FRASER BASIN COUNCIL

Cariboo Regional District Flood Hazard Assessment

FINAL
June 4, 2021

Project No.:
0511007

Prepared by BGC Engineering Inc. for:
Fraser Basin Council

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

Dear Mike,

Re: Cariboo Regional District Flood Hazard Assessment – FINAL

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

Should you have any further 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	May 17, 2021		Issued for Review by FBC and CRD
FINAL	June 4, 2021	0	Minor updates as per FBC comments

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 (Director, Interior Regional Programs, Fraser Basin Council); Nigel Whitehead (Manager of Planning Services, Cariboo Regional District); Rupal Brahmbhatt (Nigel Whitehead, Cariboo Regional District).

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

- Nigel Whitehead (Manager of Planning Services, Cariboo Regional District), 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, BC Ministry of Transportation and Infrastructure (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); Patrick Grover (Technical Reviewer, Modelling); Kenneth Lockwood (Lead Hydraulic Modeller); Rebecca Lee (Technical Lead), Alistair Beck (software); Elisa Scordo (hydrology); Matthew Buchanan (GIS); Sarah Kimball (Exposure Assessment Lead); Zeneca Kubota (Exposure Assessment); Hamish Weatherly (Technical Reviewer); Michael Porter (Reviewer).

LIMITATIONS

BGC Engineering Inc. (BGC) prepared this document for the account of Fraser Basin Council (FBC) and Cariboo Regional District (CRD). The material in it reflects the judgment of BGC staff in light of the information available to BGC at the time of document preparation. Any use which a third party makes of this document or any reliance on decisions to be based on it is the responsibility of such third parties. BGC accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this document.

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EXECUTIVE SUMMARY

Fraser Basin Council (FBC), on behalf of Cariboo Regional District (CRD, the District) retained BGC Engineering Inc. (BGC) to carry out flood hazard identification and mapping, hazard exposure assessment, and updated geohazard risk prioritization within the District.

This study represents a continuation of a geohazard risk management initiative for the Thompson River watershed (TRW[1]), which was launched in February 2018 at a Community-to-Community Forum in Kamloops, British Columbia (BC). The objectives of the current project are as follows:

- *Regional floodplain identification*: provide maps identifying, at a screening level of detail, the approximate extent of a 200-year floodplain for all watercourses in the District.
- *Hazard exposure (elements at risk) update*: refine the identification of assets in hazard areas based on updated information about critical facilities and building improvements.
- *Risk prioritization update*: update BGC's September 24, 2020 risk prioritization to distinguish impacts to settled, populated areas from impacts to lifelines (linear infrastructure).
- *Base level flood hazard maps:* update existing base level flood hazard mapping (BGC, April 3, 2020) for Bridge Creek (Camin Lake to 100 Mile House) using newly available lidar topography, and complete new base level (regional) flood hazard maps for seven additional areas: Chimney Creek, Fraser River (Quesnel to MacAlister), Cottonwood River, Baker Creek, Horsefly River, Nazko River, Lac la Hache (waterbody), and Bridge Creek (Camin Lake to 100 Mile House).

The project objectives focus primarily on supporting mitigation planning aspects of emergency management[2], but will also benefit preparedness, response and recovery by providing hazard and risk information required during emergencies.

The results of this study include hazard maps, risk priority ratings, and supporting information. *Cambio Communities* (www.cambiocommunities.ca) displays all geohazard areas and is the easiest way to interact with study results, which are also tabulated in Appendix E and provided as GIS data for download. Appendix A provides a guide to navigate *Cambio*.

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

The results of this study include:

- **This report section** provides a summary overview of results.
- ***Cambio Communities* (www.cambiocommunities.ca)** displays all geohazard areas and is the easiest way to interact with study results. Users can see large areas at a glance or view results for a single site. Appendix A provides a guide to navigate *Cambio*.
- **Appendix E** provides an Excel spreadsheet with tabulated results.

1 See www.thompsonflood.ca.

2 i.e., mitigation and prevention, preparedness, response and recovery, as defined by the BC Emergency Management System (Province of BC, 2016).

- **Data download** of prioritized, attributed geohazard areas in geodatabase format.
- **Hazard model scenario maps** provided in digital format (GIS files) for each study area.

BGC provides the following recommendations based on the results of this study:

- **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 results of 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.
- **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.
- **Data Gaps and Uncertainties:** Develop a plan to resolve the technical data gaps and uncertainties identified in BGC's September 24, 2020 study and this study.
- **Emergency flood modelling:** In a flood emergency, deploy the hydraulic models developed for this study to help Emergency Operations Center (EOC) directors issue evacuation alerts and orders with improved knowledge about the potential extent and characteristics of flooding.
- **Stakeholder collaboration:** Abundant information about geohazards in the TNRD exists in the private sector that is relevant to geohazards management for communities. Connect private and public resources for geohazard and risk management to reduce risk beyond what any single party can accomplish in isolation.
- **Detailed flood hazard maps:** Prepare detailed flood hazard maps within the base level flood hazard mapping areas delivered by this study.

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1. INTRODUCTION

1.1. Objective

Fraser Basin Council (FBC), on behalf of Cariboo Regional District (CRD, the District), retained BGC Engineering Inc. (BGC) to carry out base level flood hazard mapping and exposure assessment for eight (8) areas within the District. The base level flood mapping encompasses a total distance of approximately 200 km along the main watercourses for these 8 areas. Funding was provided through the Union of BC Municipalities Emergency Preparedness Fund. This work was carried out under the terms of a contract between FBC and BGC dated November 25, 2020, administered by FBC in a contribution agreement between FBC 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.

Subsequently, BGC completed floodplain mapping at a "base level"[4] of detail for ten riverine flood hazard areas in the TRW identified as high priority during the Stream 1 study (BGC, April 3, 2020). Bridge River within the CRD was included for hazard mapping; the remaining areas were in the Thompson Nicola Regional District (TNRD). BGC subsequently extended flood risk prioritization to encompass the entire Cariboo Regional District (BGC, September 24, 2020, "CRD Prioritization").

The objectives of the current project are as follows:

- *Regional floodplain identification*: provide a map identifying the approximate extent of a 200-year floodplain for watercourses in the District.
- *Base level flood hazard maps:* Update existing base level flood hazard mapping (BGC, April 3, 2020) for Bridge Creek (Camin Lake to 100 Mile House) using newly available lidar topography, and complete new base level (regional) flood hazard maps for seven (7) additional areas.
- *Hazard exposure (elements at risk) update*: refine the identification of assets in hazard areas based on updated information about critical facilities, building locations and building improvement values.
- *Risk prioritization update*: update BGC's March 31, 2019 risk prioritization to distinguish between impacts to settled, populated areas (communities) from impacts to lifelines (linear infrastructure on which the community depends).

[3] See www.thompsonflood.ca.

[4] Base level is defined as an intermediate step between screening level flood hazard identification and more costly, detailed floor hazard mapping.

Due to the integrated nature of the work, both the previous and the current work are referred to throughout this document.

This study focuses primarily on supporting mitigation planning aspects of emergency management[5], but will also benefit preparedness, response and recovery (i.e., by providing hazard and risk information required during emergencies). 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 report is best read with access to Cambio Communities, which displays the results of previous work and this study (Figure 1-1). The application can be accessed at www.cambiocommunities.ca. Appendix A provides a Cambio user guide. Appendix D provides terminology definitions.

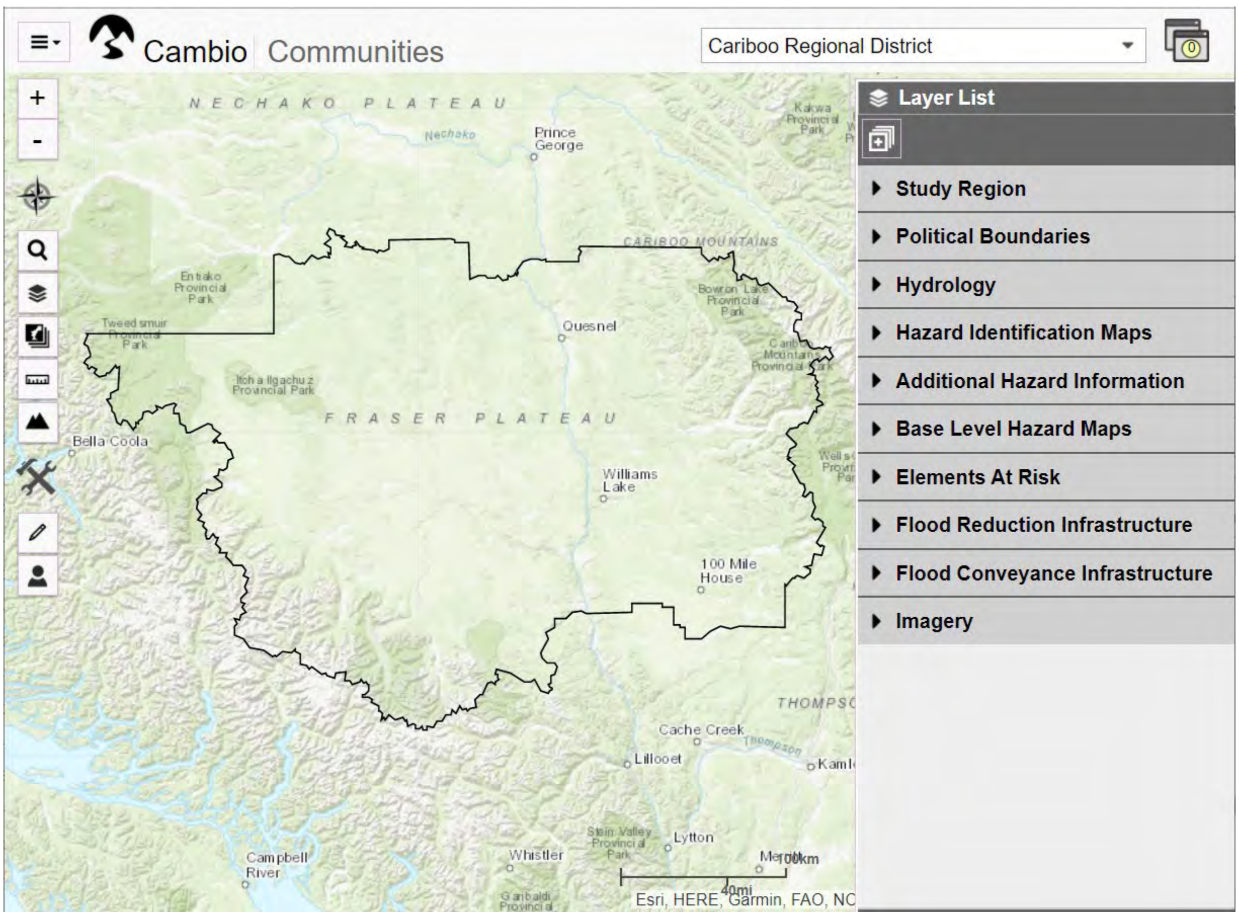


Figure 1-1. Example of Cambio Communities web application.

5 i.e., mitigation and prevention, preparedness, response, and recovery, as defined by the BC Emergency Management System (Province of BC, 2016).

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, May 3, 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. Levels of Detail

The deliverables of this study include a District-wide flood hazard identification map, and "base level" flood hazard maps. Table 1-1 clarifies these levels of detail in terms of their applicability to decision making. Consistent with the strategic approach of the Thompson Hazard Initiative, each increased level of detail is a refinement of previous work, along a long-term path to measurable risk reduction for communities in the CRD. Through the provision of flood hazard maps and information hazard exposure, project deliverables support decision making related to planning, policy, bylaws, emergency management, and hazard mitigation.

Table 1-1. Hazard assessment levels of detail.

Points of Comparison	Hazard Identification Maps	Flood Hazard Assessment & Maps	
		Base Level	Detailed[1]
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 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 velocity or depth) displayed within the hazard boundary	Hazard characteristics displayed within the hazard boundary
Relative level of effort for a given study area	$	$$	$$$$
Examples and application to this scope of work.	CRD risk prioritization; Floodplain identification map **provided in this study**	Base level flood mapping; **provided in this study.**	Detailed flood mapping proposed for Bridge Creek (BGC, 2021).

Points of Comparison	Hazard Identification Maps	Flood Hazard Assessment & Maps	
		Base Level	Detailed[1]
Inputs	Desktop analyses	Desktop analyses, limited fieldwork	Desktop analyses, hydrometric surveys, and fieldwork
Hazard return periods considered	Single (to compare sites)	One or more return periods	Multiple return periods & scenarios
Qualitative/Quantitative	Relative, qualitative	Quantitative	Quantitative
Map Deliverables	Hazard boundaries	Hazard maps	Hazard maps
Applicable Guidelines	NRCAN (2018)	NRCAN (2018); FEMA (2018)	EGBC (2017, 2018)

For clarity, BGC emphasizes that the flood hazard maps provided by this study do not replace detailed floodplain maps 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.

1.3. Study Area

Figure 1-2 and Table 1-2 show the eight mapping areas selected for base level flood hazard mapping, which in total encompass approximately 200 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 CRD prioritization study; records of previous events; reference to previous reports; and available funding.

Further information on physiography and hydroclimate throughout the CRD, including the areas assessed in this study, was previously provided as part of the CRD prioritization study (BGC, September 24, 2020). The sites chosen are not necessarily the locations where the "next" damaging geohazards event will occur in the CRD, which is not known.

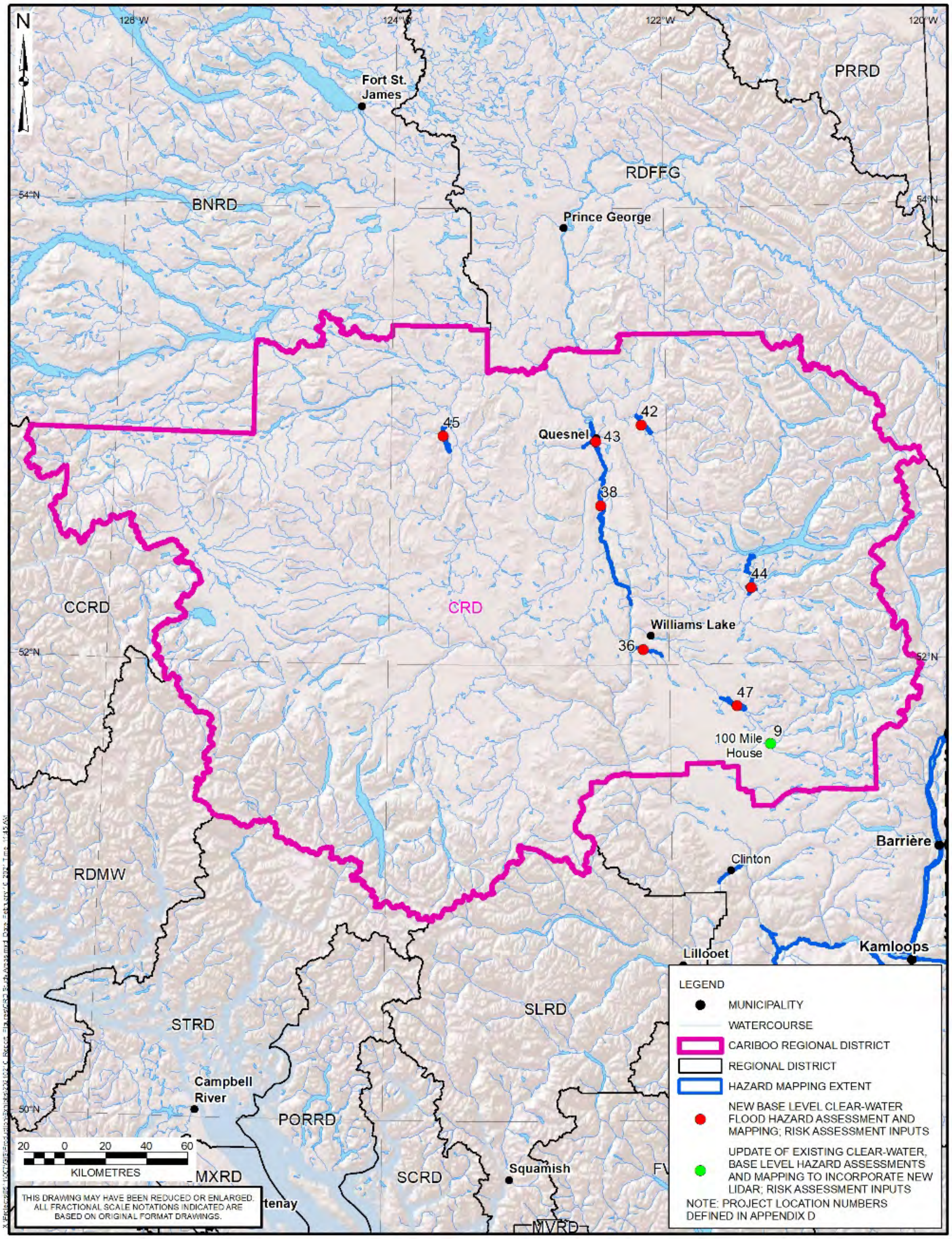


Figure 1-2. Study areas, numbered according to Table 1-2.

Table 1-2. Summary of flood hazard areas identified for base level flood hazard mapping.

Project Objective	Site No.	Watercourse (Area)1
Flood Hazard Mapping	36	Chimney Creek
	38	Fraser River (Quesnel to MacAlister)
	42	Cottonwood River
	43	Baker Creek
	44	Horsefly River
	45	Nazko River
	47	Lac la Hache (waterbody)
Flood Hazard Mapping Update	9	Bridge Creek (Camin Lake to 100 Mile House)

1.4. Scope of Work

Table 1-3 lists the activities and tasks included in the scope of work.

Table 1-3. 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	Hazard and Hazard Exposure Analysis	Base inputs for hazard analyses and study integration such as lidar topography	• LiDAR (as available) • BGC team • District team • Project stakeholders
Flood Hazard Mapping: update (one area) and new mapping (seven areas)	Hydraulic modelling	Base level flood hazard maps.	• BGC team
Exposure Analysis Update	Elements-at-risk update focusing on flood hazard map areas.	Exposure model.	• BGC team
Reporting	Reporting	Description of methods, results, and limitations.	• BGC team
Maps and Data	Hazard Maps	Clear-water flood hazard maps showing areas of inundation; access to data and web services for dissemination of study results.	• BGC team

Activities	Tasks	Deliverables/Products	Resources
	Exposure model	Elements at risk data provided in ArcGIS SDE Geodatabase.	• BGC team
Presentation	Presentation	Presentations of results.	• BGC team • District team • Project stakeholders

2. METHODS

Appendix B provides a full description of the flood hazard mapping methodology, including data compilation, hydrologic analyses, and hydraulic modelling. This section summarizes the major steps of analysis listed in Table 1-3 (Section 1.4).

2.1. 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 (i.e., gauge records of streamflow discharges collected at Water Survey of Canada (WSC) hydrometric stations). Some of the creeks and rivers in this study were gauged and therefore had historical streamflow records available; however, many had never been gauged. The creeks and rivers fell into 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.
- Ungauged rivers and creeks.

For the first case a single-station flood frequency analysis (FFA) was performed using the historical streamflow records.

For the second case, nearby gauges were reviewed to see if they could be a proxy for the gauge of interest and years of overlapping data were compared to develop a relationship between peak annual discharges. If a relationship could not be established, then these study areas were treated as ungauged sites.

For the third case (ungauged sites), a regional flood frequency analysis (Regional FFA) was performed using the index-flood method, which is described further in Appendix B.

Climate change is expected to have an impact on the magnitudes of the peak flows. BGC applied a 20% upwards adjustment of flood quantiles for hydraulic modelling completed in all hazard mapping areas (Section 1.2) except the Fraser River and Lac La Hache study areas. Applying current flood frequency estimates (without adjustment) on the Fraser River reflected assessment of projected changes in runoff variability and flow regimes of the Fraser River Basin by Islam et al. (2019). For Lac La Hache, no climate adjustment was included given the numerous uncertainties in the available date. For reference, BGC recently completed detailed flood mapping for sixteen areas in the Regional District of Central Kootenay (RDCK) (BGC, March 31, 2020), where statistical and process-based approaches to consider climate change in flood frequency analysis, while not conclusive, supported a similar upwards adjustment of flood quantiles.

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.

2.2. 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 here referred to as Base Level hazard mapping.

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[6]. 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 1.2 provided further context on different levels of mapping detail and their applicability to decision making.

2.3. Base Level Flood Modelling and Mapping (Hydraulics)

BGC developed a two-dimensional (2D) hydraulic model for each site to estimate the inundation extents, flood depths and peak flow velocities. The 2D hydraulic models were run to steady state using the inflow boundary conditions based on the hydrological analysis described in Section 2.2. Based on the results of hydraulic modelling, BGC prepared maps for each study area that show the estimated depth and flow velocity for areas inundated during an estimated 200-year flood discharge under current conditions and adjusted for climate change. Hydraulic modelling was performed using the HEC-RAS version 6 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).

The terrains used to define the model geometries in HEC-RAS used the topographic data from airborne lidar if available, or the Canadian Digital Elevation Model (CDEM). Table 2-1 summarizes the terrain source for the different study areas. 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

[6] 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.

in the east-west direction, depending on location. For the CRD this yields an approximate 20 m grid cell resolution (Government of Canada, 2016). In contrast, the base grid cell resolution for the airborne lidar was 1 m grid cell resolution. Table 1-1 provides an overview of the level of detail of this study. Further information on the hydraulic modelling is provided in Appendix B, and Appendix E describes uncertainties.

Table 2-1. Terrain source for the study areas.

Study Area	Terrain Source
Chimney Creek	CDEM
Fraser River (Quesnel to MacAlister)	Airborne lidar
Cottonwood River	CDEM
Baker Creek	Airborne lidar
Horsefly River	CDEM
Nazko River	CDEM
Lac la Hache	CDEM
Bridge Creek	Airborne lidar

2.4. Hazard Exposure (Elements at Risk)

Appendix C describes the types and organization of data about elements at risk, which in summary are organized according to population, building value, businesses, critical facilities, lifelines, and environmental values. Data organization is the same as that provided by BGC (September 24, 2020), but the content has been updated as follows:

- Updated inventory of critical facilities, prepared in collaboration with CRD (March 31, 2020).
- Updated building assessment values (BC Assessment, 2021).
- New building footprints derived from lidar data obtained by Terra Remote Sensing (2020), and Microsoft Open Data Canadian building footprints data (2019).

2.5. Risk Prioritization Update

BGC (September 24, 2020) previously completed a flood risk prioritization for the CRD. Detailed description of prioritization methodology is contained in that report. This section summarizes the approach and describes updates provided as part of this assessment.

Table 2-2 displays a matrix used to prioritize each geohazard area based on geohazard and consequence ratings. The geohazard rating considers the relative chance that that geohazard events occur and – if they occur – impact areas with elements at risk. The consequence rating considers the relative potential for loss between hazard areas, given hazard impact.

Table 2-2. Prioritization matrix (assets).

Geohazard Rating	Priority Rating				
Very High	M	H	H	VH	VH
High	L	M	H	H	VH
Moderate	L	L	M	H	H
Low	VL	L	L	M	H
Very Low	VL	VL	L	L	M
Consequence Rating	Very Low	Low	Moderate	High	Very High

BGC's 2020 assessment considered all elements at risk together to estimate hazard exposure and risk priority. Subsequent use of BGC's 2020 prioritization revealed a need to better distinguish risk priority for areas with community development versus areas crossed by lifelines on which a community depends (e.g., transportation and utilities infrastructure). This need reflects loss indicators of the Sendai Framework for Disaster Risk Reduction (Sendai Framework), where services disruption is distinguished from public safety, economic loss, environmental loss, or social loss (United Nations, 2016; UNISDR, 2015).

