and 100 Mile House.	701116.0003	5673234.0000
					3	Multiple	South Thompson River (Kamloops to Chase)	TNRD	1894, 1928, 1935, 1948, 1972, 1990, 1996, 1997, 1999, 2012	City of Kamloops updated floodplain maps in 2004. Portion of Tk'emlups te Secwepemc reserve land had floodplain mapped as part of City of Kamloops in 2004. Area could be prioritized lower due to more recent floodplain mapping.	722283.2420	5617956.7530
					5	Multiple	Nicola/Coldwater Rivers (Nicola Lake to Spences Bridge)	TNRD	1894, 1922, 1954, 1974, 1980, 1984, 1991, 1997, 2002, 2017, 2018	Debris and sediment pile up at mouth of Nicola River at Spences Bridge. LiDAR was collected in 2016 for City of Merritt area. Stump Lake previously flooded in 2017 and TNRD is assessing options to manage Stump Lake water levels. Many of the areas in Nicola/Merritt Valley were impacted by 2017 and 2018 flooding. First Nations completed hydrological study in 2015 and has funds for flood mitigation planning.	633275.0000	5570583.0000
					7	Multiple	Chase Creek (Chase)	TNRD	1935, 1948, 1954, 1960, 1972, 1996, 1997	Past flood events from high water levels, Little Shuswap Lake.	732220.2742	5635782.3740
					12	Multiple	Thompson River / Kamloops Lake (Savona to Ashcroft)	TNRD	1894, 1900, 1903, 1948, 1972, 1990	Past flood events from rise of Kamloops Lake and flooding on Deadman Creek. Flooding has caused damage to property within Savona and infrastructure (bridges and railway lines) along Thompson River. Flooding in 1990 caused approximately $50,000 in damage (Septer, 2007).	651607.0578	5624231.9920
					13	Multiple	Bonaparte River (Cache Creek)	TNRD	1866, 1875, 1880, 1990, 1997, 1999, 2015, 2017, 2018	Flooding in 1990 caused approximately $100,000 in damage (Septer, 2007). 40% of Bonaparte River catchment was burned in 2017 Elephant Hill wildfire. Existing floodplain mapping limited to Cache Creek and could be extended to Ashcroft. Cache Creek has secured funding to support flood mapping studies (FBC 2018), which BGC understands are being used for LiDAR data acquisition.	614943.0000	5632557.0000
					14	Multiple	Cherry Creek	TNRD	1997, 2018	Impacts to homes and road washouts during previous flood events.	672536.0001	5614144.0000
					15	Multiple	Thompson River (Spences Bridge to Lytton)	TNRD	1894, 1900, 1946, 1948, 1958, 1972, 1974, 1990, 1999	History of past flood and landslide events along the Thompson River corridor between Spences Bridge to Lytton. In 1899 a landslide event dammed the Thompson River at Spences Bridge.	614062.4457	5572894.0780
					16	Multiple	Thompson River (Ashcroft to Spences Bridge)	TNRD	1881, 1894, 1900, 1903, 1946, 1948, 1960, 1972, 1974, 1982, 1999	History of past flood and landslide events along the Thompson River corridor between Ashcroft to Spences Bridge. Potential for landslide dam induced flooding.	619436.9656	5608894.2100
			4. New detailed clear-water flood hazard assessment and mapping	Complete field surveys and detailed flood hazard mapping (City of Merritt).	46	Multiple	Nicola/Coldwater Rivers at Merritt	Merritt	1894, 1922, 1954, 1972, 1974, 1980, 1981, 1991, 2002, 2017, 2018	History of past floods and related washout (roads and railways) along Nicola River and Coldwater River. In 1894, bridges over Nicola River washed away. In 1922, Nicola River rose an estimated 9 m in less than 20 minutes after an irrigation dam broke due to warm weather causing lake levels to rise. Series of flooding events (1954, 1972, 1974, 1980, 1981) affecting roads and bridges, and causing washouts, including damage to Coldwater Valley roads in 1981 estimated at $250,000 (Septer, 2007). Ice jam between Merritt and Colletville in 1991 affected some 100 residents and up to $1 million worth of damage (Septer, 2007). 2018 event required emergency mitigation works and triggered Disaster Financial Assistance.	656980.0001	5553707.0000
Steep Creek	Selected steep creek hazard areas (fans) in District of Sicamous, District of Barriere and CSRD	Hazard identification & priority setting ongoing	5. New detailed steep creek hazard assessment and mapping	Complete detailed (desktop and field-based) steep creek geohazard assessments and mapping for selected high priority areas; building level hazard exposure modelling.	20	844	Barrière River	Barrière (in TNRD)	1945, 1948, 1972, 1997, 1999, 2005	Past flood events forced residents to be evacuated and reloacted over multiple days (1972). The 1997 flood event damage totalled $100,000 (Septer, 2007). Eighty nine people were affected due to flooding in 1999. Two ice jams caused flooding in Barrière River in 2005.	700420.7614	5674440.4090
					27	1534	Hummingbird and Mara Creeks (near Swansea Point)	CSRD	1997, 2012, and possibly in 1930s	Fan-delta into Mara Lake, high aggradation and avulsion potential, events in 1997, 2012, and possibly in 1930s. Event in 1997 caused extensive damage to homes and cabins.	781234.7582	5631525.2151
					26	1341	Sicamous Creek	Sicamous (in CSRD)	1920s, 1950s, 1997, 2012	Fan-delta into Mara Lake, high aggradation and avulsion potential. Events in 1997 and 2012 avulsed and damaged several homes. Creek was subject of major litigation from 2012 event.	783755.7126	5636105.4860