For this assessment, BGC divided types of elements at risk into two groups, termed "community" and "lifelines", which were considered separately for risk prioritization. Table 2-3 lists the groups of assets[7] used to consider hazard exposure from the perspective of community and lifelines. The original prioritization (all assets combined) was also retained.

Table 2-3. Prioritization scenarios considered in the exposure assessment.

Hazard Exposure Group	Description	Elements at risk	Status
Community	Group of asset types within settled areas.	People, Buildings, Critical Facilities, Businesses and Environmental Values	New
Lifelines	Group of linear infrastructure assets.	Roads, Highways, Railways, Petroleum, Electrical, Communication, Water, Sanitary, or Drainage Infrastructure	New
Combined	All assets.	See above	Consistent with Stream 1 study (BGC, March 31, 2019)

[7] BGC applies the following definitions in this report: an asset is anything of value, including both anthropogenic and natural assets. Elements at risk are assets exposed to potential consequences of geohazard events. A hazard exposure model is a type of data model describing the location and characteristics of elements at risk.

Figure 2-1 shows an example clear-water flood hazard area located 3 km east of Williams Lake, with $2M in assessed buildings value, an estimated population of 6 and a minor road. The area received a Low Community priority rating given the modest value of development, and a High Lifeline priority rating that reflects the presence of the railway, road, electrical and petroleum infrastructure. The example shows how priorities may differ depending on the elements at risk considered. As with all prioritized hazard areas, users can view the supporting data shown in Cambio and in Appendix F to determine how each parameter contributed to the priority ratings.

Figure 2-1. Example clear-water flood hazard area located about 3 km east of Williams Lake.

BGC notes that assigning consequence ratings for risk prioritization is completed in advance of detailed assessment of high priority sites (e.g., quantitative risk assessment). The consequence rating considers the combined presence and value of elements at risk within the hazard area (hazard exposure), and the intensity of flows that could impact elements at risk. Given the scale of study and diversity of the asset inventory, asset vulnerability is not directly assessed. Instead, hazard intensity is used as a proxy for vulnerability, where higher value or a greater number of elements at risk, combined with the potential for more highly destructive flows, are assumed to have greater loss potential.

Implications of the approach taken herein could include over-estimation of loss where elements have low vulnerability (e.g., a transmission line that spans a floodplain), or priority ratings that do not reflect the needs of a specific stakeholder (e.g., who is concerned with a particular asset or type of risk). BGC suggests that users review Appendix F to identify the factors contributing to a particular hazard, consequence, or priority rating.

3. DELIVERABLES

3.1. Summary

The results of this study include hazard maps for the eight areas assessed, updated risk priority ratings, and supporting information. *Cambio Communities* (www.cambiocommunities.ca) is the easiest way to interact with study results. Appendix A provides a guide to navigate *Cambio*.

3.1.1. Risk Prioritization

Appendix F and Cambio Communities provide updated risk priority ratings for Community and Lifelines asset groups (as defined in Section 2.5). Figure 3-1 provides a visual comparison of clear-flood risk priority ratings for the Community asset group (right image) and Lifelines asset group (left image) across the CRD, highlighting how higher lifelines priority ratings are concentrated along corridors connecting settled areas.

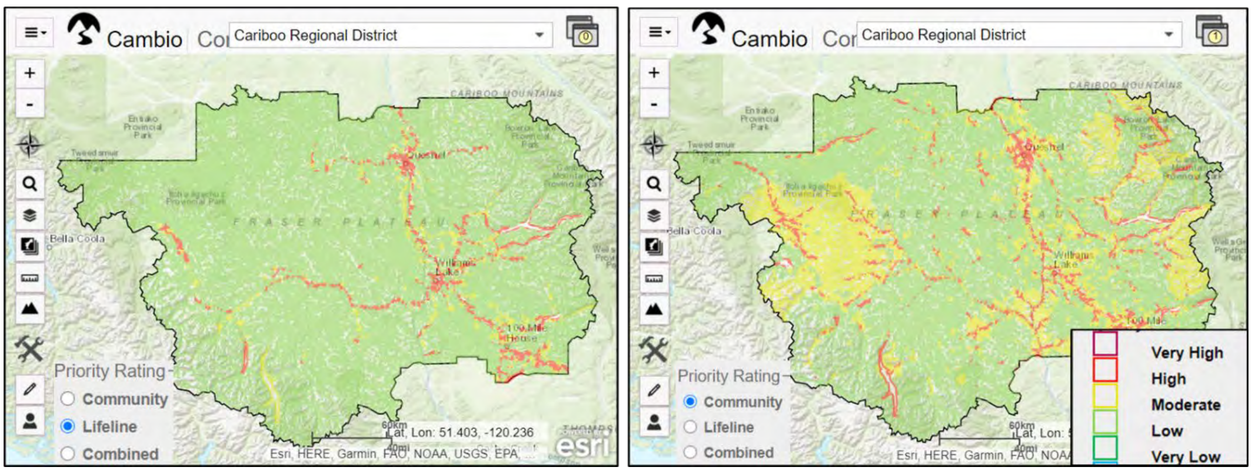


Figure 3-1. Distribution of clear-water flood risk priority areas across the CRD.

3.1.2. Flood Hazard Maps

The Base Level hazard maps display modelled extent and depth of inundated areas for an estimated 200-year flood discharge. Figure 3-2 provides an example screen-capture from the Nazko River study area. Hazard map layers for each area are also provided separately for download.

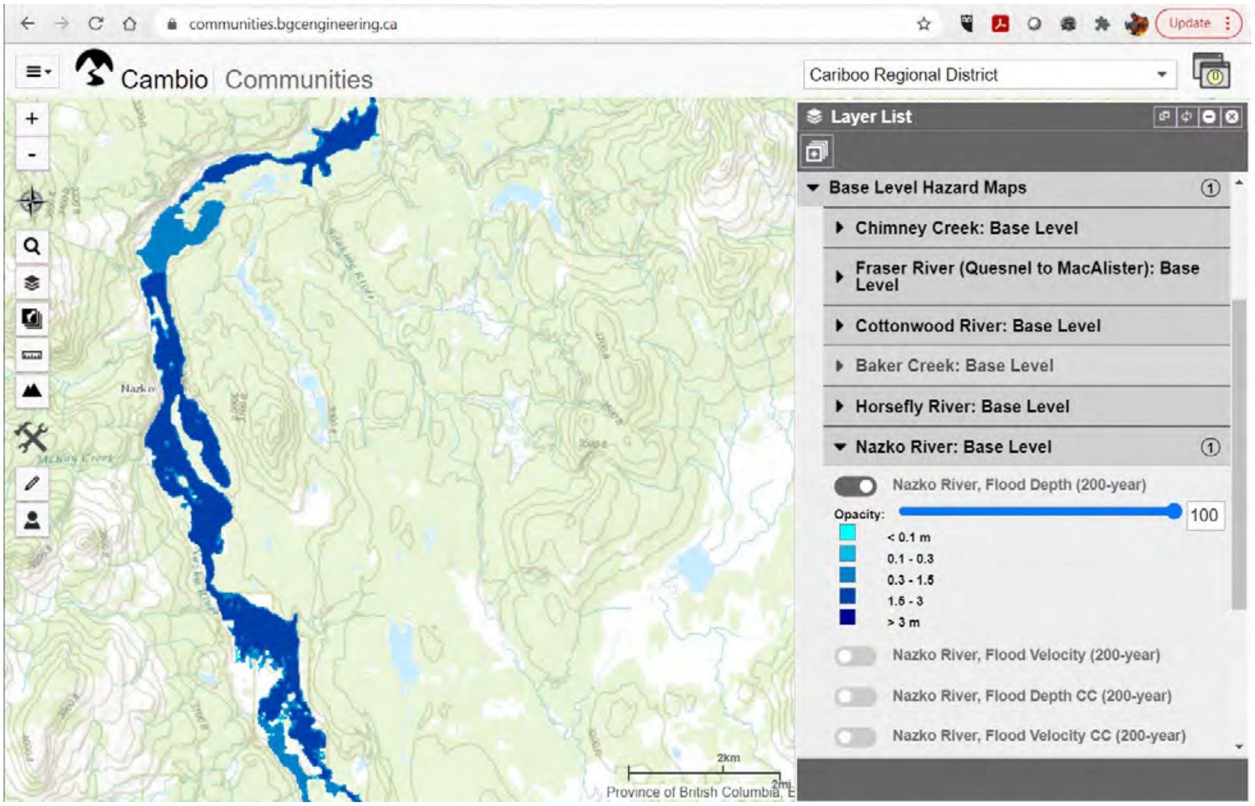


Figure 3-2. Example flood depth for Nazko River study area, in Cambio Communities.

3.2. Users and Use-Cases

BGC anticipates that a wide range of parties will use the results of both the CRD prioritization study (BGC, September 24, 2020) and this project. Table 3-1 provides examples of potential use cases. Both the prioritization study 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 3-1. Intended users of the clear-water flood hazard 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 prioritization 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. 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 prioritization 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., FBC	"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.

4. RECOMMENDATIONS

BGC (September 24, 2020) provided recommendations for the development of long-term geohazard risk management plans within the District. BGC notes the following key recommendations for implementation by the District that are also relevant to this study:

- **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 results of 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. BGC (February 12, 2021) provided a work plan to organize such a workshop, which BGC understands has been approved by the CRD Board on a schedule to be confirmed.
- **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 makes the following additional recommendations, which are described further in Sections 4.1 to 4.5:

- **Data Gaps and Uncertainties:** Resolve data gaps and uncertainties identified in BGC's September 24, 2020 study and Appendix E of this study.
- **Emergency flood modelling:** In a flood emergency, consider the hydraulic models developed for this study as a resource to help Emergency Operations Center (EOC) directors issue evacuation alerts and orders with improved knowledge about the potential extent and characteristics of flooding.
- **Stakeholder collaboration:** Abundant information about geohazards in the TNRD exists in the private sector that is relevant to geohazards management for communities. Connect private and public resources for geohazard and risk management to reduce risk beyond what any single party can accomplish in isolation.
- **Detailed flood hazard maps:** Refine the base level flood hazard mapping areas delivered by this study to a level of detail required for regulation, including the preparation of Flood Construction Level (FCL) maps.

4.1. Data Gaps and Uncertainties

Recommendation:

- *Develop and implement a plan to resolve the technical data gaps and uncertainties outlined in this study.*

Appendix E summarizes gaps in data that informed the study, implications for analysis, and considerations to resolve these gaps.

4.2. Emergency Flood Modelling

Recommendation:

- *In a flood emergency, deploy hydraulic modelling to help Emergency Operations Center (EOC) directors issue evacuation alerts and orders with improved knowledge about the potential extent and characteristics of flooding.*

The BC River Forecast Centre (RFC) provides daily 10-day forecasts of discharges at specific WSC gauges along rivers and creeks across BC, including the CRD. Flood forecasts indicate potential flooding but cannot provide any information on where the water is likely to go (extent), its characteristics (depth, velocity) and when (timing).

During a flood emergency, the hydraulic models used to prepare base level flood hazard maps can potentially be re-run with forecast data. The results can help EOC directors issue evacuation alerts and orders with improved knowledge about the potential extent and characteristics of flooding.

The following may warrant consideration when preparing and using flood forecasts in combination with hydraulic models for emergency response support:

- Given the limited time available in an emergency, it is helpful to initiate discussion about potential emergency flood modelling in advance of an emergency (e.g., before Spring freshet), to make sure that resources are available if needed.
- To make effective use of emergency flood models, EOC teams require geomatics specialists to quickly incorporate geospatial data provided by Qualified Professionals and develop derivative products for decisions (e.g., to query flood extents to develop contact lists for evacuation orders).
- The use of emergency flood models should be supported by Qualified Professionals that can interpret the information provided and discuss implications of uncertainties.
- To support decisions resulting from flood forecasting and emergency hydraulic modelling, it is helpful to develop criteria in advance that tie anticipated scenarios to emergency response decisions and protocols.

The RFC also maintains a web map layer displaying the following Advisory and Warning Levels for major basins and sub-basins in British Columbia:

- High Streamflow Advisory (yellow): River levels are rising or expected to rise rapidly, but that no major flooding is expected. Minor flooding in low-lying areas is possible.
- Flood Watch (orange): River levels are rising and will approach or may exceed bankfull conditions. Flooding of areas adjacent to affected rivers may occur.

- Flood Warning (red): River levels have exceeded bankfull or will exceed bankfull conditions imminently, and that flooding of areas adjacent to the rivers affected will result.

Cambio Communities displays current advisories and warning levels under “Additional Hazard Information” in the layer list. It can be used to identify flood advisory or warning areas where hydraulic models exist and can potentially be deployed to support emergency response.

4.3. Hazard Monitoring and Warning

Recommendation:

- *Combine hazard mapping with precipitation and streamflow monitoring and forecasts to develop alerts to support emergency management.*

This study is a potential stepping-stone towards establishing flood hazard monitoring and warning systems in the CRD. Such approaches would support emergency management and could support risk management where existing structural measures are absent or inadequate, constrained resources must be deployed across large regions, and where the cost of structural mitigation is high in relation to the value of development.

As a starting point for geohazard monitoring in the absence of additional analyses, BGC notes that Cambio Communities displays all WSC real-time flow gauges within the CRD, coloured by the return period of current flows (e.g., Figure 4-1). Clicking any real-time flow gauge will display flow information. Where located in base level flood hazard mapping areas, these may be useful to compare real-time flows to the discharge associated with the flood hazard map.

With further work, monitored streamflow can be compared to predetermined thresholds and an alert be sent to relevant emergency response staff if the threshold is exceeded. Such flow alerts are already operational for pipeline operators elsewhere in BC for geohazards management at some stream crossings. Figure 4-2 provides an example of a notification email provided to a linear infrastructure operator. Adapting such an approach to communities would require using the hydraulic models developed for this study to develop pre-determined thresholds. Recognizing the uncertainties of base level modelling, additional hazard scenario modelling and more detailed hazard mapping may be required beyond that completed in this study to develop site-specific thresholds triggering alerts.

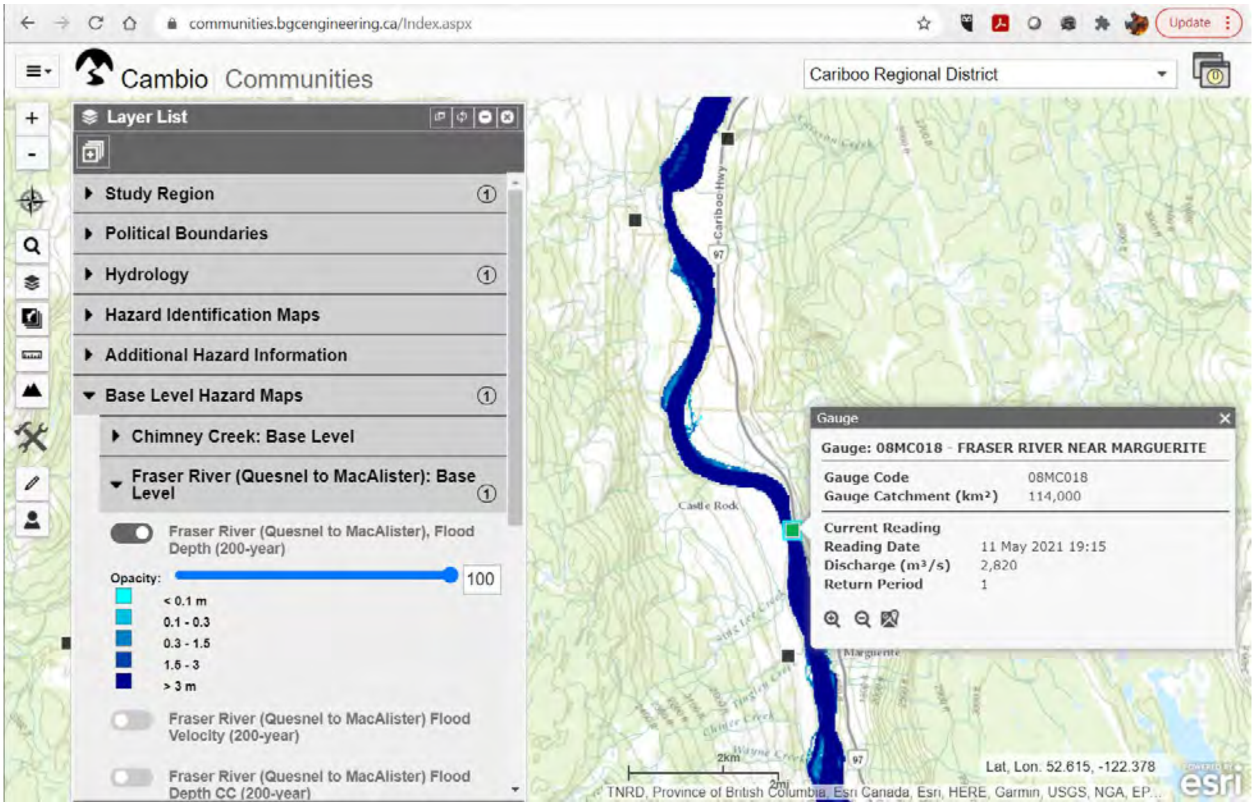
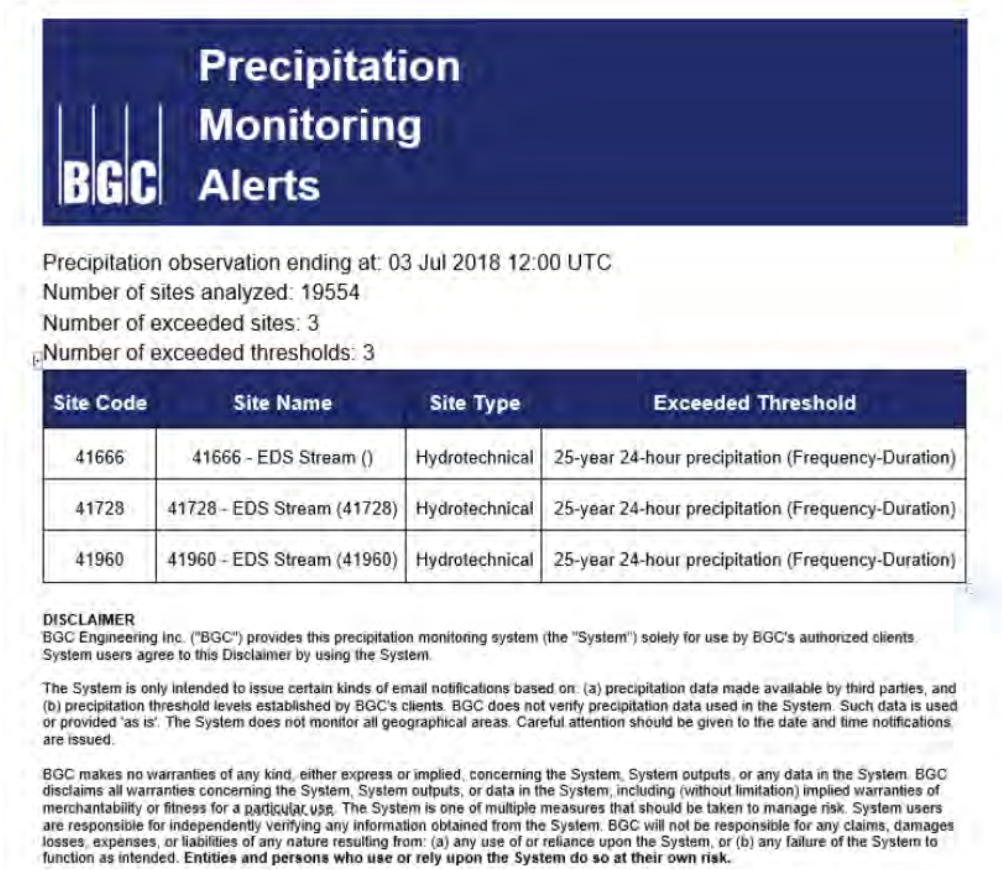


Figure 4-1. Example of a real-time streamflow gauge on the Fraser River near Marguerite.



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 4-2. Example email notification from a software tool used in geohazards management for the pipelines sector.

4.4. Multi-Stakeholder Collaboration

Recommendation:

- *Connect private and public resources for geohazard and risk management that amplify their effectiveness to reduce risk beyond what can be accomplished in isolation.*

The results of this study are applicable to a wide range of private and public stakeholders. Government and owner-operators of major utilities (e.g., road, rail, power and telecommunications, and pipeline operators) in a hazard area have different responsibilities but share requirements to understand and manage geohazard risk. The decisions by any single owner may have downstream implications (e.g., potential risk transfer), and gaps in knowledge sharing may negatively impact the speed and effectiveness of decisions that are made.

Knowledge about landslides and hydrotechnical hazards exists within the CRD that has been developed in support of geohazards management programs for major private industry, such as for pipeline operators, and for provincial infrastructure operators (e.g., BC MOTI)). For example, Figure 4-3 shows the location of major linear infrastructure operators in the CRD, including some for which BGC maintains operational geohazards management programs. Work of potential relevance to the CRD includes lidar acquisition and lidar change detection analysis, satellite-based ground motion monitoring, landslide and hydrotechnical hazard inventory and field inspection programs, real-time precipitation and streamflow monitoring and alerts, and software development required to deliver operational programs through a web platform (Cambio).

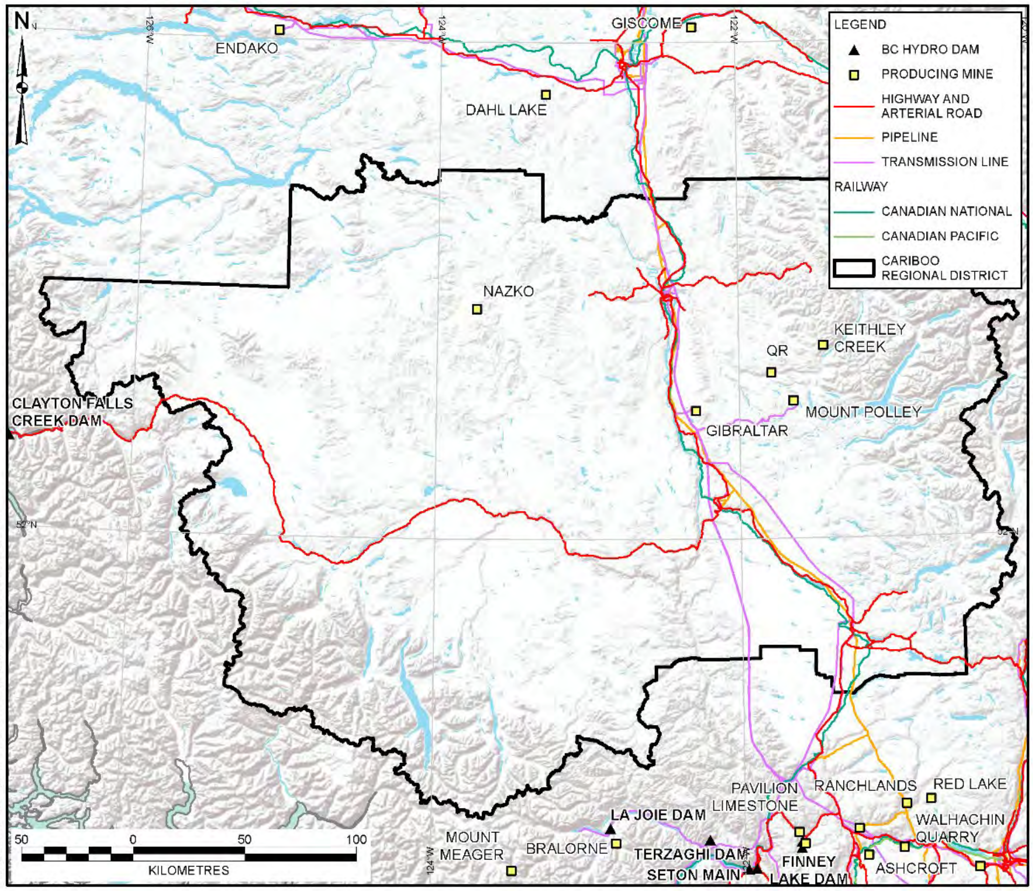


Figure 4-3. Locations and alignments of major utilities infrastructure in the CRD. The earth science knowledge generated through the management of these assets has broad potential application to geohazards management for communities in the CRD.

Recent advancements in information management have overcome many of the technical, technological, and cost barriers to knowledge sharing that existed in the past. Challenges related to disclosure, cost, and liability remain, as well as the need for Qualified Professional involvement to guide the use of geohazards knowledge for different applications. However, BGC believes there is incentive to overcome such challenges by identifying common needs and objectives. BGC suggests that CRD consider the following factors when exploring options for information sharing with private sector stakeholders:

- Consider the different strengths contributed by each stakeholder. For example, operational programs for geohazard risk and asset management are more frequently updated than hazard maps funded by grant applications, and typically cover a broader range of hazard types. The results of such programs can potentially be re-purposed for community applications with long-term maintenance supported through cost-sharing.

Conversely, regional hazard maps developed for local government contain attributes readily transferable to risk management for linear assets.

- Find information sharing options where baseline data can be shared through information management platforms (hydrology, hazard inventories, hazard monitoring) without needing disclosure of project details for a specific asset.
- Consider the assessment and management of public services (transportation, water supply, residential assets) as common needs between communities and industry, who also depend on public services and assets to operate.

Given the professional reliance model for geohazards practice in BC, Qualified Professionals are positioned to act as a bridge between the private and public sector. BGC currently works with several operators of major utilities within the CRD and can help identify areas where the study results could be applied in stakeholder collaborations, on request.

4.5. Further Assessments

Recommendations:

- *Prepare detailed flood hazard maps within the base level flood hazard mapping areas delivered by this study.*
- *Leverage regional flood frequency analysis completed by this study for future work.*

This assessment delivered base level flood hazard maps for eight high priority areas within the CRD. While an advancement over previous work, the current studies are based on hydraulic modelling without field investigation or bathymetric surveys. Additional fieldwork, surveys, and more detailed hydraulic analyses are required to prepare maps suitable for regulation and mitigation planning, including the preparation of FCL maps.

In a continuation of the Thompson Geohazards Initiative, the FBC, with technical contribution from BGC, applied for funding from the Union of BC Municipalities to advance sections of Bridge Creek flood hazard mapping area to detailed flood assessments (BGC, February 25, 2021). The work includes the preparation of flood hazard maps for a range of return periods (20- to 500-year) and FCL maps for use in regulation (floodplain bylaws). Because hydraulic models already exist, the work would be a seamless progression of previous work. The maps will include modelled flood scenarios based on current and projected future flows due to climate change.

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,

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REFERENCES

Auditor General of British Columbia. (2018). Managing Climate Change Risks: An Independent Audit. Report of the Auditor General of British Columbia dated November 28, 2017, published February 2018. 117 pp.

BC Assessment. (2021). *BC Assessment Custom Report.* Provided by CRD via email attachment dated December 2020.

BGC Engineering Inc. (2019, March 31). *Thompson River Watershed Geohazard Risk Prioritization* [Report]. Prepared for Fraser Basin Council.

BGC Engineering Inc. (2020, April 3). *Thompson River Watershed Base Level Flood Hazard Mapping* [Report]. Prepared for Fraser Basin Council.

BGC Engineering Inc. (2020, September 24). Flood Risk Prioritization, Cariboo Regional District [Report]. Prepared for Fraser Basin Council.

BGC Engineering Inc. (2020, March 31). *RDCK Detailed Floodplain and Steep Creeks hazard Assessment: Summary Report*.

BGC Engineering Inc. (2021 February 21). *Flood and Steep Creek Hazards Workshop for Decision Makers.* Work plan prepared for Cariboo Regional District.

BGC Engineering Inc. (2021, February 25). *Work Plan: Detailed Flood Hazard Mapping, Bridge Creek* [Proposal]. Prepared for Fraser Basin Council in support of a funding application to the Union of BC Municipalities Emergency Preparedness Fund.

Brunner, G. W., & CEIWR-HEC. (2016). HEC-RAS River Analysis System 2D Modeling User's Manual. Retrieved from www.hec.usace.army.mil

Engineers and Geoscientists of BC (EGBC). (2017, January). Guidelines for Flood Mapping in BC. Web link: https://www.egbc.ca/getmedia/8748e1cf-3a80-458d-8f73-94d6460f310f/APEGBC-Guidelines-for-Flood-Mapping-in-BC.pdf.aspx.

Engineers and Geoscientists of BC (EGBC). (2018, August 28). Guidelines for Legislated Flood Assessments in a Changing Climate in BCC. Version 2.1. August 28. Web link: https://www.egbc.ca/getmedia/f5c2d7e9-26ad-4cb3-b528-940b3aaa9069/Legislated-Flood-Assessments-in-BC.pdf.aspx.

GeoBC Ministry of Forest, Lands and Natural Resources Operations GeoBC (GeoBC). (2019, May 3). *Specifications for Airborne Lidar for the Province of British Columbia, Version 4.0.* Victoria, BC.

Islam, S. Ul, Curry, C.L., Dery, S.J., & Zwiers, F.W. (2019, February). Quantifying projected changes in runoff variability and flow regimes of the Fraser River Basin, British Columbia. *Hydrology and Earth System Sciences, 23*, 811-828. https://doi.org/10.5194/hess-23-811-2019. https://www.hydrol-earth-syst-sci.net/23/811/2019/

Federal Emergency Management Agency (FEMA). (2018). Guidance for Flood Risk Analysis and Mapping, Base Level Engineering (BLE) Analysis and Mapping. Guidance Document 99.

Government of Canada. (2016). Canadian Digital Elevation Model (CDEM) Product Specifications. Available online at http://ftp.geogratis.gc.ca, accessed December 2018.

Jakob, M. (2020). Landslides in a Changing Climate. In: Landslides, Hazards, Risks and Disasters., 2nd edition. Elsevier.

Ministry of Forests, Lands, Natural Resource Operations (MFLNRO) and Rural Development. (n.d.). Guidance for Selection of Qualified Professionals and Preparation of Flood Hazard Assessment Reports.

Natural Resources Canada (NRCAN). (2018). Federal Floodplain Mapping Guidelines. Available online at: https://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/dsstr-prvntn-mtgtn/ndmp/fldpln-mppng-en.aspx [accessed: 2/10/2021].

Province of BC. (2016). British Columbia Emergency Management System: Guide. Source: https://www2.gov.bc.ca/gov/content/safety/emergency-preparedness-response-recovery/emergency-management-bc/bcems

Terra Remote Sensing. (2020). Thompson River Watershed lidar topography and orthographic imagery prepared for Fraser Basin Council.

United Nations. (2016). Working Text on Indicators. Information from negotiations during the Second Session of the Open-ended Inter-governmental Expert Working Group on Indicators and Terminology relating to Disaster Risk Reduction, held in Geneva, Switzerland from 10-11 February 2016. Issued on March 3, 2016, and revised March 24, 2016.

United Nations Office for Disaster Risk Reduction (UNISDR). (2015). Sendai Framework for Disaster Risk Reduction – UNISRD. Website accessed November 2018: https://www.unisdr.org/we/coordinate/sendai-framework.

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, CRD Prioritization and Base Level Flood Hazard Mapping 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 study results is called Cambio Communities. Other versions exist to support operational geohazard risk and information management programs for pipelines, roads, railways and the mining sector. 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 areas might require further assessment for a development approval application?
- What geohazard information is available in an area to support further assessment?

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

Hazard Information:

- Geohazard maps at three levels of detail: hazard identification, "base level", and detailed[1].
- Supporting information, e.g. hazard characteristics, 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 identification areas (elements at risk).
- Prioritization of geohazard identification areas based on geohazard and consequences ratings.

[1] See the main document of this report for further description of mapping levels of detail and use.

- Access to data downloads and reports for geohazard areas if available[2].

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.

Cambio study areas are organized by Regional District. Local government users and contractors may have access to a single district; provincial or federal users may have access to multiple Regional District study areas.

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 study areas.

A.1.3. Navigation

Figure A-1 provides a screen shot of Cambio following user login and acceptance of terms and conditions. Section A.1.4 describes map controls and tools, including how to turn layers on and off for viewing. Section A.2 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.2).

[2] 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.

Figure A-1. Online map overview.

A.1.4. Overview of 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). Section A.3 describes 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.

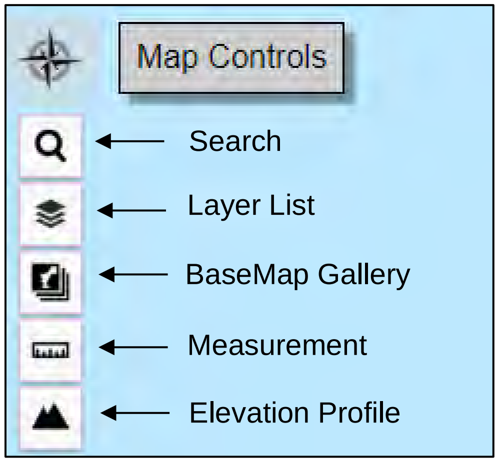

Figure A-2. Map controls.

A.2. LAYER LIST

A.2.1. Introduction

The layer list 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.

Each layer list drop-downs is described further below.

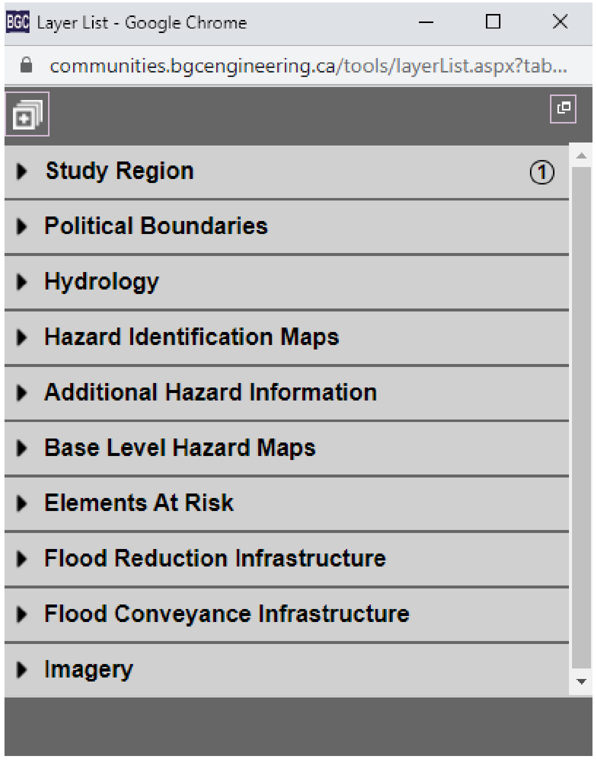

Figure A-3. Layers list.

A.2.2. Study Region

This section allows the user to display the boundaries of the study areas available to the user.

A.2.3. Political Boundaries

This section allows the user to display administrative boundaries of local governments, parks, and First Nations reserves.

A.2.4. Hydrology

A.2.4.1. River Network

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-4). 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.

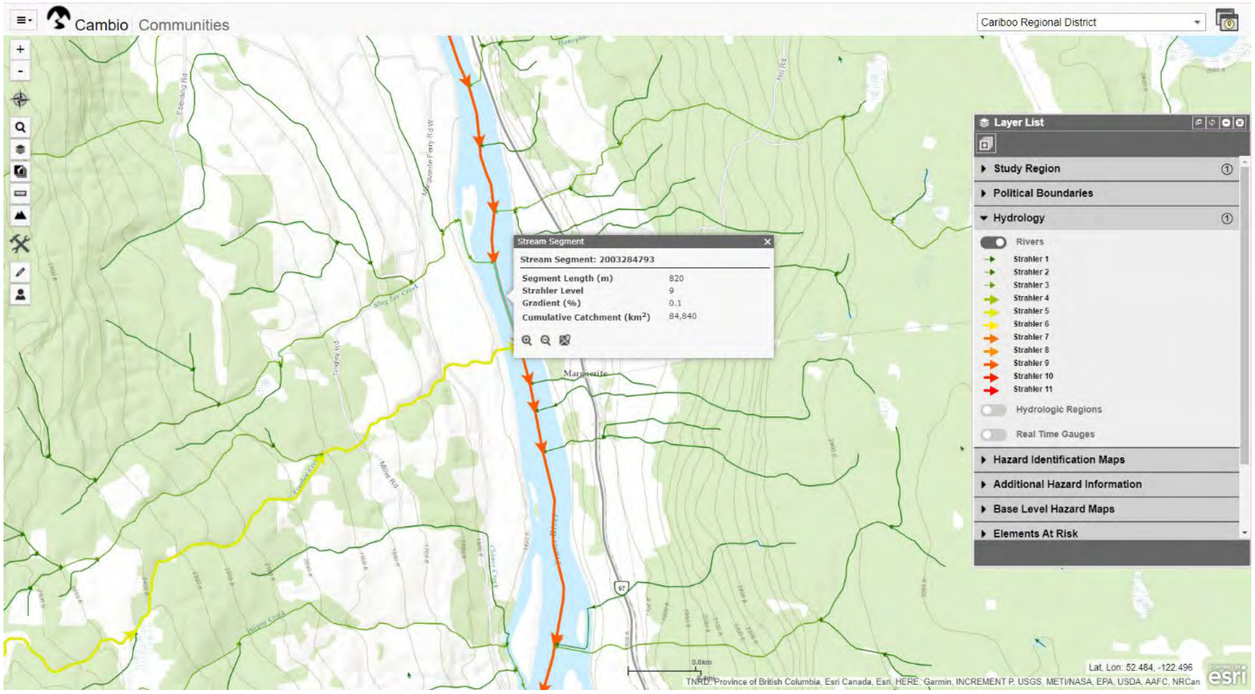

Figure A-4. Interactive Stream Network. The popup shows information for the highlighted orange stream segment.

A.2.4.2. 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-5). 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.

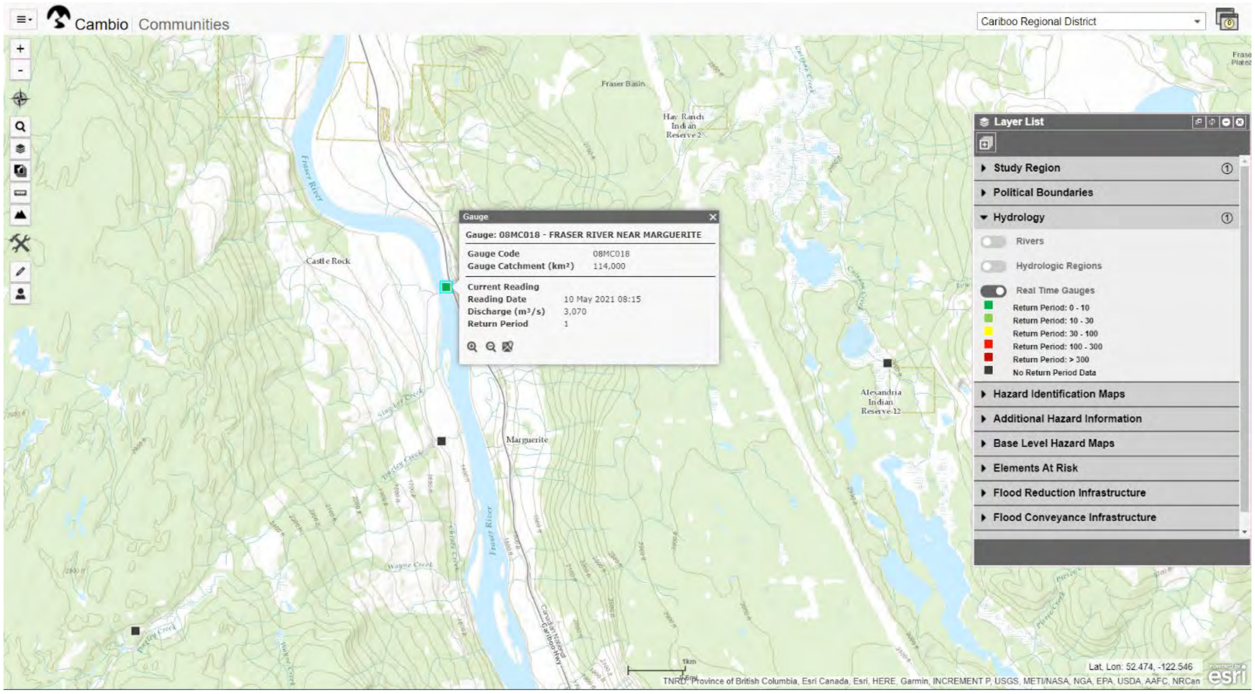

Figure A-5. Near real-time flow gauge. The popup shows gauge information including measured discharge and return period for a given reading date and time.

A.2.5. Hazard Identification Maps (including Risk Prioritization)

Hazard identification areas can be added to the map by selecting a given geohazard type under “Hazard Identification Maps” in the layer list. Once selected, the hazard areas can be colored coded by hazard type, hazard rating, priority rating, or consequence rating.

Clicking on an individual hazard feature reveals a popup window indicating the study area, hazard code (unique identifier), and hazard name (Figure A-6). Below this identifying information, the Hazard Rating as well as the community, lifeline, and combined Consequence and Priority Ratings are displayed for specific site.

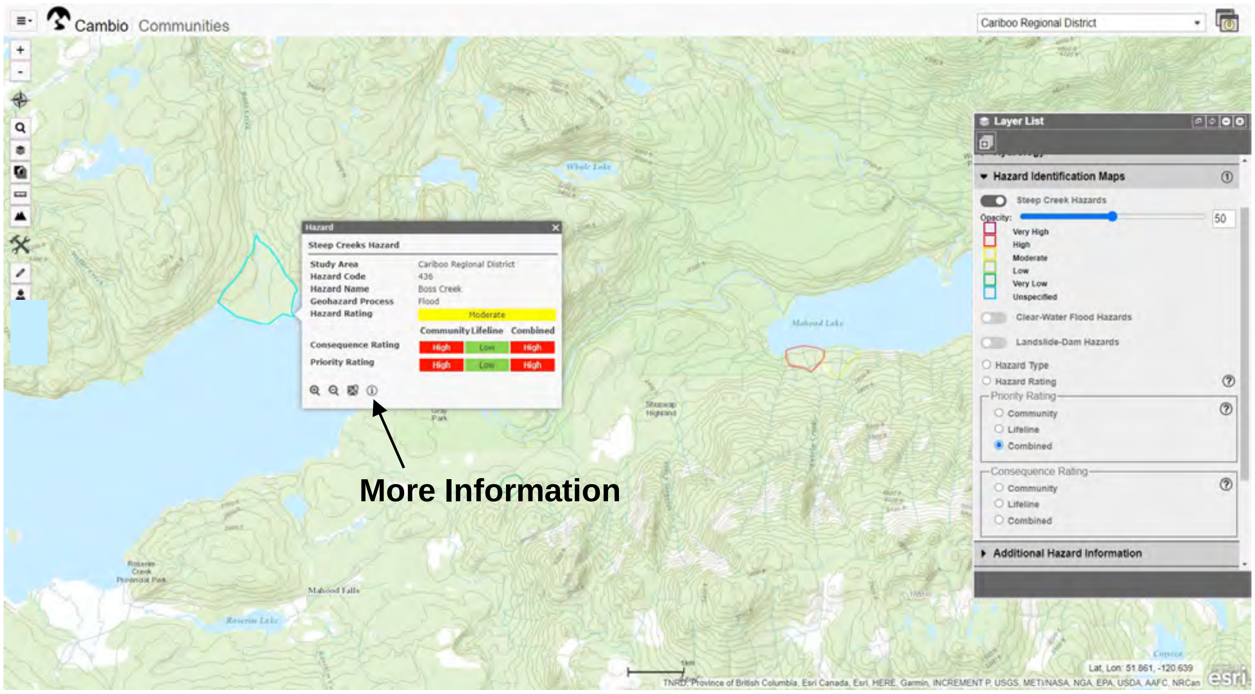

Figure A-6. Geohazard feature popup.

At the bottom of the popup window, there are several options (Figure A-6). Clicking the Google Maps icon opens Google Maps in a new browser window at the hazard site. This feature can be used to quickly access Google Street View to view ground level imagery where available. Clicking the "ℹ" icon opens a sidebar on the right side of the screen with detailed information about the hazard (Figure A-7). Drop-down menus allow the user to view as much detail as required.

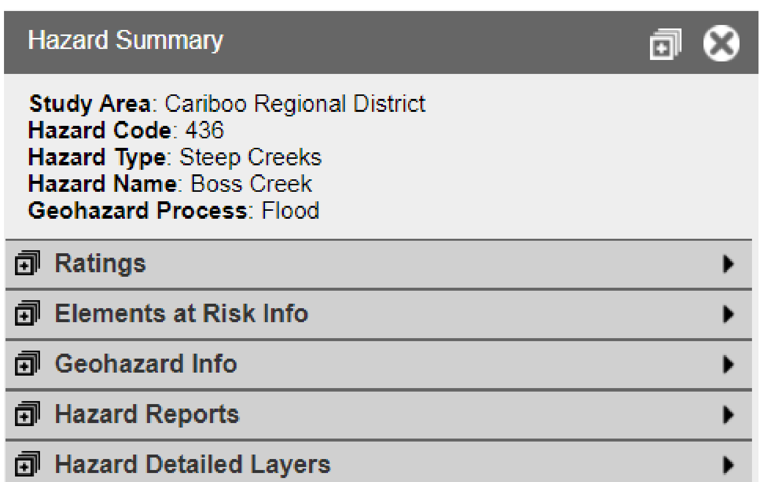

Figure A-7. Hazard summary sidebar.

Table A-1 summarizes the information displayed within the sidebar drop-down menu. In summary, clicking Ratings reveals the site Priority, Consequence, and Hazard Ratings within their respective matrices. See Section 5.0 of the CRD prioritization (BGC, September 24, 2020) for further description of these ratings. The geohazard, elements at risk, and hazard reports drop-downs display site specific data and supporting information. Hover the mouse over the "❓" icon in each row to view a more detailed definition, the assumptions made, and/or the limitations for the information displayed.

Click the "⬇" icon at the bottom right of the sidebar to download the hazard summary in either comma-separated values (CSV) or JavaScript Object Notation (JSON) format.

Table A-1. Hazard summary sidebar contents summary.

Drop-down Menu	Contents Summary
Ratings	Provides Geohazard, Consequence and Priority Ratings for an area, displayed graphically as matrices. The community, lifeline, and combined ratings are plotted separately within the Priority and Consequence Rating matrices. The Geohazard and Consequence Ratings combine to provide the Priority Rating. For more information on ratings methodology, see the CRD Prioritization Study (BGC, September 24, 2020).
Elements at Risk Info	Summary of the elements at risk and/or values within the geohazard area. This includes data on population, land and improvements, businesses, lifelines, and environmentally sensitive habitat. These inputs form the basis for the consequence rating for a given area.
Geohazard Info	Summary of the geohazard characteristics and/or values for the specific geohazard feature. This includes data on watershed parameters, hydrology, dam details, and comments. There is also metadata provided for the inspection entry date and the inspection author (if applicable). These inputs form the basis of the geohazard rating and intensity (destructive potential) component for the consequence rating of a given area.
Hazard Reports	Links to download previous reports associated with the area (if any) in pdf format.