APPENDIX D
TERMINOLOGY

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

Table D-1. Geohazard terminology.

Term	Definition	Source
Active Alluvial Fan	The portion of the fan surface which may be exposed to contemporary hydrogeomorphic or avulsion hazards.	BGC
Aggradation	Deposition of sediment by a (river or stream).	BGC
Alluvial fan	A low, outspread, relatively flat to gently sloping mass of loose rock material, shaped like an open fan or a segment of a cone, deposited by a stream at the place where it issues from a narrow mountain valley upon a plain or broad valley, or where a tributary stream is near or at its junction with the main stream, or wherever a constriction in a valley abruptly ceases or the gradient of stream suddenly decreases	Bates and Jackson (1995)
Annual Exceedance Probability (P_H) (AEP)	The Annual Exceedance Probability (AEP) is the estimated **probability** that an event will occur exceeding a specified magnitude in any year. For example, a flood with a 0.5% AEP has a one in two hundred chance of being reached or exceeded in any year. AEP is increasingly replacing the use of the term **'return period'** to describe flood recurrence intervals.	Fell et al. (2005)
Avulsion	Lateral displacement of a stream from its main channel into a new course across its fan or floodplain. An "avulsion channel" is a channel that is being activated during channel avulsions. An avulsion channel is not the same as a paleochannel.	Oxford University Press (2008)
Bank Erosion	Erosion and removal of material along the banks of a river resulting in either a shift in the river position, or an increase in the river width.	BGC
Clear–water flood	Riverine and lake flooding resulting from inundation due to an excess of clear-water discharge in a watercourse or body of water such that land outside the natural or artificial banks which is not normally under water is submerged.	BGC
Climate normal	Long term (typically 30 years) averages used to summarize average climate conditions at a particular location.	BGC
Consequence (C)	In relation to risk analysis, the outcome or result of a **geohazard** being realised. Consequence is a product of **vulnerability** (V) and a measure of the **elements at risk** (E)	Fell et al. (2005); Fell et al. (2007), BGC