A.2.6. Additional Hazard Information

Additional geohazard-related layers are found under "Additional Hazard Information" in the layer list. Available layers include historical floodplains, historical wildfire events, flood plain identification modelling results, and flood advisory and warning notifications. These should be reviewed with reference to the main report document for context and limitations.

A.2.7. Base Level 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 area. Selecting “Base Level Hazard Maps” under the layer list will display the available geohazard identification areas (Figure A-8). There is the option to view a 200-year event flood depth map and/or a flood velocity map for each area with and without climate change (CC) consideration. The maps can be added to the web display by selecting a given hazard layer within the geohazard identification area drop-down menu.

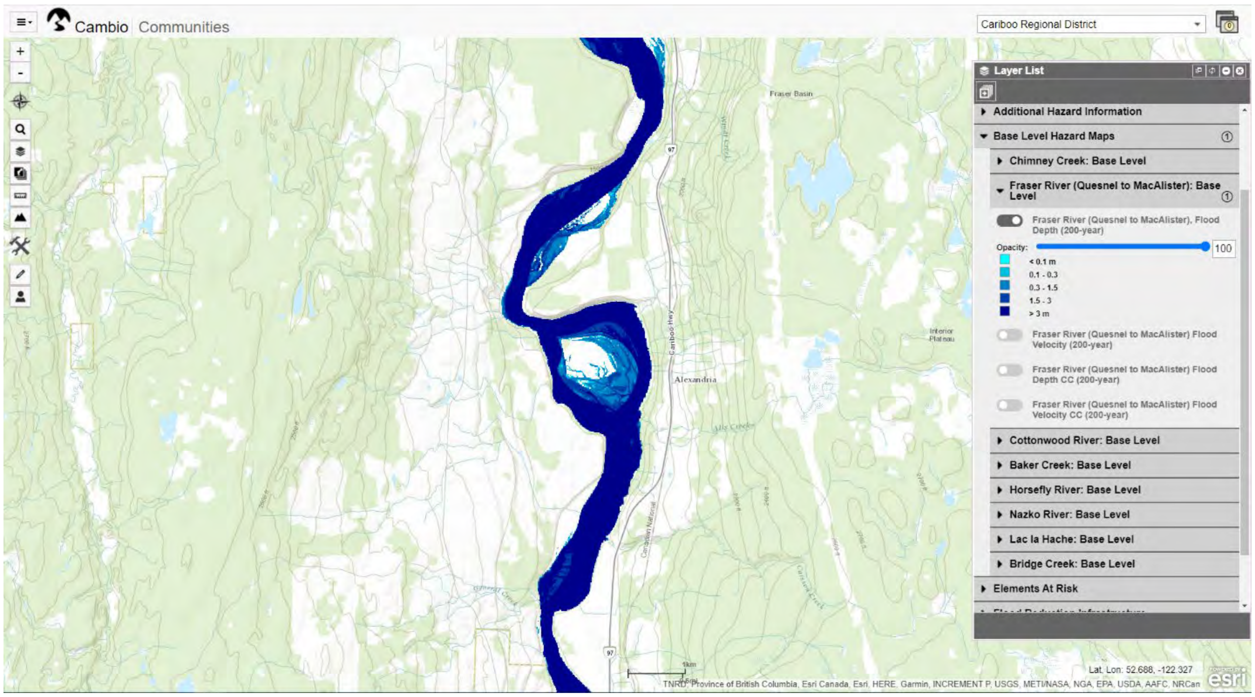

Figure A-8. Example base level hazard map layers.

A.2.8. Detailed Hazard Maps

Detailed hazard maps are not yet available for the Cariboo Regional District. Detailed instructions are provided below in the event that the district undertakes a detailed hazard assessment study with BGC.

Detailed hazard maps show spatial information about hazards within a geohazard identification area. Once this layer is selected, a drop-down list of each geohazard identification area where geohazard maps are available is displayed (Figure A-9). The geospatial data includes multiple maps at the range of return periods assessed as well as maps which include climate change (CC) consideration. Hazard map layers can be viewed by selecting the toggle-switch icon located left of the layer name (Figure A-9). Hazard map layers can also be accessed through the “Hazard Identification Maps” sidebar under “Hazard Detailed Layers” (Figure A-7).

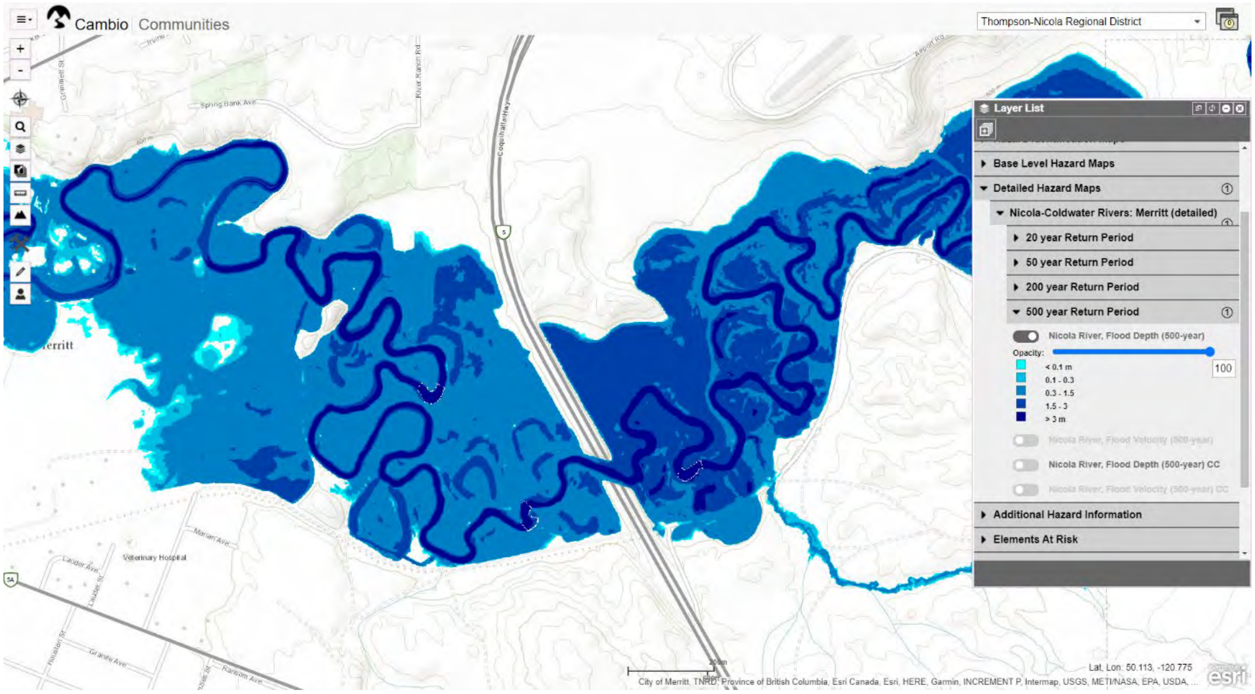

Figure A-9. Example detailed hazard map layers.

A.2.9. Elements at Risk

Elements at risk can be displayed on the map by selecting a given asset type in the layer list. The available elements at risk include community assets (land and improvements, business, critical facilities, environmental values) and lifelines. Infrastructure labels will show up for select features at a higher zoom level. BGC notes that the asset data displayed on the map is not necessarily complete.

A.2.10. Flood Reduction Infrastructure

Flood reduction infrastructure can be displayed on the map by selecting a given infrastructure type in the layer list. The available flood reduction structures include dikes, appurtenant structures, and dams. BGC notes that the infrastructure data displayed on the map is not necessarily complete.

A.2.11. Flood Conveyance Infrastructure

Flood conveyance infrastructure can be displayed on the map by selecting a given infrastructure type in the layer list. The available flood conveyance structures include culverts and bridges. BGC notes that the infrastructure data displayed on the map is not necessarily complete.

A.2.12. Imagery

The imagery drop-down provides access to lidar hillshades and ortho-imagery as available.

A.3. ADDITIONAL MAP CONTROLS

A.3.1. Search

Search is currently available for hazard identification map names and street addresses. To search for hazards:

a. Select the hazard type from the drop-down menu.
b. Scroll through the drop-down list to select the feature of interest.

A.3.2. Basemap Gallery

The basemap gallery allows the user to switch between 14 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.3.3. 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.3.4. 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 “ℹ” in the upper right corner of the profile viewer screen displays elevation gain and loss statistics. The precision of the profile tool corresponds to the resolution of the digital elevation model (approximately 25 m DEM). As such, the profile tool should not be relied upon for design of engineering works or to make land use decisions reliant on high vertical resolution.

A.4. FUTURE DEVELOPMENT

BGC is working to develop future versions of Cambio Communities, 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.
- Administrative functions for data management 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).
- 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.

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

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

APPENDIX B
CLEAR-WATER FLOOD HAZARD ASSESSMENT METHODS

B.1. INTRODUCTION

This appendix provides an overview of the approach used by BGC to develop the hydrological and hydraulic models for the Cariboo Regional District (CRD) Flood Hazard Mapping. This appendix is organized as follows:

- Section B.2 provides a summary of the hydrology methodology and 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.
- Section B.5 illustrates how the model results are presented in Cambio Communities.

B.2. HYDROLOGY

B.2.1. Flood Frequency Analysis Methodology

Peak discharges for the 200-year return period flood (Annual Exceedance Probability of 0.005) were determined through statistical analysis of historical streamflow records (i.e., gauge records) 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.
- Ungauged rivers and creeks.

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 either the *L*-moments method or the maximum likelihood estimate (MLE) depending on the period of record and fit of the data.

For the second case, nearby gauges were reviewed to see if they could be a proxy for the gauge of interest and years of overlapping data were compared to develop a relationship between peak

[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 annual maximum daily discharges were available, a model was built to interpolate the peak instantaneous discharge from the peak daily discharge.

annual discharges. If a relationship could not be established, then these study areas were treated as ungauged sites.

For the third case (ungauged sites), a regional flood frequency analysis (Regional FFA) was performed using the index-flood method, which is described further in Section B.2.1.2.

B.2.1.1. 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. A re-analysis of climate change variables for the Cariboo was not completed and instead a 20% upwards adjustment of flood quantiles was applied to all study areas excluding Lac La Hache and the Fraser River.

Climate change considerations were not accounted for at Lac La Hache, 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 water elevation due to climate change would have limited meaning relative to the uncertainty and resolution of the coarse DEM.

For the Fraser River, no climate adjustment to the peak discharge was applied. Almost half of the entire Fraser Basin is anticipated to transition from a snow-dominated runoff regime in the 1990s to a primarily rain-dominated regime in the 2080s, therefore potentially decreasing the freshet flood elevation. At the same time, more frequent landfalling atmospheric rivers are projected which is anticipated to increase the cold season runoff and resultant floods (Islam et. al., 2019).

B.2.1.2. Index Flood Methodology

The index flood method (IFM) is a commonly used technique for the construction of a flood frequency curve for catchments that either lack sufficient streamflow data or are ungauged. The IFM was developed by the United States Geological Survey (Dalrymple, 1960) and is based on the assumption that flood flows in a hydrologically similar region, when standardized by an appropriate index flood, are identically distributed. An index-flood is selected and used to scale the regional growth curve for the ungauged watershed of interest. To estimate the 200-year flood using the index flood method, the following relationship was used:

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

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

B.2.1.2.1 Formation of Hydrological Regions

Gauge records were assembled for British Columbia as well as northern portions of Washington, Idaho, and Montana as well as the eastern Slopes of the Rocky Mountains, to avoid introducing boundary effects. Candidate gauges were identified based on several criteria:

- Estimated catchment area within ± 15% of the published value.
- Less than 25% of the catchment area is regulated (i.e., located upstream of a dam).
- Maximum catchment area of 5,000 km^2. Catchments with a greater catchment area size are most likely well gauged and studied that a regionalization of flood is not required.
- Hydrometric stations along the same watercourse were removed to reduce cross-correlation.
- A minimum of 6 years of maximum peak instantaneous streamflow data was set as a minimum for analysis.
- Hydrometric stations recording water level only were excluded, as well as stations located within or immediately at the outlet of lakes.

Catchment characteristics were selected based on potential to influence flood events. A suite of 18 catchment characteristics including geometric, topographic, climatological and physiographic characteristics, were ultimately selected and estimated for each candidate hydrometric station.

The catchment characteristics were used to group the hydrometric stations into hydrological regions using a cluster analysis to develop multivariate linear regression curves for each region/cluster. The essence of cluster analysis is to identify clusters (groups) of hydrometric stations such that the stations within a cluster are similar while there is dissimilarity between the clusters. The algorithm used by BGC to group hydrometric stations was Agglomerative Hierarchal Clustering. Several statistical measures were used to guide the number of clusters to partition the hydrometric stations. The statistical measures include the Elbow Method, the Silhouette Score, and review of the dendrogram. The selection of the number of clusters was also subjectively assessed by reviewing the physical basis of the cluster distribution to verify that they are physically plausible. Based on an iterative selection process, the 898 hydrometric stations were ultimately organized into ten clusters or regions (Figure B.1). Once the clusters were confirmed, flood statistics (L-moments and flood quantile estimates) were calculated using the flood record for all candidate hydrometric stations.

The clusters were further subdivided as necessary to optimize the statistical homogeneity test (H-Test) score. Additionally, stations within the clusters were checked for discordancy (D_i) in terms of their calculated L-moments (Hosking & Wallis, 1997) and stations with a high discordancy were removed from the region.

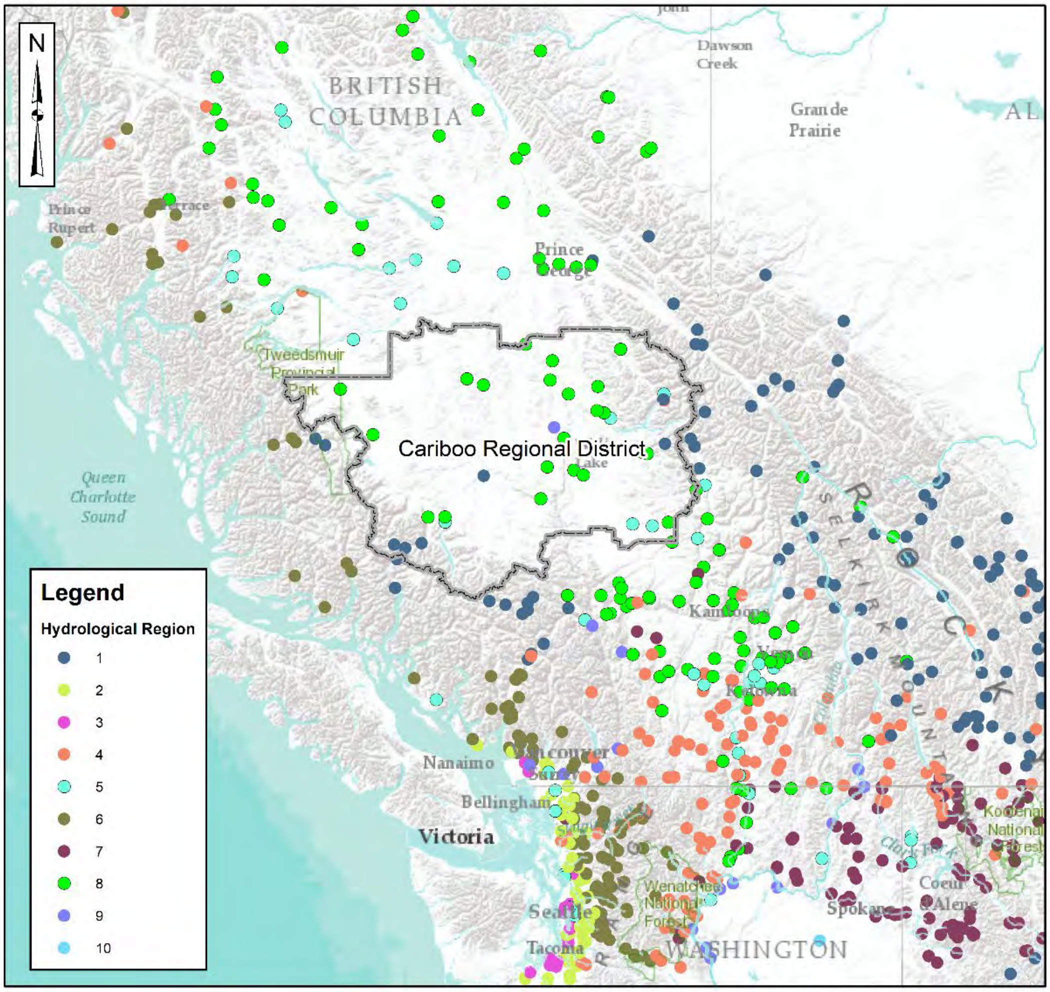

Figure B.1. Spatial distribution of the ten hydrological regions.

B.2.1.2.2 Development of Regional Growth Curves

Regional growth curves for the homogeneous regions were developed using the methodology described in Hosking and Wallis (1997) as implemented in the lmomRFA R-package version 3.3. The selection of an appropriate probability distribution for the growth curves was done using a goodness-of-fit test (*Z* statistics $\leq$1.64) and visual review of L-moment ratio diagrams. A Monte Carlo simulation was run to estimate the variability in the quantile estimates from the regional GEV distribution. This variability was used to set the error bounds on the regional growth curve.

B.2.1.2.3 Index Flood Estimation

The index-flood (Q_{mean}) was estimated using a multiple linear regression. Multiple linear regression is a classic statistical method to describe the relationship between a dependent variable and independent variables (catchment characteristics). The multiple linear regression model is for hydrological models is typically expressed as follows:

$$Q_T = a x_1^{\beta_1} x_2^{\beta_2} \cdots x_p^{\beta_p} \quad \text{[Eq. B-2]}$$

where Q_T is the flood quantile of interest (i.e. Q_{mean}), *a* is a constant, x_i is the i^{th} catchment characteristic, β_i is the i^{th} model parameter and *p* is the number of catchment characteristics. To solve for the model parameters, Eq. B-2 is linearized through a logarithmic transformation leading to:

$$log(Q_T) = log(a) + \beta_1 log(x_1) + \beta_2 log(x_2) + \cdots + + \beta_3 log(x_p) \quad \text{[Eq. B-3]}$$

These coefficients were estimated using the Weighted Least Squares method introduced by Tasker (1980), which accounts for the sampling error introduced by unequal record lengths. Unequal record lengths mean that the sampling errors of the observations (flood quantiles) are not equal (heteroscedastic) and the assumption of constant variance in Ordinary Least Squares method is not valid.

A provincial scale regression model was developed which used all hydrometric stations within the extent of the RFFA were used. The provincial model was developed to capture the range of hydrological processes which define mean annual flood in British Columbia. A number of candidate models were developed relating the Q_{mean} to the catchment characteristics. The top five models were selected using consideration for the adjusted R^2 and the Bayesian information criterion (BIC). The five models with the lowest BIC were selected and the Q_{mean} estimate was averaged.

B.2.2. Flood Quantiles

B.2.2.1. Site 36 – Chimney Creek

Although there are two historical WSC gauges on Chimney Creek (08MC036, 08MC004), the gauges were operated seasonally, and were operational for less than 5 years and therefore a flood series suitable for FFA could not be determined. Therefore, flood quantiles were estimated using the Regional FFA procedure based on the index-flood method (Section B.2.1.2). The watershed area was calculated to be 192 km^2 and the catchment characteristics are summarized in Table B-1. Based on its catchment characteristics, Chimney Creek was assigned to the Region 8 - Western Cordillera hydrological region. A regional growth curve was developed using a subset of gauges with catchment areas less than 500 km^2. The provincial regression model was used to estimate index the flood and the Q_{200} for the site was determined to be 37 m^3/s (Table B.2).

No significant tributaries are located in the study reach.

Table B-1. Catchment characteristics for Chimney Creek.

Variable	Value
Area (km^2)	192
Relief (m)	661
Catchment Length (km)	63

Variable	Value
Slope (%)	1.0
Centroid Latitude (º)	52.0
Centroid Longitude (º)	-122.0
Centroid Elevation (m)	721
Mean Annual Precip. (mm)	465
Mean Annual Temp. (ºC)	4.4
Precipitation as Snow (mm)	138
Winter Precip. (mm)	105
Summer Precip. (mm)	93
Forest (%)	35
Water and Wetland (%)	3.4
Urban (%)	0.0
Runoff Curve-Number (CN)	73

Table B.2. Hydrologic region assignment for Chimney Creek.

Catchment Name	Hydrometric Station	Catchment Area (km^2)	Hydrologic Region	Q_{mean} (m^3/s)	Flood Quantiles (m^3/s)		
					0.05 AEP	0.02 AEP	0.005 AEP
Chimney Creek	-	191	8	10	22	27	37

B.2.2.2. Site 38 – Fraser River (Quesnel to McAllister)

The real-time WSC gauge 08MC018 (*Fraser River Near Marguerite*) is located midway along the study reach. The watershed for the study area was calculated to be 116,028 km^2. Flood quantiles were calculated for the gauge based on the 1950 to 2015 record and preliminary data for 2016, 2017, and 2020[3] and prorated to the study area. The Q_{200} for the site was estimated to be 6919 m^3/s.

As part of their flood hazard and floodplain mapping study for the City of Quesnel, Urban Systems (July 2020) estimated the Q_{200} for the Fraser River at Quesnel to be 7903 m^3/s. This value was determined by prorating the *Fraser River Near Marguerite* gauge. Urban Systems does not indicate which distribution model they selected. The value obtained for the station by Urban Systems falls within the 95% confidence intervals calculated by BGC for the generalized extreme value (GEV) distribution, as shown in Figure B.2.

[3] Despite the gauge being a real-time hydrometric station, WSC had not published records instantaneous records beyond 2015 and daily records beyond 2017 at the time of our analysis. A preliminary peak daily value for 2020 was included in the analysis.

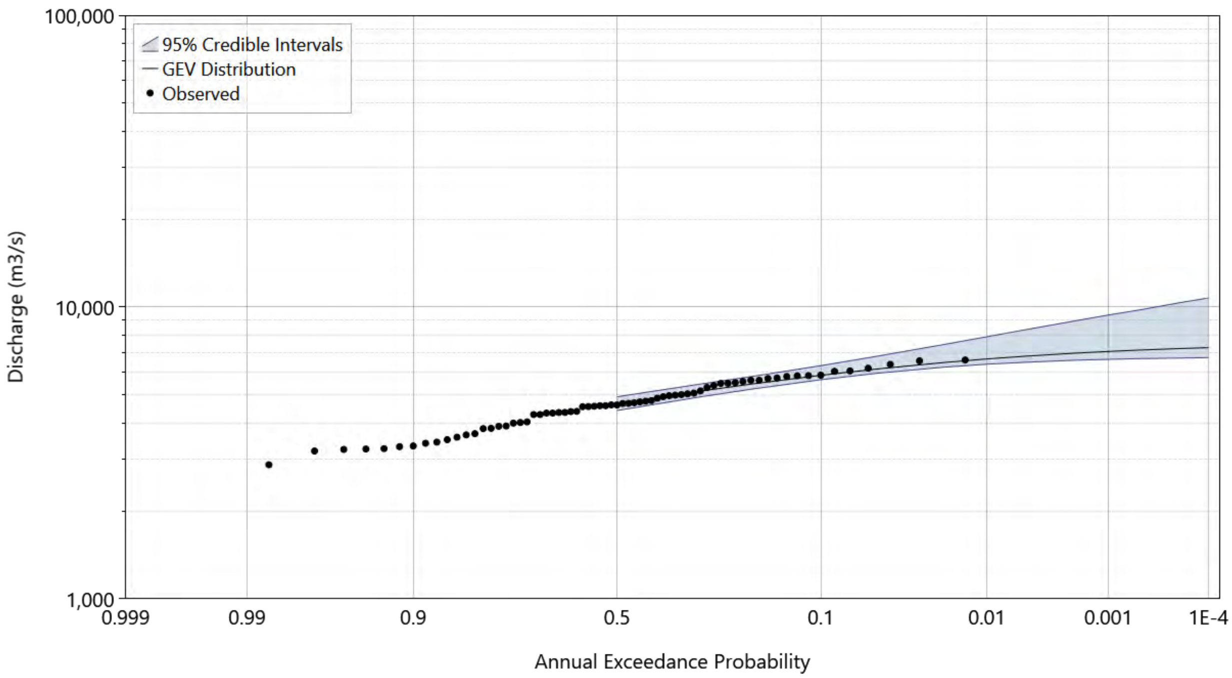

Figure B.2. Distribution fitting analysis for post-regression peak annual discharges, WSC gauge 08MC018 *Fraser River at Marguerite*. Confidence intervals (95%) for the GEV model are shaded.