Term	Definition	Source
Consultation Zone	The Consultation Zone (CZ) includes all proposed and existing development in a geographic zone defined by the approving authority that contains the largest credible area affected by specified **geohazards**, and where damage or loss arising from one or more simultaneously occurring specific **geohazards** would be viewed as a single catastrophic loss.	Adapted from Porter et al. (2009)
Debris Flow	Very rapid to extremely rapid surging flow of saturated, non-plastic debris in a steep channel (Hungr, Leroueil & Picarelli, 2014). Debris generally consists of a mixture of poorly sorted sediments, organic material and water (see Appendix B of this report for detailed definition).	BGC
Debris Flood	A very rapid flow of water with a sediment concentration of 3-10% in a steep channel. It can be pictured as a flood that also transports a large volume of sediment that rapidly fills in the channel during an event (see Appendix B of this report for detailed definition).	BGC
Elements at Risk (E)	This term is used in two ways: a) To describe things of value (e.g., people, infrastructure, environment) that could potentially suffer damage or loss due to a **geohazard**. b) For risk analysis, as a measure of the value of the elements that could potentially suffer damage or loss (e.g., number of persons, value of infrastructure, value of loss of function, or level of environmental loss).	BGC
Encounter Probability	This term is used in two ways: a) **Probability** that an event will occur and impact an element at risk when the element at risk is present in the **geohazard** zone. It is sometimes termed **"partial risk"** b) For quantitative analyses, the **probability** of facilities or vehicles being hit at least once when exposed for a finite time period L, with events having a **return period** T at a location. In this usage, it is assumed that the events are rare, independent, and discrete, with arrival according to a statistical distribution (e.g., binomial or Bernoulli distribution or a Poisson process).	BGC
Erosion	The part of the overall process of denudation that includes the physical breaking down, chemical solution and transportation of material.	Oxford University Press (2008)

Term	Definition	Source
Flood	A rising body of water that overtops its confines and covers land not normally under water.	American Geosciences Institute (2011)
Flood Construction Level (FCL)	A designated flood level plus freeboard, or where a designated flood level cannot be determined, a specified height above a natural boundary, natural ground elevation, or any obstruction that could cause flooding.	BGC
Flood mapping	Delineation of flood lines and elevations on a base map, typically taking the form of flood lines on a map that show the area that will be covered by water, or the elevation that water would reach during a flood event. The data shown on the maps, for more complex scenarios, may also include flow velocities, depth, or other hazard parameters.	BGC
Floodplain	The part of the river valley that is made of unconsolidated river-borne sediment, and periodically flooded.	Oxford University Press (2008)
Flood setback	The required minimum distance from the natural boundary of a watercourse or waterbody to maintain a floodway and allow for potential bank erosion.	BGC
Freeboard	Freeboard is a depth allowance that is commonly applied on top of modelled flood depths. There is no consistent definition, either within Canada or around the world, for freeboard. Overall, freeboard is used to account for uncertainties in the calculation of a base flood elevation, and to compensate for quantifiable physical effects (e.g., local wave conditions or dike settlement). Freeboard in BC is commonly applied as defined in the BC Dike Design and Construction manual (BC Ministry of Water, Land and Air Protection [BC MWLAP], 2004): a fixed amount of 0.6 m (2 feet) where mean daily flow records are used to develop the design discharge or 0.3 m (1 foot) for instantaneous flow records.	BC Ministry of Water, Land and Air Protection [BC MWLAP] (2004)