No significant tributaries are located in the study reach.

B.2.2.3. Site 42 – Cottonwood River

At the upstream end of the modelled reach is the confluence of two rivers (Lightening Creek and Swift River) which form the Cottonwood River downstream of the confluence. An active WSC gauge is located on Swift River, but the gauge is located in upper reaches of the watershed and is therefore not suitable for pro-rated analysis. Therefore, flood quantiles were estimated using the Regional FFA procedure based on the index-flood method (Section B.2.1.2). The watershed area was calculated to be 1296 km^2 and the catchment characteristics are shown in Table B-3. Based on catchment characteristics the Cottonwood River watershed was assigned to the Region 8 - Western Cordillera hydrological region. A regional growth curve was developed using a subset of gauges located within the Western Cordillera Ecozone. The global regression model was used to estimate index the flood and the Q_{200} for the site was determined to be 283 m^3/s (Table B-4).

No significant tributaries are located in the study reach.

Table B-3. Catchment characteristics for Cottonwood River.

Variable	Value
Area (km^2)	1296
Relief (m)	1052
Catchment Length (km)	115
Slope (%)	0.9
Centroid Latitude (º)	52.9
Centroid Longitude (º)	-121.9
Centroid Elevation (m)	1275.1
Mean Annual Precip. (mm)	798.7
Mean Annual Temp. (ºC)	3.1
Precipitation as Snow (mm)	313.1
Winter Precip. (mm)	195.6
Summer Precip. (mm)	160.4
Forest (%)	23
Water and Wetland (%)	1
Urban (%)	1
Runoff Curve-Number (CN)	81

Table B-4. Hydrologic region assignment for Cottonwood River.

Catchment Name	Hydrometric Station	Catchment Area (km^2)	Hydrologic Region	Q_{mean} (m^3/s)	Flood Quantiles (m^3/s)		
					0.05 AEP	0.02 AEP	0.005 AEP
Cottonwood River	-	1296	8	114	193.9	228	283

B.2.2.4. Site 43 – Baker Creek

Real-time WSC gauge 08KE016 (*Baker Creek at Quesnel*) is located at the downstream end of the study reach. The flood quantiles were developed by conducting an FFA on the post-regression flows for the 1964-2018 gauge record, plus the provisional peak daily discharge[4] for the 2020 event of 149 m^3/s. The Q_{200} for the study site was estimated to be 231 m^3/s.

The study reach ends near the confluence of Baker Creek with the Fraser River. As part of their flood hazard and floodplain mapping study for the City of Quesnel, Urban Systems (July 2020) determined that peak flows on Baker Creek are independent from flows on the Fraser River. Typically, Baker Creek peaks in the first half of May, while the Fraser typically peaks in mid-June.

4 https://wateroffice.ec.gc.ca/report/real_time_e.html?stn=08KE016. Accessed April 8, 2021.

Therefore, backwater effects from the Fraser River were not considered by BGC for this site. Urban Systems did not estimate the Q_{200} for Baker Creek and instead used the average annual flow on Baker Creek as the inflow to the model and examined the backwater effects of the Fraser River Q_{200} on flooding in Baker Creek.

No significant tributaries are located in the study reach.

B.2.2.5. Site 44 – Horsefly River

Three major tributaries contribute flow to the model study area (Figure B.3). At the upstream end, Moffat Creek and Horsefly River converge near the Community of Horsefly. Horsefly Lake discharges to the Little Horsefly River which is a tributary to the Horsefly River part-way along the study reach. Near the downstream end of the study reach is WSC real-time gauge 08KH031 – *Horsefly River above Quesnel Lake*. Table B-5 lists the tributaries, relevant hydrometric gauges, and associated catchment areas.

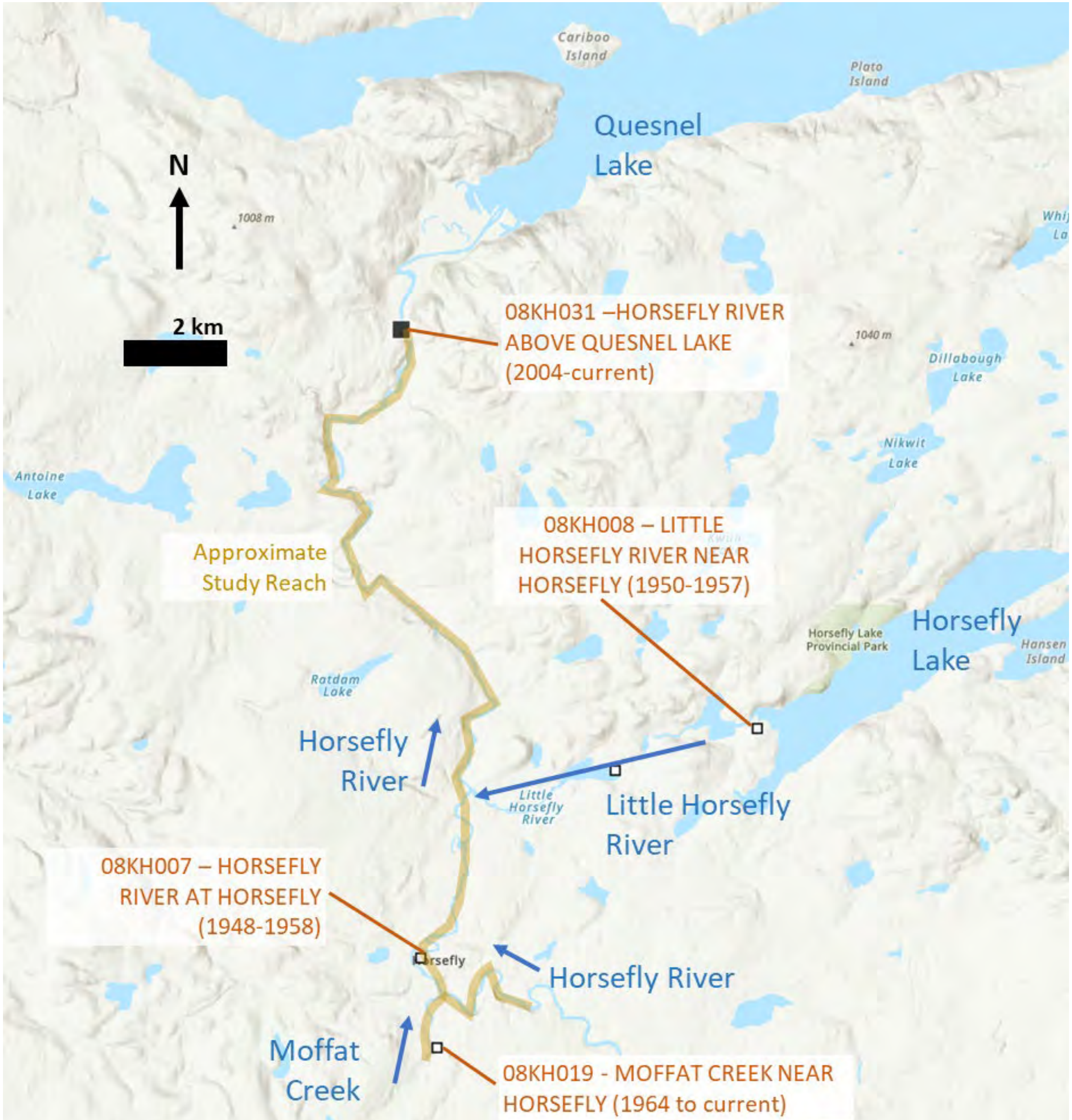

Figure B.3. The Horsefly River study area in relation to WSC gauges and tributary rivers and lakes. Background image: ESRI 2021.

Table B-5. Horsefly River study reach tributaries.

Tributary	Catchment Area (km^2)	Related WSC Gauge	Gauge Catchment Area (km^2)
Moffat Creek	521	08KH019 *Moffat Creek Near Horsefly* (1964-2018)	530
Horsefly River	1611	08KH010 *Horsefly River Above McKinley Creek* (1956-1957 and 1965 - 2015)	785
		08KH007 *Horsefly River at Horsefly* (1948 to 1958)	2145
Little Horsefly River	483	08KH031 *Horsefly River Above Quesnel Lake* (2005-2006 and 2008 - 2016)	2722
		08KH010 *Horsefly River Above McKinley Creek* (1956-1957 and 1965 - 2015)	785
		08KH008 *Little Horsefly River Near Horsefly* (1950 – 1957)	424

Inflow to the model from Moffat Creek was derived directly from the 1964 to 2018 records from the *Moffat Creek near Horsefly* gauge (08KH019).

Inflow to the model from the Horsefly River upstream of the community of Horsefly was derived from a frequency analysis of the 1956-1957 and 1965-2015 gauge records for real-time station 08KH010 (*Horsefly River Above McKinley Creek*). Scaling of the gauge flows to the model inlet was done using a site-specific exponent of 0.4, which was derived from a comparison of overlapping records between station 08KH010 and 08KH007 (*Horsefly River at Horsefly*, 1948 to 1958).

At the downstream end of the study reach is real-time gauge 08KH031 (*Horsefly River Above Quesnel Lake*), with records for 2005-2006 and 2008-2016. A comparison of the 10 years of overlapping data with gauge 08KH010 (*Horsefly River Above McKinley Creek*) show that:

- Both gauges typically peak within days of each other.
- The gauge above McKinley Creek is approximately 40% of the contributing area of the gauge above Quesnel Lake, but contributes approximately 60-90% of the peak discharge. This is due to the significant dampening effect of Horsefly Lake in the Little Horsefly River watershed, the catchment for which is 20% of the catchment to the gauge above Quesnel Lake.

In order to determine the inflows from Horsefly Lake via the Little Horsefly River, first the annual instantaneous maximum discharge record for the *Horsefly River Above Quesnel Lake* gauge was extended with the post-regression record for the *Horsefly River Above McKinley* gauge to generate a 54-year record. The extended record was then transposed to Little Horsefly River using a site-specific exponent of 4.6, which was developed by comparing the overlapping data from the *Little Horsefly River Near Horsefly* gauge (08KH008, 1950 – 1957) and *Horsefly River* *above McKinley* gauge[5]. The exponent was then modified to provide comparable total inflows with total outflows as calculated by an FFA of the extended *Horsefly River Above Quesnel Lake* gauge.

Design inflows (Q_{200}) are as follows:

- Moffat Creek = 66 m^3/s
- Horsefly River = 282 m^3/s
- Little Horsefly River = 24 m^3/s.

At the downstream end of the study reach the Horsefly River discharges into the Quesnel Lake. Relative water surface elevation of the lake has been recorded at gauge station 08KH011 (*Quesnel Lake near Likely*) from 1956 to 2021 (present). As the datum of the gauge has not been established by WSC, BGC calculated the difference between the average water surface elevation and the maximum annual water surface elevation and adopted the difference to represent the expected increase in stage during a high flood event. A 1.2 m difference in relative water surface elevation was estimated. Historical satellite and aerial imagery of the lake was cross referenced with annual water surface elevation levels to discern the degree of change in water surface area as a result of changes in water level. Based on this assessment, a relative change of 1.2 m in stage is consistent with water levels reaching the high-water mark/shoreline of the lake. The average lake elevation was assumed to be 729 m, as captured in the Canadian Digital Elevation Model (CDEM) dataset. Given low resolution of the dataset, the relative change in surface elevation was rounded to the nearest meter, resulting in the modelled lake elevation of 730 m.

B.2.2.6. Site 45 - Nazko River

WSC gauge 08KF001 (*Nazko River Above Michelle Creek*, 1965 - 1995, 3107 km^2) is located near the downstream end of the study reach. An FFA was conducted on the post-regression record and the flood quantiles prorated to the study reach catchment area of 4016 km^2. The quantiles were then divided based on contributing area between the Nazko River and the Snaking River model inflows. For the 200-year peak, this produced the following values:

- Nazko River (3364 km^2) = 127 m^3/s
- Snaking River (651 km^2) = 54 m^3/s.

Significant flooding was experienced for this reach during the 2020 freshet. The nearest active gauge, *West Road River Near Cinema* (08KG001, 1953 to present, 8808 km^2), identified the 2020 peak as the largest event on record (preliminary value of 482 m^3/s). A regression was developed between the West Road River Gauge and the Nazko River gauge for the 28 years of overlapping post-regression peak flow data. The regression was used to extend the Nazko gauge record to include the years 1996-2017 and 2020. A flood frequency of the extended Nazko record produced design inflows (Q_{200}) as follows:

- Nazko River = 156 m^3/s
- Snaking River Creek = 67 m^3/s.

[5] Typically, the exponent would have a value between 0 and 1; however, because the discharge at Little Horsefly River Near Horsefly gauge is heavily regulated by Horsefly Lake, the exponent is greater than 1.

The higher values are recommended for design.

B.2.2.7. Site 47 – Lac La Hache

The watershed upstream and in the downstream vicinity of Lac La Hache is poorly gauged. A WSC gauge recorded lake levels from 1955 to 1979 (08MC009 *Lac La Hache Near Lac La Hache*). The outlet of the lake is dammed but little information is publicly available on the condition of the private dam or its influence on lake hydraulics. The BC Dam inventory[6] identifies the following properties of the dam:

- Material: Steel
- Crest Elevation: 808.6 m
- Crest Length: 30 m
- Height: 0.3 m.

The CRD provided a photo taken of the dam on April 21, 2020 (Figure B.4) which appears to show the spillway to be a low-head weir.

Figure B.4. Spillway of regulated dam at the outlet of Lac La Hache on April 21, 2020. Photo Credit: CRD.

Water licenses for storage in the lake go back to 1924 and it is likely that the weir was built at that time. New licenses for water storage were issued in 1982, 1983, and 1987. Therefore, the gauge records of lake water levels likely account for the presence of the weir.

[6] https://maps.gov.bc.ca/ess/hm/imap4m/?catalogLayers=3959

A bathymetric survey of the lake (MOE, 1983) was conducted on June 2, 1981, at which time the lake surface elevation was identified as 807.7 m with a stored volume of 320 Mm^3. The survey did not identify the presence of the dam, confirming it is not a prominent feature.

Based on frequency analysis of gauge 08MC009 lake levels (including 18 years of measured values and 6 interpreted values), return period lake elevation estimates are shown in Table B-6.

Table B-6. Peak annual water elevation quantiles developed from the 08MC009 gauging station.

Return Period (years)	Stillwater Lake Elevation (m)
2	807.9
20	808.2
200	808.3

Lidar data was not available for this site, and therefore CDEM data was used to estimate the inundation extents of the 200-year stillwater lake level. Given the low resolution of the topographic data, the limited historical lake level records, and limited dam hydraulics information, a horizontal buffer of 30 m was applied[7] to the 808.3 m elevation polygon to account for uncertainty.

Layers presented in the webmap include:

1. Lac La Hache, 808.3 m Stillwater Flood Elevation (200-year)
2. Lac La Hache, 30 m Setback from 808.3 m Elevation.

B.2.2.8. Site 9 – Bridge Creek (100 Mile House to Canim Lake)

The design flow developed for the previous model for Bridge Creek (BGC, April 30, 2020) was carried over to this study. The Q_{200} of 32 m^3/s was developed from a single station analysis of WSC gauge 08LA020 (*Bridge Creek at Outlet of Horse Lake*).

B.2.3. Design Discharge Values

A summary of the design discharge values used in the hydraulic models are summarized in Table B-7.

[7] A 30 m buffering distance is commonly used in BC to approximate the riparian zone for smaller watercourses and as a minimum setback distance from top of bank for infrastructure from natural streams (as established in MWLAP, 2004; EGBC, 2017).

Table B-7. 200-year peak flow instantaneous flow estimates for study creeks.

Site	Watercourse (Area)	Method	Q_{i200} (m^3/s)
36	Chimney Creek	RFFA	37 (44) [1]
38	Fraser River (Quesnel to MacAlister)	Single station 08MC018	6919 [2]
42	Cottonwood River	RFFA	283 (340) [1]
43	Baker Creek	Single station 08KE016	231 (277) [1]
44	Horsefly River	Multiple regressions and correlations between single stations including 08KH019, 08KH010, 08KH007, 08KH031, 08KH008	Moffat Creek = 66 (79) [1] Horsefly River = 282 (338) [1] Little Horsefly River = 24 (29) [1]
45	Nazko River		Nazko River = 156 (187) [1] Snaking River = 67 (80) [1]
47	Lac la Hache (waterbody)	Single Station 08MC009	30 m setback from the 808.3 m contour[2] (Stillwater flood elevation)
9	Bridge Creek (Camin Lake to 100 Mile House)	Single Station 08LA020	Bridge Creek (at Horse Lake) = 23 (28) [1] Little Bridge Creek = 2.1 (2.5) [1] Buffalo Creek = 6.8 (8.2) [1]

Notes:
1. Climate adjusted peak discharge with additional 20%.
2. No climate adjustment to the peak discharge was applied.

B.3. HYDRAULIC MODELLING

B.3.1. Modelling Software

The HEC-RAS version 6.0 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.

B.3.2. Modelling Development

Separate models were developed for all of the sites except Lac La Hache, where hydraulic modelling was not undertaken. 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

<u>Model DEM and Terrain</u>

The models used the topographic data from Canadian Digital Elevation Model (CDEM) except for the Fraser River and Baker 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 the TNRD, this yields approximately a 20 m grid cell resolution (Government of Canada, 2016). For the Fraser River and Bridge Creek, 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 (as no site-specific data were available for these structures).and artificial blockages of the watercourses caused by the interpolation. Other artifacts were observed in the CDEM topographic models, but these could not be removed.

<u>Modelling Scenarios</u>

For this project, only modelling of the Q_{i200} and climate adjusted Q_{i200} in the primary watercourse was considered. The 200-year peak discharges in tributary creeks and rivers were not modelled as this was not part of the model scope.

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.

Hydraulic Structures

Hydraulic structures such as bridges and culverts were not explicitly modelled. The bridge embankments on either side of the bridges were incorporated within the models using the DEM derived from airborne lidar (Site 43 – Baker Creek and Site 38 – Fraser River) and therefore the constriction at bridges was accounted for. However, the accuracy of the hydraulics at the crossing is uncertain without a survey to define the geometry of the bridge including the geometry and elevation of the bridge deck, and soffit. The CDEM resolution is too coarse to represent hydraulic structures and roadway embankments.

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 and calibrated using historical high-water events if they are available. For this study, the models are uncalibrated with the Manning's n values being selected with guidance from the literature and using empirical equations. Manning's n values for floodplain areas are based on land cover types with Manning's n values for each land cover type from Chow (1959). The spatial land cover distributions were imported from digital land cover maps from the North American Land Change Monitoring System (NRCAN, 2019).

B.4. RESULTS

A summary of the models developed for each of the sites is presented in Table B-8. Water surface profiles and flow depths for each modelled area along with brief descriptions are presented in the following sections.

Table B-8. Summary of hydraulic models for each of the sites.

Watercourse (Area)	Inflow Boundary1	Outflow Boundary	Mesh Resolution
Site 36 - Chimney Creek	Inflow: 43.9 m^3/s	Normal Depth	20 m general resolution mesh
Site 38 - Fraser River (Quesnel to MacAlister)	Inflow: 5919 m^3/s	Normal Depth	50 m general resolution mesh, 20 m resolution for channel centreline, 4 repeats
Site 42 - Cottonwood River	Inflow: 283 m^3/s	Normal Depth	30 m general resolution mesh, 20 m resolution for breaklines, 4 repeats at the centreline, 3 repeats along the banks
Site 43 - Baker Creek	Inflow: 231 m^3/s	Stage Hydrograph: 470 m	25 m general resolution mesh, 5 m resolution for breaklines and refinement regions
Site 44 - Horsefly River	Horsefly River: 239 m^3/s Little Horsefly River: 19 m^3/s Moffat Creek: 48 m^3/s	Stage Hydrograph (Quesnel Lake): 730.1 m	30 m general mesh resolution, 20 m resolution for breaklines
Site 45 - Nazko River	Main channel inflow : 142 m^3/s Tributary inflow: 60 m^3/s	Normal Depth	25 m general resolution mesh, 20 m resolution for breaklines, 2 repeats
Site 9 - Bridge Creek (100 Mile House to Canim Lake)	Horse Lake: 23 m^3/s Buffalo Creek: 6.8 m^3/s Little Bridge Creek:2.1 m^3/s	Stage Hydrograph (Canim Lake): 769.2 m	25 m general mesh, 5 m refinement area along river

Note:

1. All inflow values provided are for the 200-year return period flood event excluding climate change. The values including climate change are 20% greater.

B.4.1. Site 36 – Chimney Creek

The water surface elevation and the flood depth for Site 36 – Chimney Creek are shown in Figure B.5 and Figure B.6. The centreline of the model taken from the 18 km upstream of the confluence of the Fraser River and Chimney Creek to the confluence. The water profile is generally shallower in the upper reaches and becomes increasingly steep as it approaches the Fraser River. This results in wider flooding extents in the upper reaches of the model particularly along Chimney Valley Road (Figure B.7) and becomes narrower downstream as the channel slope increases. The model was unable to correctly capture the flows at the very downstream end of the model and the results were clipped upstream of the confluence of the Fraser River. The resolution of the CDEM is too course to capture the channel of Chimney Creek and as such the actual flood extents may be greater than would actually occur.

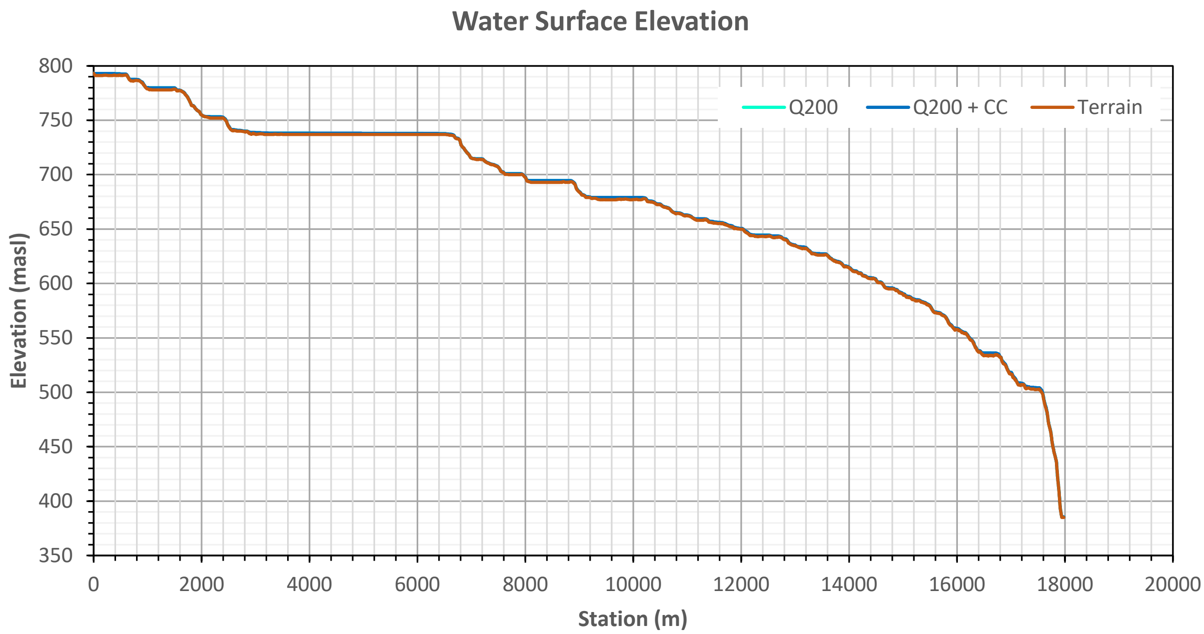

Figure B.5. Water surface elevation for Site 36 – Chimney Creek.

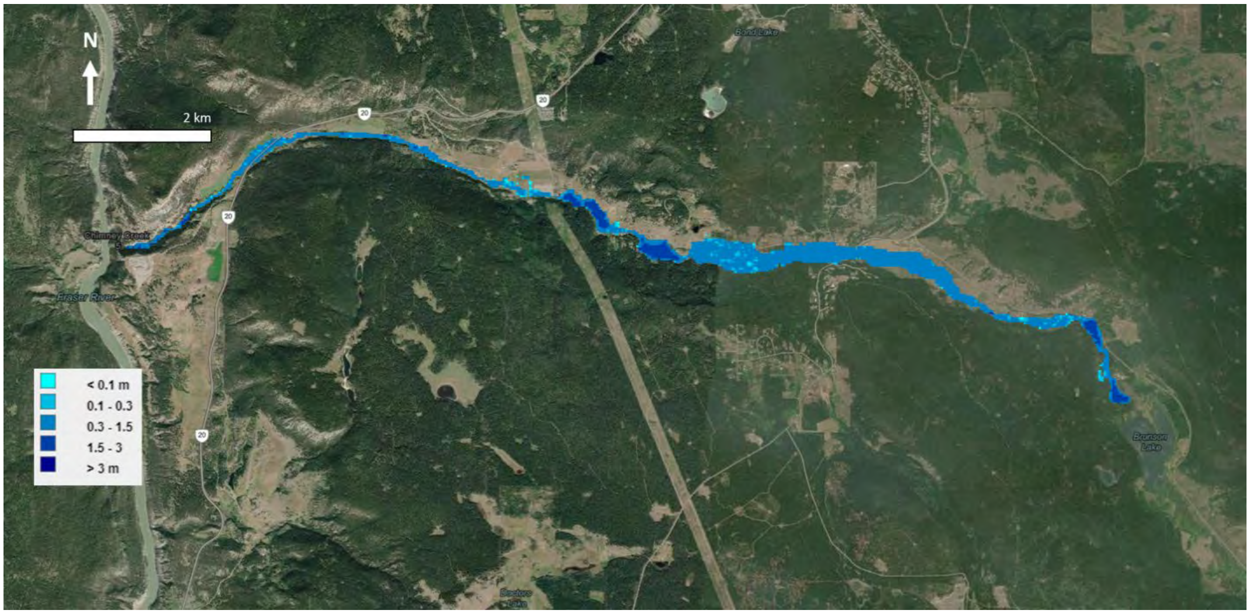

Figure B.6. Flood depth for Site 36 – Chimney Creek.

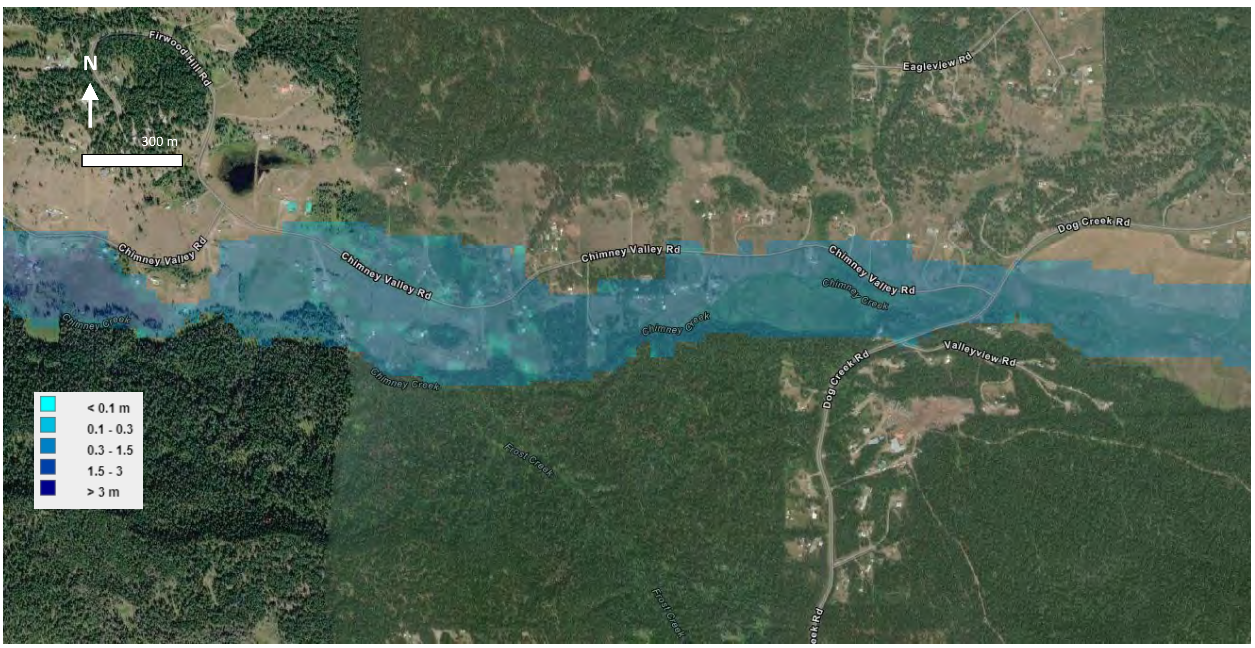

Figure B.7. Flood depth for Site 36 – Chimney Creek along Chimney Valley Rd.

B.4.2. Site 38 – Fraser River (Quesnel to McAllister)

The water surface elevation and the flood depth for Site 38 – Fraser River are shown in Figure B.8 and Figure B.9. The centreline of the model covers approximately 60 km of the Fraser. The water profile maintains a relatively constant slope throughout the entire modelled area. The flows are generally confined to the main channel with some flooding of the adjacent lands as shown in Figure B.10 around Marguerite.

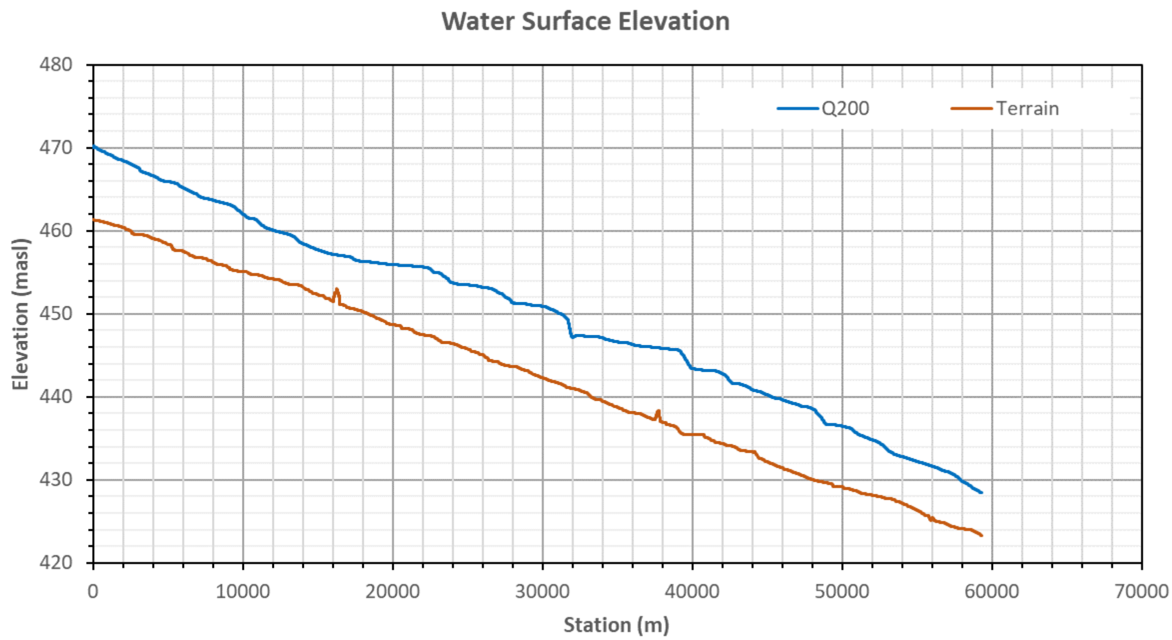

Figure B.8. Water surface elevation for Site 38 – Fraser River (Quesnal to MacAlister).

Figure B.9. Flood depth for Site 38 – Fraser River (Quesnal to MacAlister).

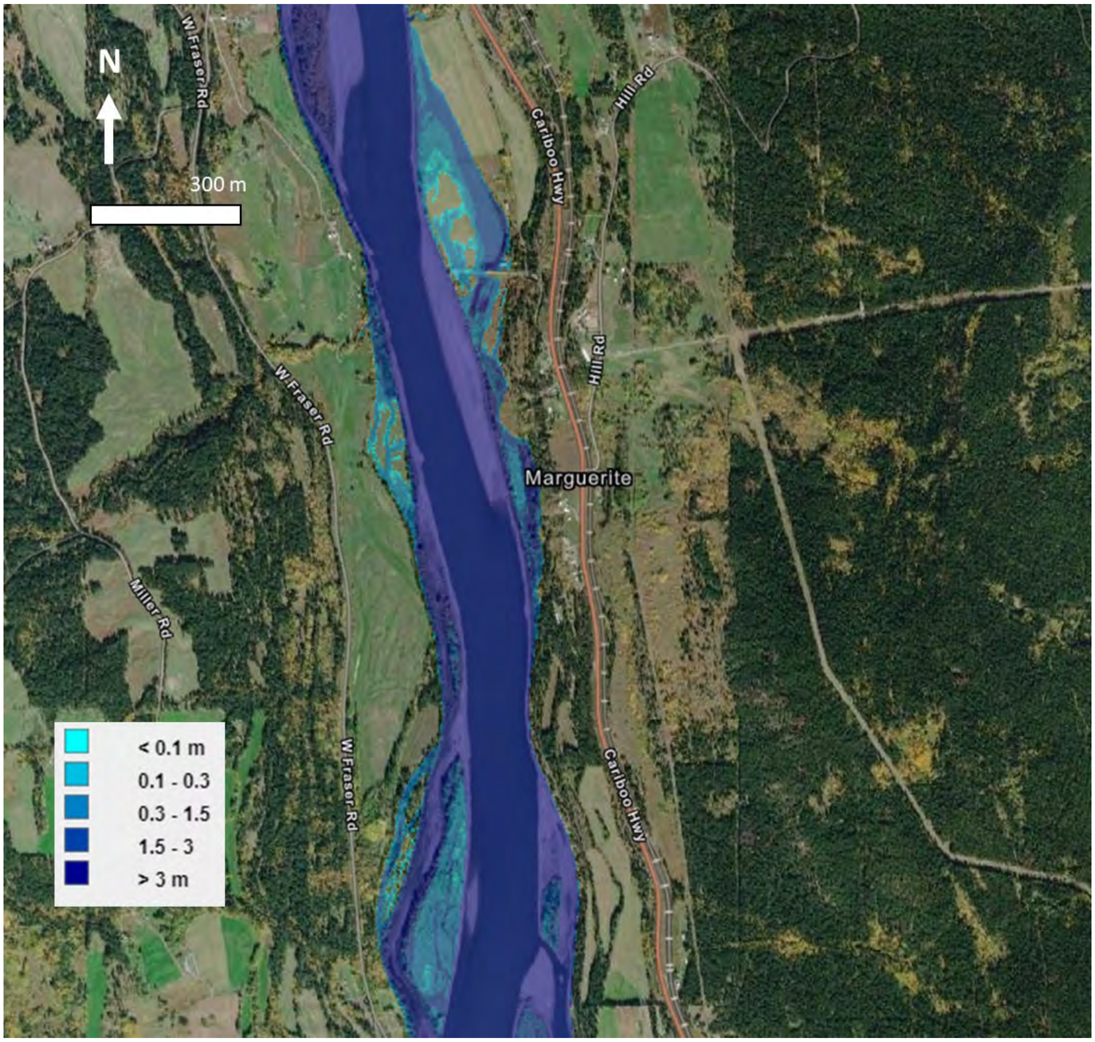

Figure B.10. Flood depth for Site 38 – Fraser River (Quesnal to MacAlister) near Marguerite.

B.4.3. Site 42 – Cottonwood River

The water surface elevation and the flood depth for Site 42 – Cottonwood River are shown in Figure B.11 and Figure B.12. The centreline of the model covers approximately 14 km of the Cottonwood River. The difference in the water surface elevation is minimal between the 200-year and 200-year plus climate change. As shown in the water surface elevation profile in Figure B.11, the river consists of both flat and steep sections. As a result, flooding extents vary along the river with wide flood extents in the flat sections and then narrower extents along the steeper sections. Figure B.13 shows the flooding extents for the 200-year flood at the town of Cottonwood.

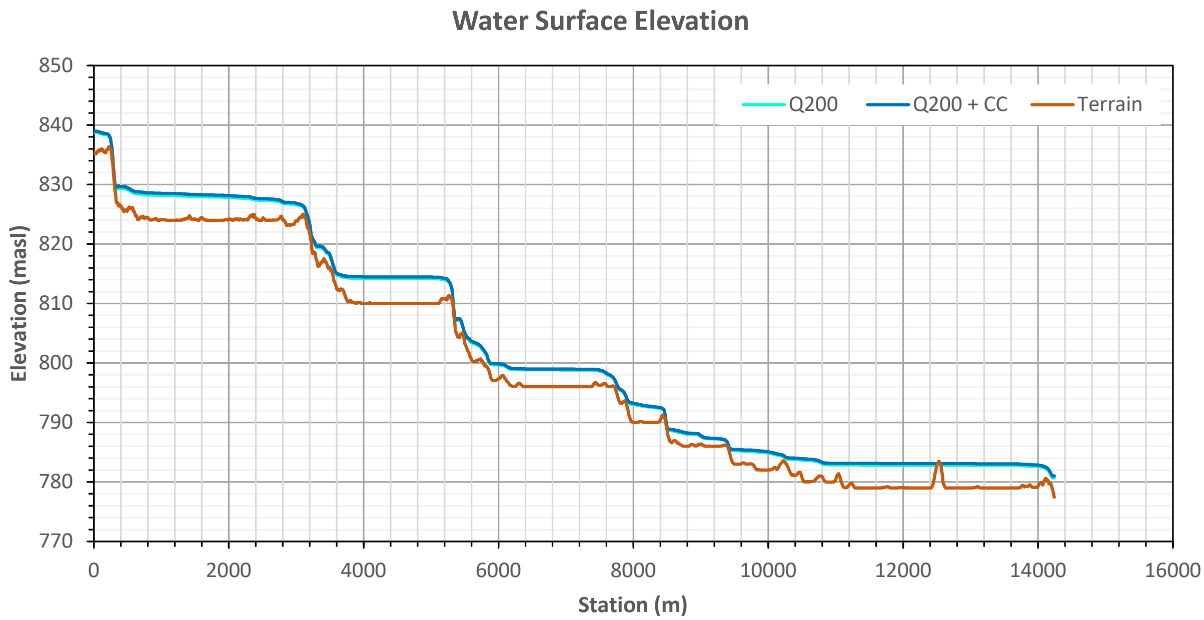

Figure B.11. Water surface elevation for Site 42 – Cottonwood River for the 200-year flood and 200-year flood with climate change.

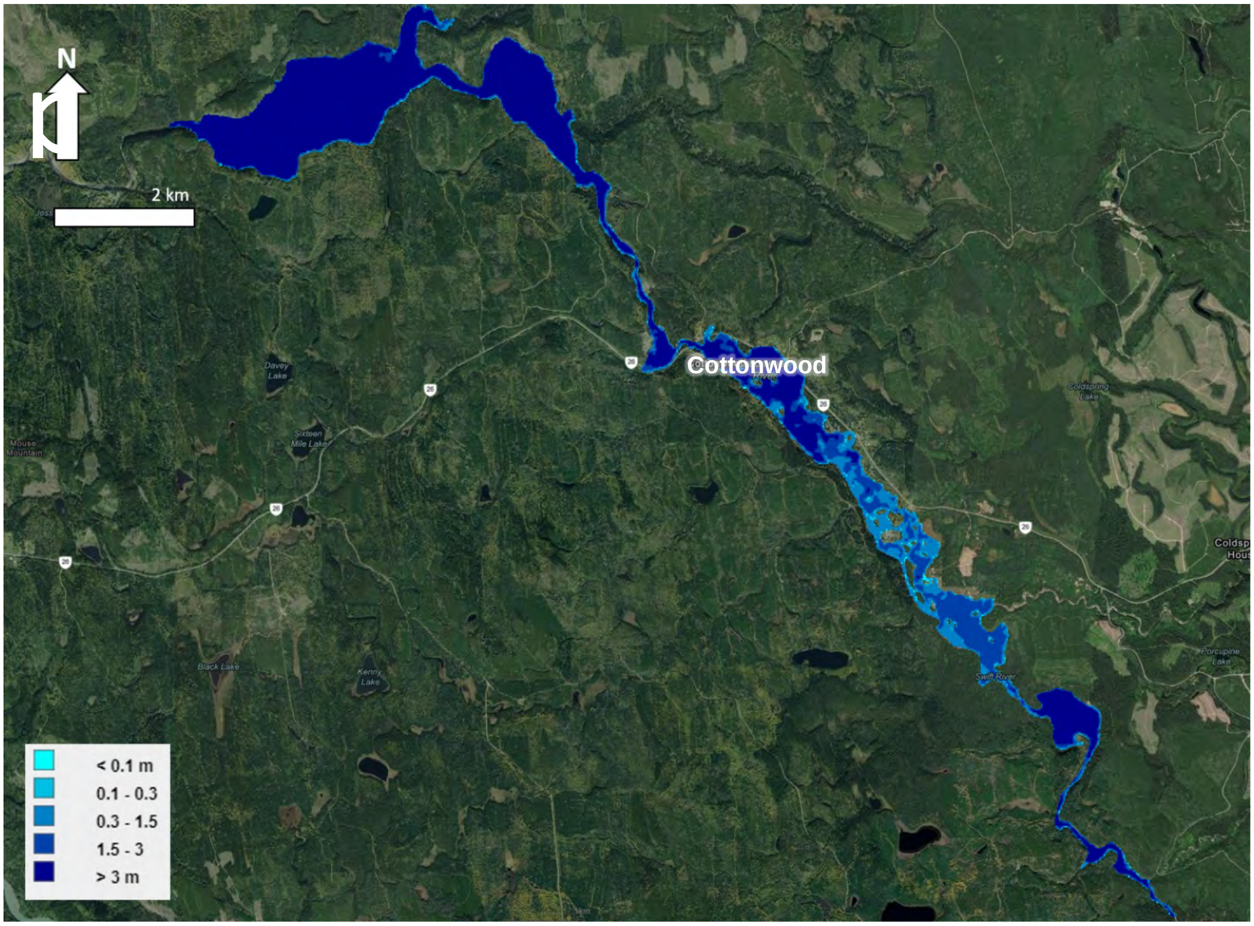

Figure B.12. Flood depth for Site 42 – Cottonwood River.

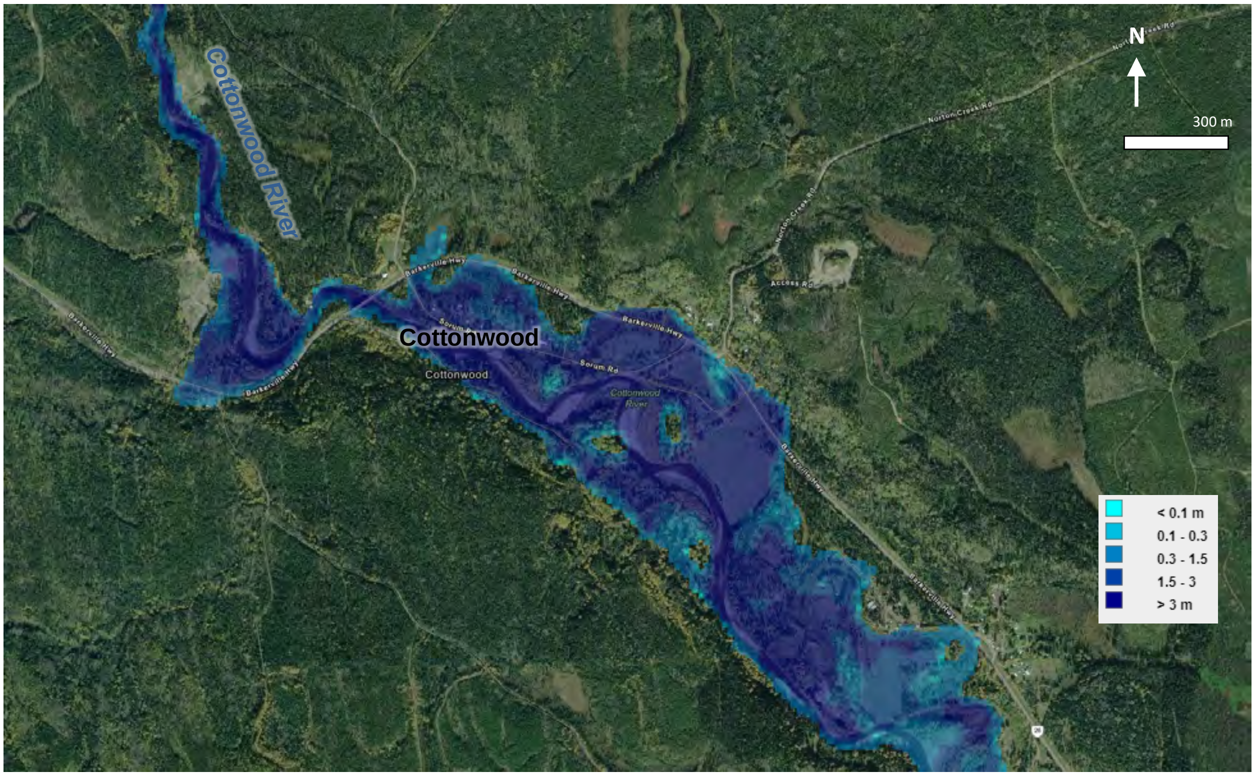

Figure B.13. Flood depth for Site 42 – Cottonwood River at Cottonwood.