Term	Definition	Source
Frequency (f)	Estimate of the number of events per time interval (e.g., a year) or in a given number of trials. Inverse of the **recurrence interval** (**return period**) of the **geohazard** per unit time. Recurring **geohazards** typically follow a **frequency-**magnitude (F-M) relationship, which describes a spectrum of possible **geohazard magnitudes** where larger (more severe) events are less likely. For example, annual **frequency** is an estimate of the number of events per year, for a given **geohazard event magnitude**. In contrast, annual **probability** of exceedance is an estimate of the **likelihood** of one or more events in a specified time interval (e.g., a year). When the expected **frequency** of an event is much lower than the interval used to measure **probability** (e.g., **frequency** much less than annual), **frequency** and **probability** take on similar numerical values and can be used interchangeably. When **frequency** approaches or exceeds 1, defining a relationship between **probability** and **frequency** is needed to convert between the two. The main document provides a longer discussion on **frequency** versus **probability**.	Adapted from Fell et al. (2005)
Hazard	Process with the potential to result in some type of undesirable outcome. Hazards are described in terms of scenarios, which are specific events of a particular frequency and magnitude.	BGC
Hazardous flood	A flood that is a source of potential harm.	BGC
Geohazard	Geophysical process that is the source of potential harm, or that represents a situation with a potential for causing harm. Note that this definition is equivalent to Fell et al. (2005)'s definition of Danger (threat), defined as an existing or potential natural phenomenon that could lead to damage, described in terms of its geometry, mechanical and other characteristics. Fell et al. (2005)'s definition of danger or threat does not include forecasting, and they differentiate Danger from Hazard. The latter is defined as the **probability** that a particular danger (threat) occurs within a given period of time.	Adapted from CSA (1997), Fell et al. (2005).

Term	Definition	Source
Geohazard Assessment	Combination of **geohazard analysis** and evaluation of results against a **hazard tolerance standard** (if existing). Geohazard assessment includes the following steps: a. **Geohazard analysis**: identify the **geohazard** process, characterize the geohazard in terms of factors such as mechanism, causal factors, and trigger factors; estimate **frequency** and magnitude; develop **geohazard scenarios**; and estimate extent and intensity of **geohazard scenarios**. b. Comparison of estimated hazards with a hazard tolerance standard (if existing)	Adapted from Fell et al. (2007)
Geohazard Event	Occurrence of a **geohazard**. May also be defined in reverse as a non- occurrence of a **geohazard** (when something doesn't happen that could have happened).	Adapted from ISO (2018)
Geohazard Intensity	A set of parameters related to the destructive power of a **geohazard** (e.g. depth, velocity, discharge, impact pressure, etc.)	BGC
Geohazard Inventory	Recognition of existing **geohazards.** These may be identified in geospatial (GIS) format, in a list or table of attributes, and/or listed in a **risk register**.	Adapted from CSA (1997)
Geohazard Magnitude	Size-related characteristics of a **geohazard**. May be described quantitatively or qualitatively. Parameters may include volume, discharge, distance (e.g., displacement, encroachment, scour depth), or acceleration. In general, it is recommended to use specific terms describing various size-related characteristics rather than the general term magnitude. Snow avalanche magnitude is defined differently, in classes that define destructive potential.	Adapted from CAA (2016)
Geohazard Risk	Measure of the **probability** and severity of an adverse effect to health, property the environment, or other things of value, resulting from a geophysical process. Estimated by the product of **geohazard probability** and **consequence**.	Adapted from CSA (1997)
Geohazard Scenario	Defined sequences of events describing a **geohazard** occurrence. Geohazard scenarios characterize parameters required to estimate risk such **geohazard extent** or **runout exceedance probability,** and **intensity.** Geohazard scenarios (as opposed to **geohazard risk scenarios**) typically consider the chain of events up to the point of impact with an element at risk, but do not include the chain of events following impact (the **consequences**).	Adapted from Fell et al. (2005)