B.4.4. Site 43 – Baker Creek

The water surface elevation and the flood depth for Site 43 – Baker Creek are shown in Figure B.14 and Figure B.15. The centreline of the model covers approximately 8.5 km of Baker Creek ending at the confluence with the Fraser River. The water surface elevation profile in Figure B.16 shows that the slope of Baker Creek is fairly consistent over the entire study area and little difference in the water elevation between the Q200 and Q200 with climate change is noted. The flooding extents are generally confined within the valley in the upstream reaches then start to widen before the creek enters Quesnel. Flooding of properties along the creek is noted including extensive flooding over Marsh Dr (Figure B.16).

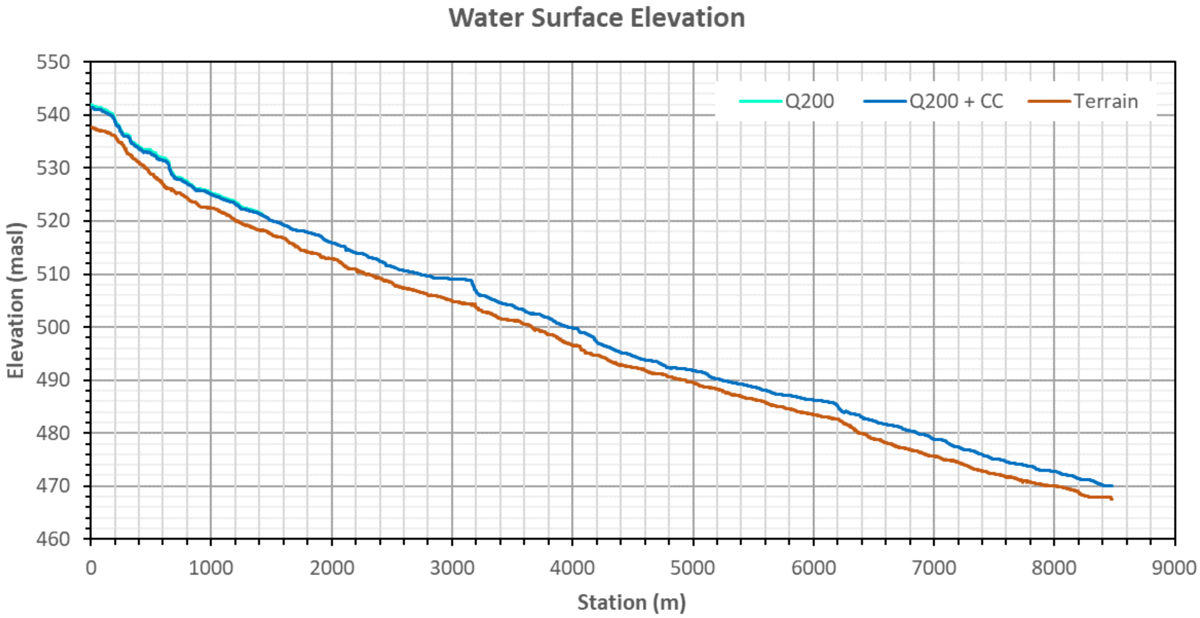

Figure B.14. Flood depth for Site 43 – Baker Creek.

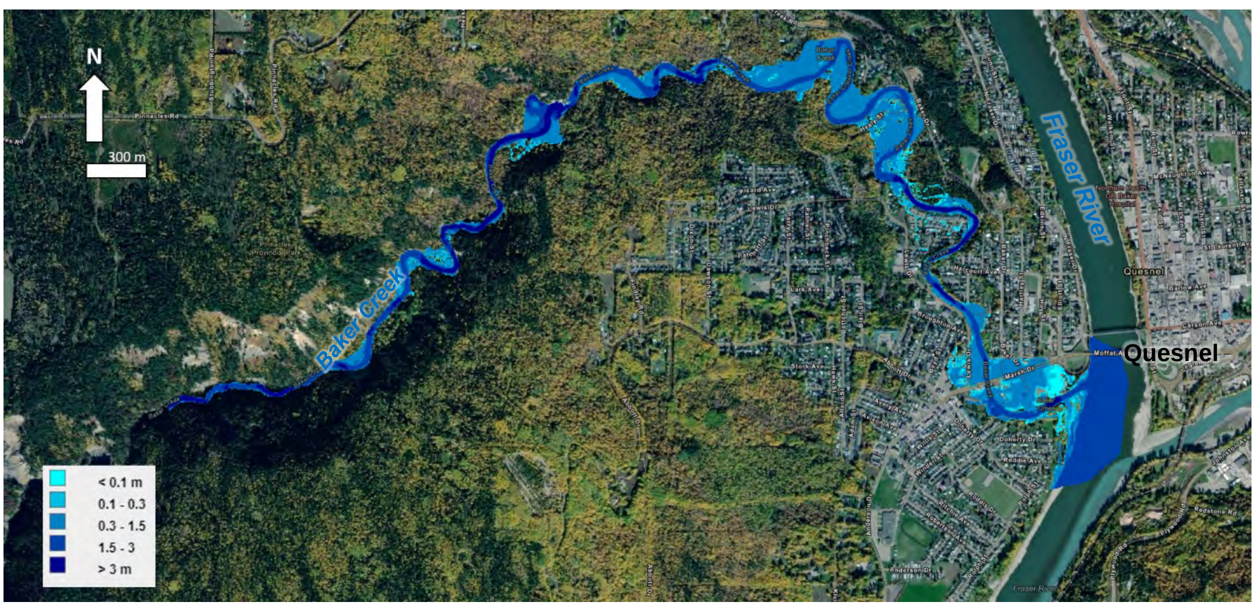

Figure B.15. Flood depth for Site 43 – Baker Creek.

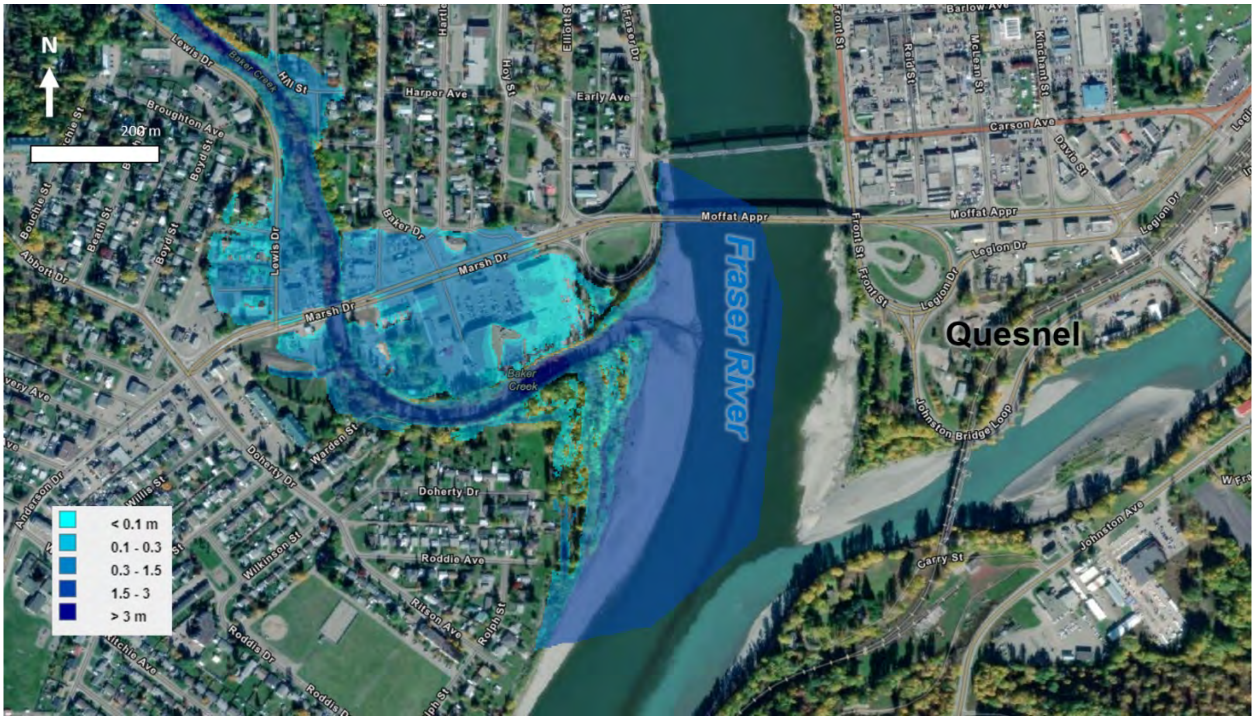

Figure B.16. Flood depth for Site 43 – Baker Creek near the confluence with the Fraser River.

B.4.5. Site 44 – Horsefly River

The water surface elevation and the flood depth for Site 44 – Horsefly River are shown in

Figure B.17 and Figure B.18. The centreline of the model covers approximately 31 km of the Horsefly River. The difference in the water surface elevation is minimal between the 200-year and 200-year plus climate change. As shown in the water surface elevation profile in Figure B.17, the river consists of both flat and steep sections. As a result, flooding extents vary along the river with wide flood extents in the flat sections and then narrower extents along the steeper sections. Figure B-19 shows the flooding extents at the village of Horsefly.

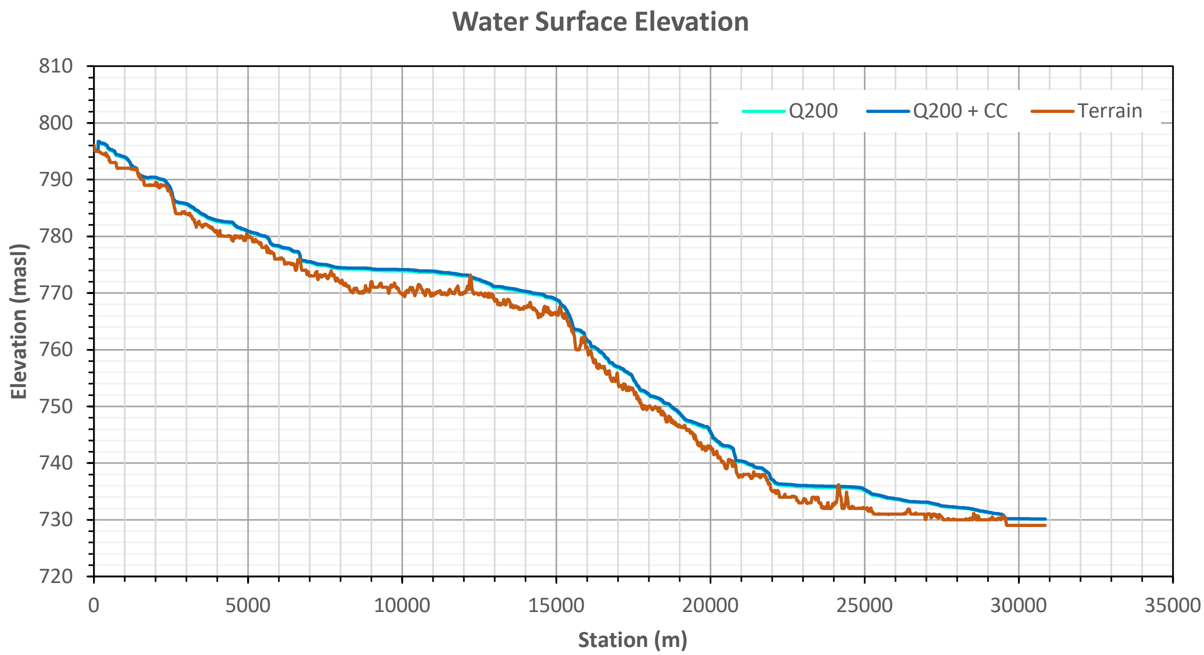

Figure B.17. Water surface elevation for Site 44 – Horsefly River.

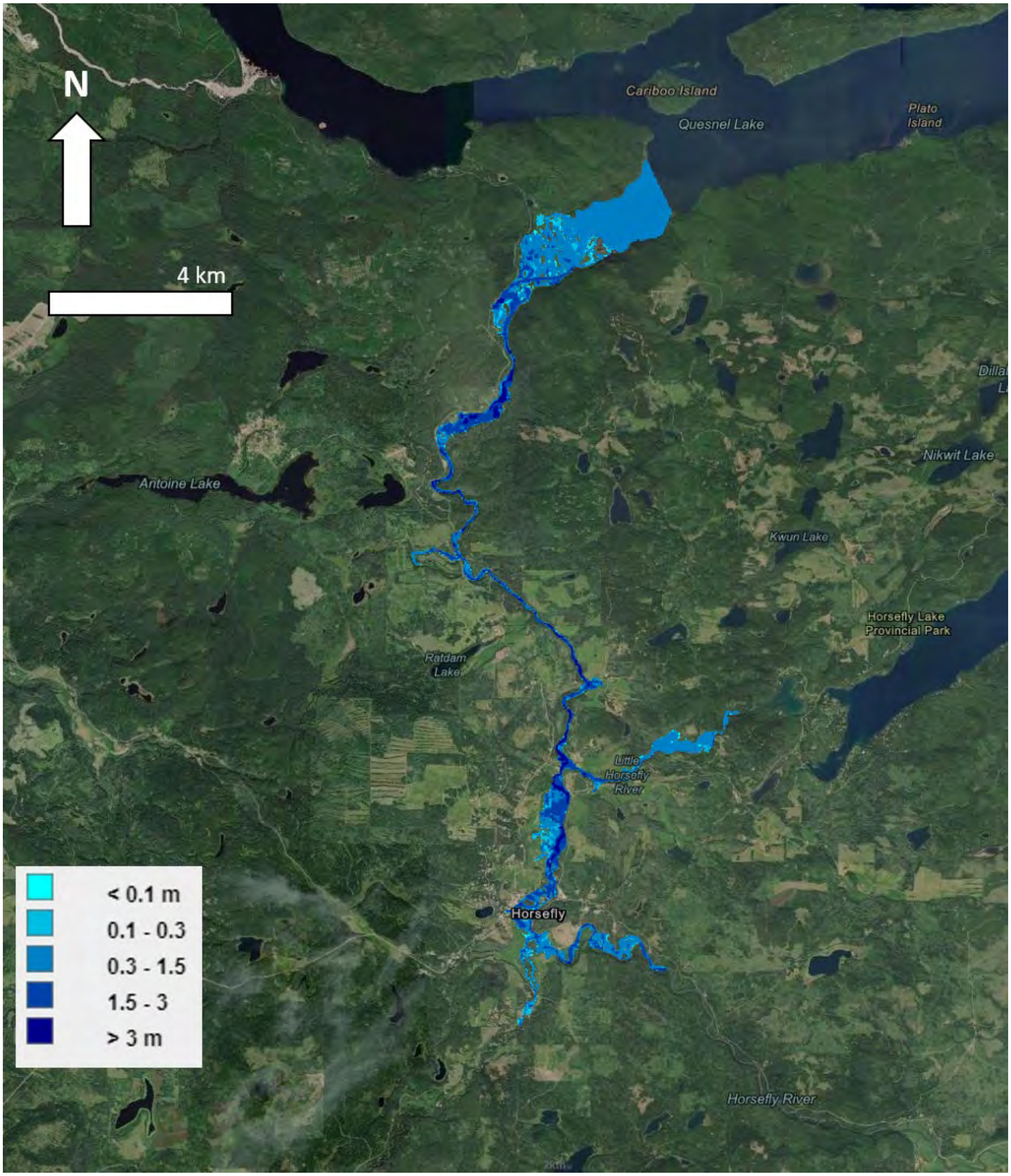

Figure B.18. Flood depth for Site 45 – Horsefly River.

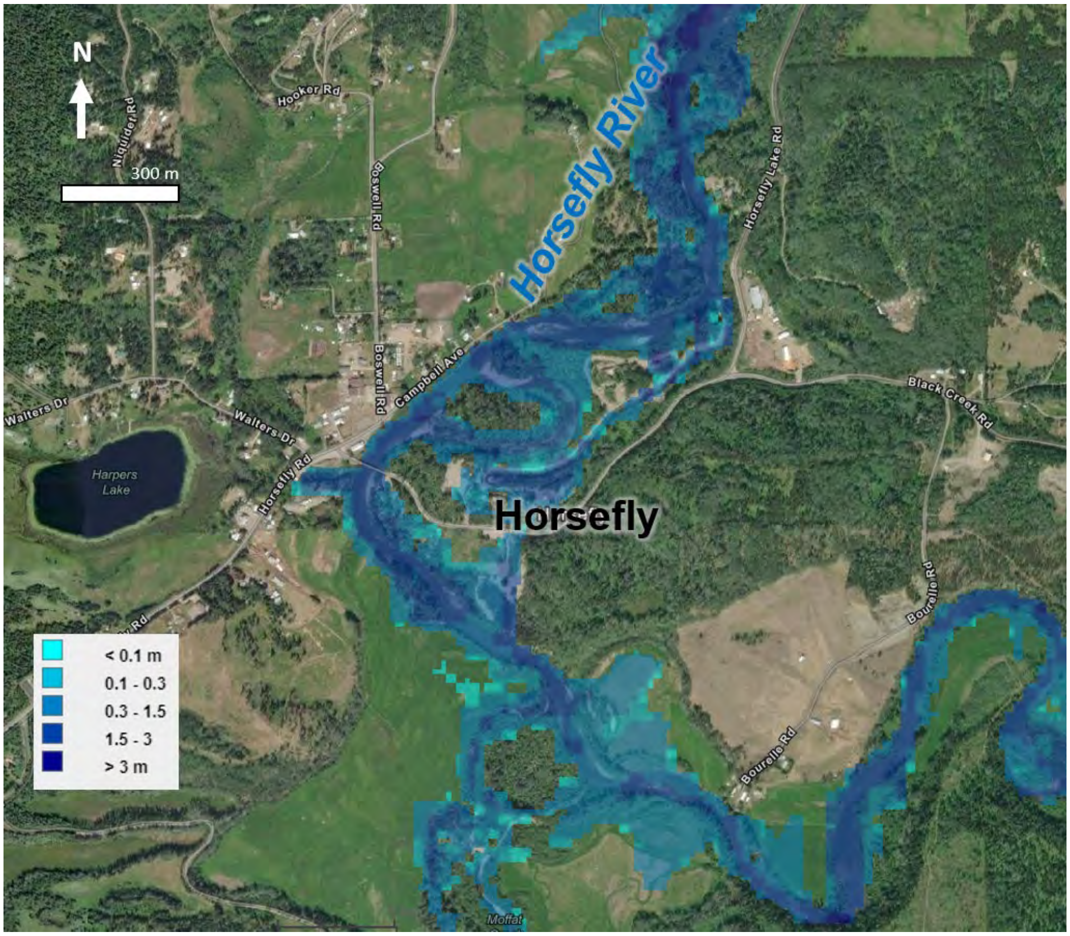

Figure B-19. Flood depth for Site 45 – Horsefly River at the village of Horsefly

B.4.6. Site 45 – Nazko River

The water surface elevation profile and the flood depth for Site 45 – Nazko River is shown in Figure B.20 and Figure B.21. The elevation profile in Figure B.20 extracted from the CDEM is almost flat for the first 16 km followed by a series of sharp drops and little difference is noted between the water surface for the Q200 and Q200 with climate change scenarios. Examination of the water surface from available imagery does not show evidence of sharp changes in the water surface elevation at the location of these drop and is an artifact in the processing of the CDEM. The flooding extents shown in Figure B.21 show that the Nazko River floodplains are quite wide particularly in the flatter sections of the CDEM and portions of the Nazko Road which follows the river to the west are flooded.

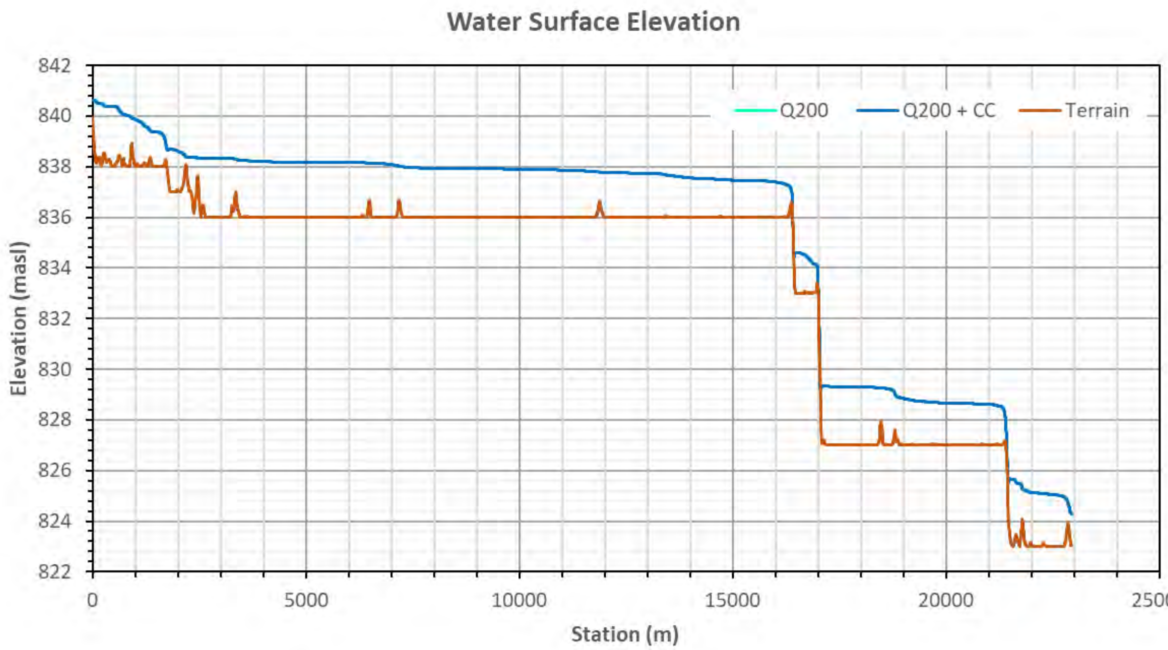

Figure B.20. Water surface elevation for Site 45 – Nazko River for the 200-year flood and 200-year flood with climate change.