Term	Definition	Source
Hazard	Process with the potential to result in some type of undesirable outcome. Hazards are described in terms of scenarios, which are specific events of a particular frequency and magnitude.	BGC
Inactive Alluvial Fan	Portions of the fan that are removed from active hydrogeomorphic or avulsion processes by severe fan erosion, also termed fan entrenchment.	BGC
LiDAR	Stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. These light pulses - combined with other data recorded by the airborne system - generate precise, three-dimensional information about the shape of the Earth and its surface characteristics.	National Oceanic and Atmospheric Administration, (n.d.).
Likelihood	Conditional **probability** of an outcome given a set of data, assumptions and information. Also used as a qualitative description of **probability** and **frequency**.	Fell et al. (2005)
Melton Ratio	Watershed relief divided by square root of watershed area. A parameter to assist in the determination of whether a creek is susceptible to flood, debris flood, or debris flow processes.	BGC
Nival	Hydrologic regime driven by melting snow.	Whitfield, Cannon and Reynolds (2002)
Orphaned	Without a party that is legally responsible for the maintenance and integrity of the structure.	BGC
Paleofan	Portion of a fan that developed during a different climate, base level or sediment transport regime and which will not be affected by contemporary geomorphic processes (debris flows, debris floods, floods) affecting the active fan surface	BGC
Paleochannel	An inactive channel that has partially been infilled with sediment. It was presumably formed at a time with different climate, base level or sediment transport regime.	BGC
Pluvial – hybrid	Hydrologic regime driven by rain in combination with something else.	BGC

Term	Definition	Source
Probability	A measure of the degree of certainty. This measure has a value between zero (impossibility) and 1.0 (certainty) and must refer to a set like occurrence of an event in a certain period of time, or the outcome of a specific event. It is an estimate of the **likelihood** of the magnitude of the uncertain quantity, or the **likelihood** of the occurrence of the uncertain future event. There are two main interpretations: i) Statistical – **frequency** or fraction – The outcome of a repetitive experiment of some kind like flipping coins. It includes also the idea of population variability. Such a number is called an “objective” or relative frequentist probability because it exists in the real world and is in principle measurable by doing the experiment. ii) Subjective (or Bayesian) probability (degree of belief) – Quantified measure of belief, judgement, or confidence in the **likelihood** of an outcome, obtained by considering all available information honestly, fairly, and with a minimum of bias. Subjective probability is affected by the state of understanding of a process, judgement regarding an evaluation, or the quality and quantity of information. It may change over time as the state of knowledge changes.	Fell et al. (2005)
Return Period (Recurrence Interval)	Estimated time interval between events of a similar size or **intensity**. Return period and **recurrence interval** are equivalent terms. Inverse of **frequency**.	BGC
Risk	Likelihood of a geohazard scenario occurring and resulting in a particular severity of consequence. In this report, risk is defined in terms of safety or damage level.	BGC
Rock (and debris) Slides	Sliding of a mass of rock (and debris).	BGC
Rock Fall	Detachment, fall, rolling, and bouncing of rock fragments.	BGC
Scour	The powerful and concentrated clearing and digging action of flowing air or water, especially the downward erosion by stream water in sweeping away mud and silt on the outside curve of a bend, or during a time of flood.	American Geological Institute (1972)
Steep-creek flood	Rapid flow of water and debris in a steep channel, often associated with avulsions and bank erosion and referred to as debris floods and debris flows.	BGC
Steep Creek Hazard	Earth-surface process involving water and varying concentrations of sediment or large woody debris. (see Appendix B of this report for detailed definition).	BGC

Term	Definition	Source
Uncertainty	Indeterminacy of possible outcomes. Two types of uncertainty are commonly defined: a) Aleatory uncertainty includes natural variability and is the result of the variability observed in known populations. It can be measured by statistical methods, and reflects uncertainties in the data resulting from factors such as random nature in space and time, small sample size, inconsistency, low representativeness (in samples), or poor data management. b) Epistemic uncertainty is model or parameter uncertainty reflecting a lack of knowledge or a subjective or internal uncertainty. It includes uncertainty regarding the veracity of a used scientific theory, or a belief about the occurrence of an event. It is subjective and may vary from one person to another.	BGC
Waterbody	Ponds, lakes and reservoirs	BGC
Watercourse	Creeks, streams and rivers	BGC

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