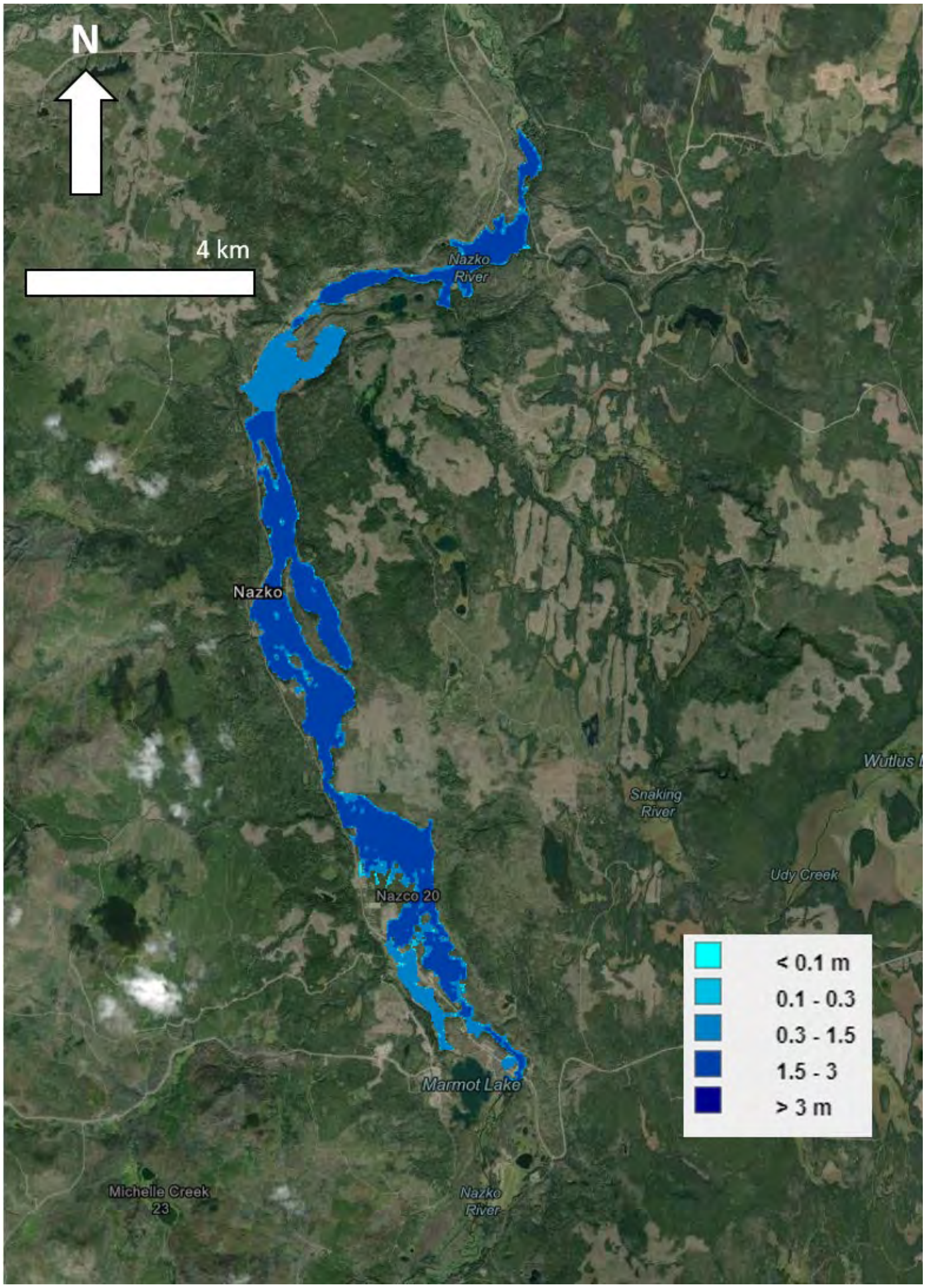

Figure B.21. Flood depth for Site 45 – Nazko River.

B.4.7. Site 47 – Lac la Hache

The 200-year, stillwater flood elevation and 30 m setback extents for portions of Lac La Hache are shown in Figure B.22 to Figure B.24.

Most lakefront properties fall within the 30 m setback polygon, while a number of properties along Forbes Road, including the road itself, are impacted by the 200-year flood elevation polygon.

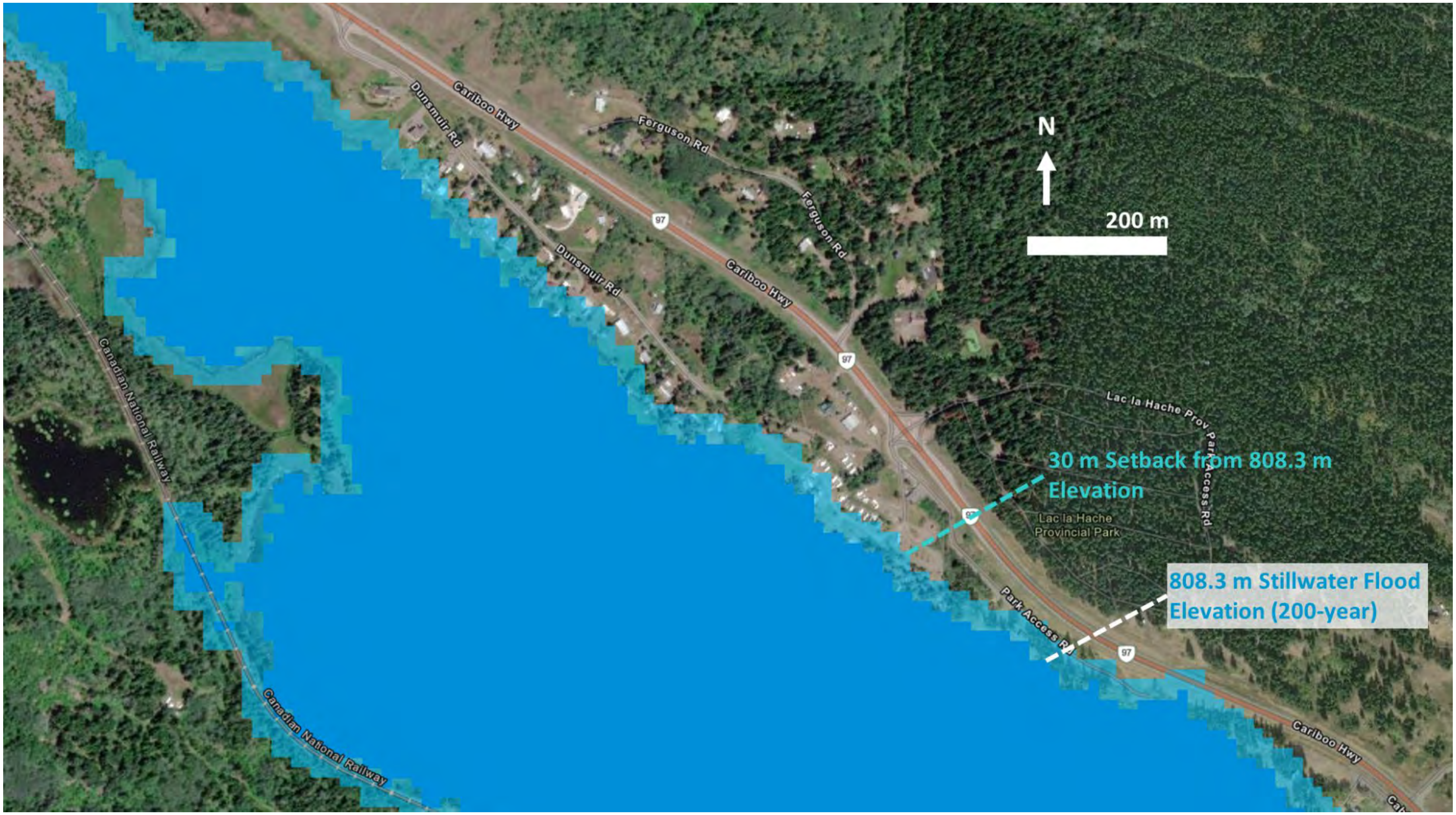

Figure B.22. Flood extents for the downstream end of Lac La Hache including Dunsmuir Road.

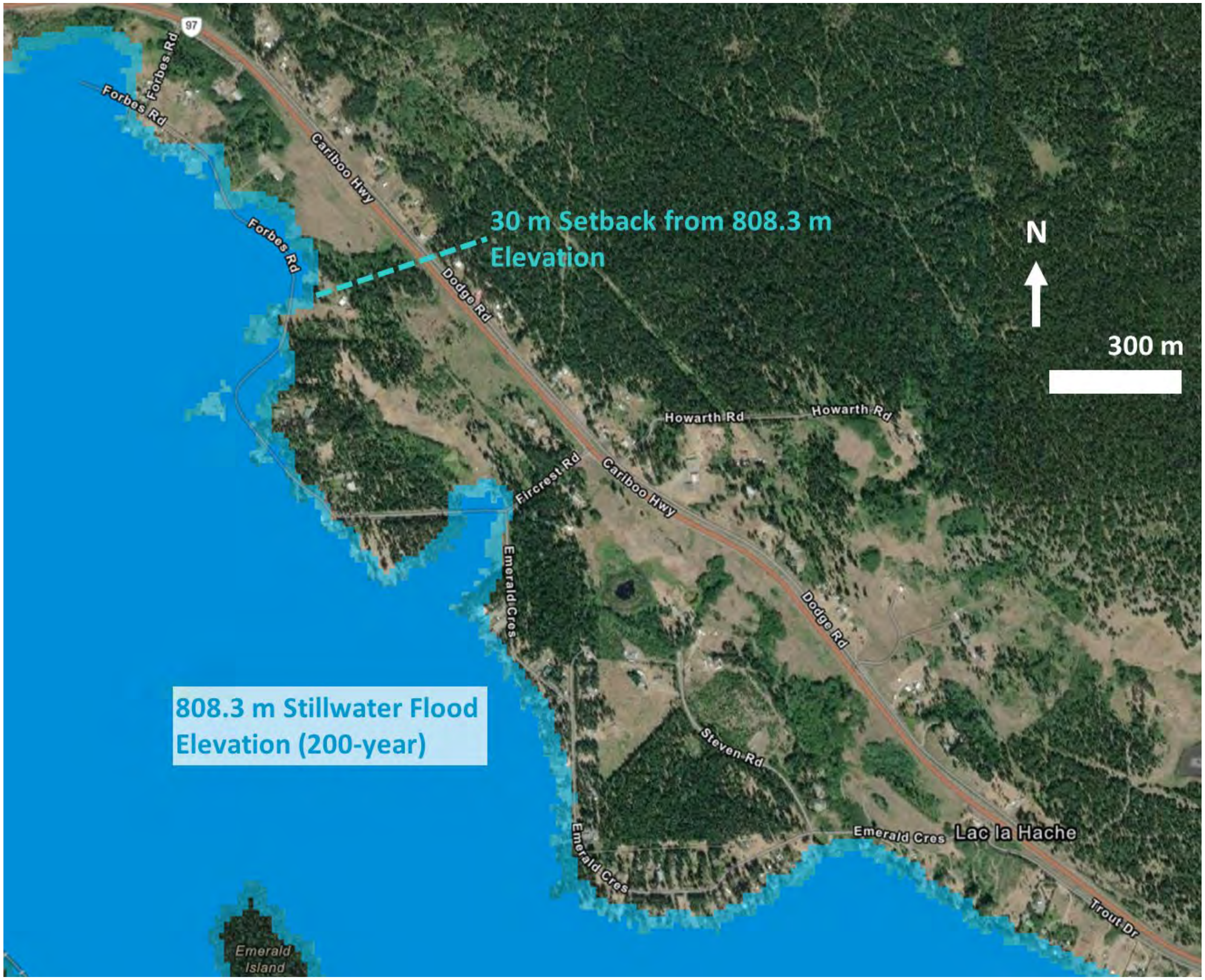

Figure B.23. Flood extents for the Forbes Road / Emerald Crescent area of Lac La Hache.

Figure B.24. Flood extents for the upstream end of Lac La Hache including McKinley Road and Caverly Road.

B.4.8. Site 9 – Bridge Creek (100 Mile House to Canim Lake)

The water surface elevation and the flood depth for Site 9 are shown in Figure B.25 and Figure B.26. The centreline of the model covers approximately 88 km. Between stations 4 km and 14 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.27 shows the flooding extents for 100-Mile House.

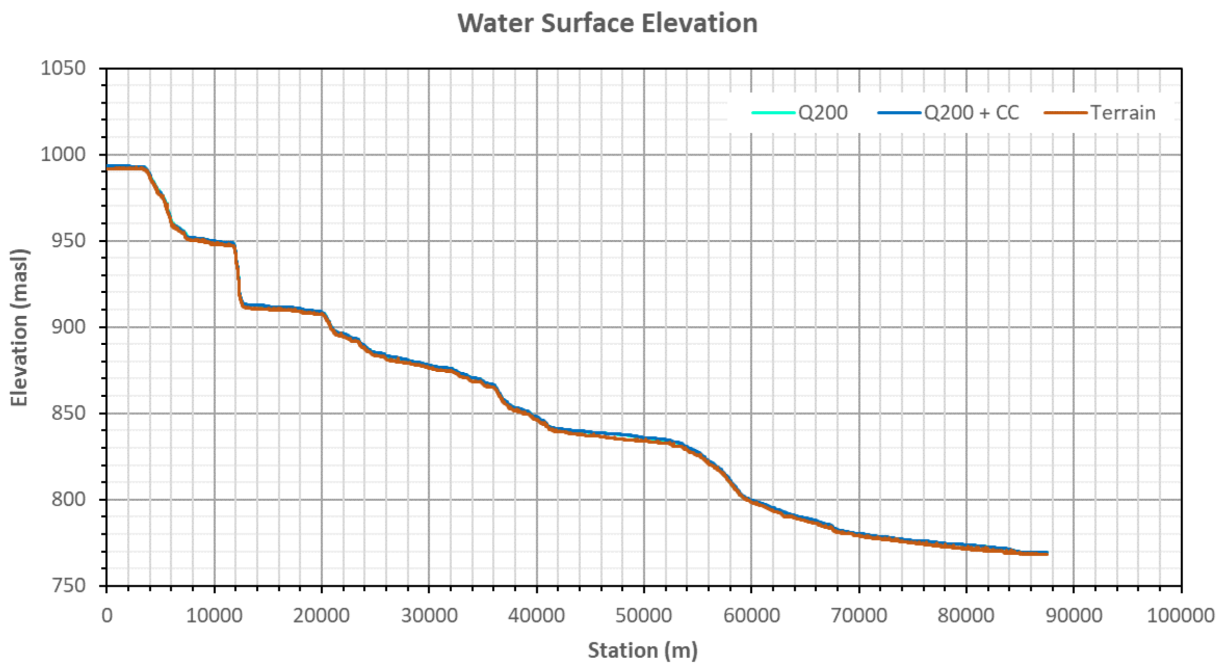

Figure B.25. Water surface elevation for Site 9 – Bridge Creek (100 Mile House to Canim Lake).

Figure B.26. Flood depth for Site 9 – Bridge Creek (100 Mile House to Canim Lake).

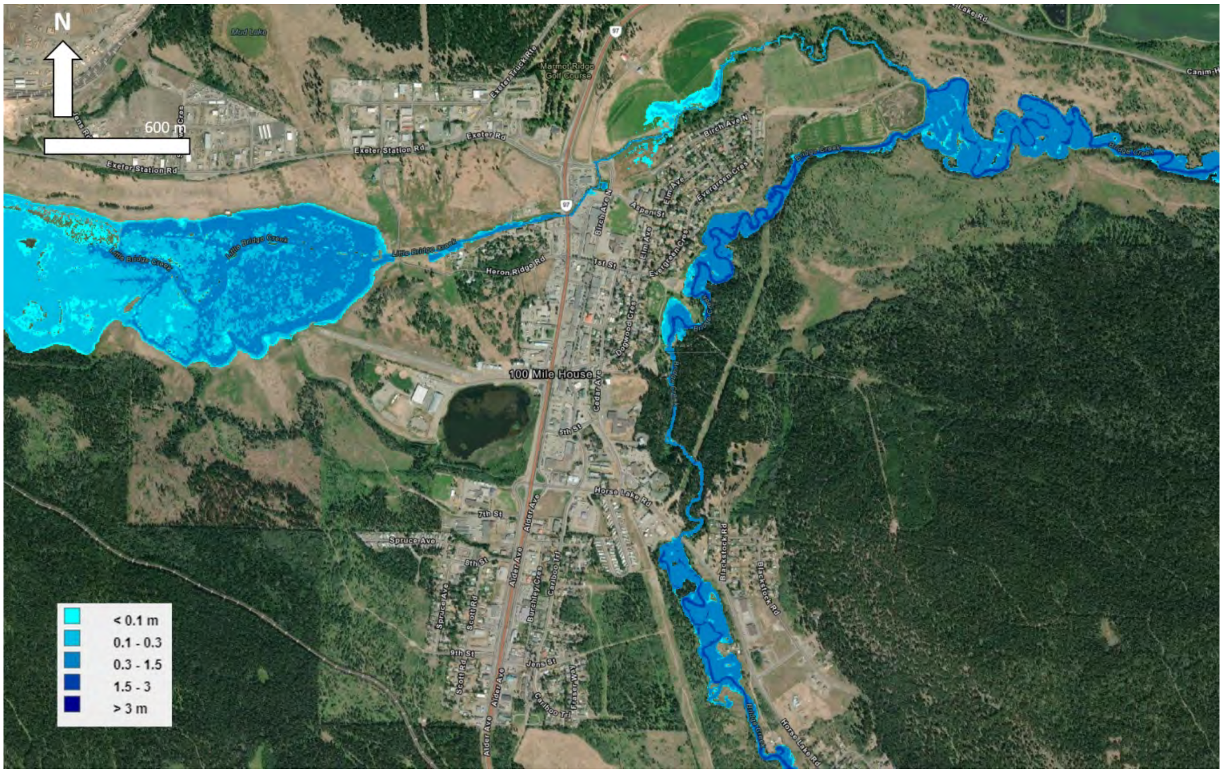

Figure B.27. Detail of flood depth for Site 9 – Bridge Creek (Canim Lake to 100 Mile House) at 100 Mile House.

B.5. 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 and velocities (Figure B.28) and imported into Cambio Communities.

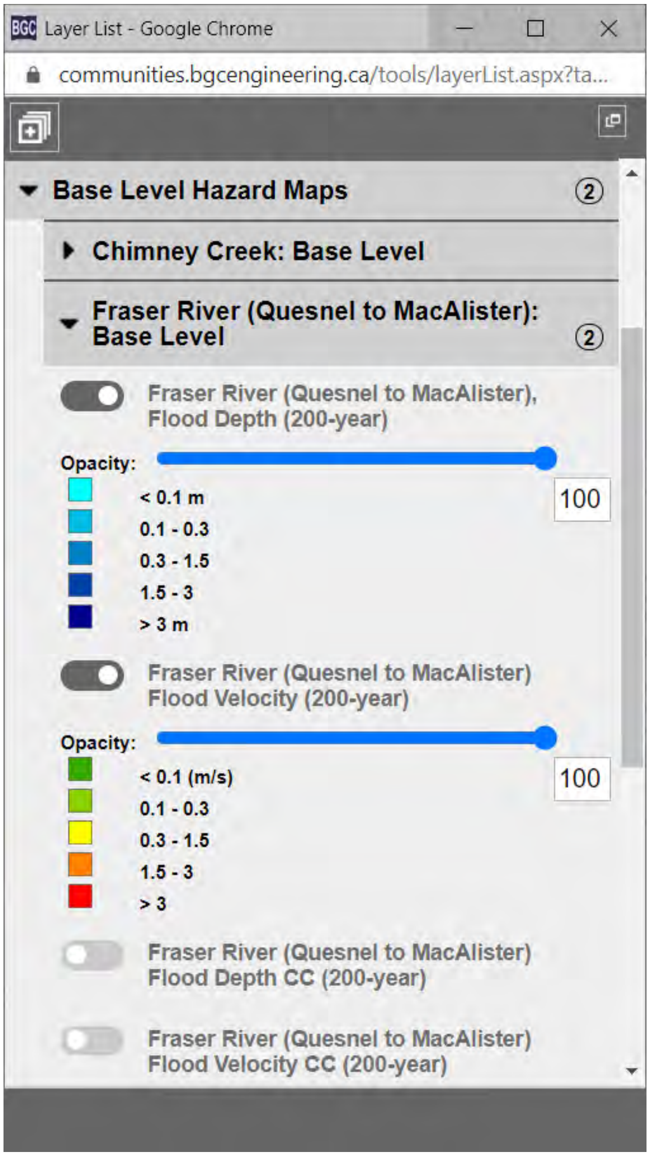

Figure B.28. Discrete flood depths used for display in Cambio Communities, using Fraser River (Quesnel to MacAlister) as an example.

REFERENCES

BC Ministry of Environment (MOE). (1983, November 17). *Lac La Hache*. Survey of Lake Bathymetry. Resource Analysis Branch, Biological Systems Section. [Map]. 1:15000 Scale. Survey date: June 2, 1981.

BGC Engineering Inc. (BGC) (April 30, 2020). Thompson River Watershed Base Level Flood Hazard Mapping. Final Report. Prepared for the Fraser Basin Council.

Brunner, G. W., & CEIWR-HEC. (2016). *HEC-RAS River Analysis System 2D Modeling User's Manual*. Retrieved from www.hec.usace.army.mil.

Dalrymple, T. 1960. Flood frequency analysis. *U.S. Geological Survey, Water Supply Paper 1543-A*.

Engineers and Geoscientists of BC (EGBC). (2017). *Guidelines for Flood Mapping in BC*. Web link: https://www.egbc.ca/getmedia/8748e1cf-3a80-458d-8f73-94d6460f310f/APEGBC-Guidelines-for-Flood-Mapping-in-BC.pdf.aspx

Engineers and Geoscientists of BC (EGBC). (2018). *Guidelines for Legislated Flood Assessments in a Changing Climate in BCC*. Version 2.1. August 28. Web link: https://www.egbc.ca/getmedia/f5c2d7e9-26ad-4cb3-b528-940b3aaa9069/Legislated-Flood-Assessments-in-BC.pdf.aspx

Government of Canada. (2016). Canadian Digital Elevation Model (CDEM) Product Specifications. Available online at http://ftp.geogratis.gc.ca, accessed December 2018.

Hosking, J. R. M., & Wallis, J. R. (2005). *Regional frequency analysis: an approach based on L-moments*. Cambridge University Press.

Islam, S. Ul, Curry, C. L., Dery, S. J., &Zwiers, F. W. (2019, February). Quantifying projected changes in runoff variability and flow regimes of the Fraser River Basin, British Columbia. *Hydrology and Earth System Sciences, 23*, 811-828. Httpsd://doi.org/10.5194/hess-23-811-2019.

McElhanney. (2019). *Hydrotechnical Analysis – Cherry Creek/Beaton Road Crossing* [Report]. Prepared for the BC Ministry of Transportation and Infrastructure.

Ministry of Water, Land and Air Protection (MWLAP). (2004). *Flood Hazard Area Land Use Management Guidelines*. Available online at: www.env.gov.bc.ca/wsd/public_safety/flood/pdfs_word/guidelines-2011.pdf

Urban Systems Ltd. (2020, July). *Flood Hazard and Floodplain Mapping* [Report]. Prepared for City of Quesnel.

Tasker, G.D. (1980). Hydrologic regression and weighted least squares. Water Resources Research, 16(6), 1107–1113.

APPENDIX C
EXPOSURE ASSESSMENT METHODS

C.1. INTRODUCTION

This study assessed areas that both contained elements at risk and that were subject to geohazards. This appendix describes how elements at risk data were organized across the study area.

This appendix uses the following terms:

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

Table C-1 lists the elements at risk considered in this study. Sections C.2 to C.8 describe methods used to characterize elements at risk and lists gaps and uncertainties. Data sources are listed in Appendix A of the prioritization report (BGC, September 24, 2020) with the following updates:

- Updated inventory of critical facilities, prepared in collaboration with CRD.
- Updated building assessment values (BC Assessment, 2021).
- New building footprints derived from lidar data obtained by Terra Remote Sensing (2020), and Microsoft Open Data Canadian building footprints data (2019).

These data were organized in an ArcGIS SDE Geodatabase stored in a Microsoft SQL Server spatial database. Software developed by BGC was used to automate queries to identify elements at risk falling within hazard areas. This will allow updates to be efficiently performed in future.

The elements at risk listed in Table C-1 were compiled from public sources including local and district government input, and data compiled by the Integrated Cadastral Information (ICI) Society available from the BC Land Title and Survey, (2018)1. It should not be considered exhaustive. The prioritized geohazard areas typically include buildings improvements and adjacent development (i.e., transportation infrastructure, utilities, and agriculture). Elements where loss can be intangible, such as objects of cultural value, were not included in the inventory.

For this assessment, BGC divided types of elements at risk into two groups, termed “community” and “lifelines”, which were considered separately for risk prioritization. Table C-1 lists the groups of assets used to consider hazard exposure from the perspective of community and lifelines. The original prioritization (all assets combined) was also retained. The results are shown on Cambio, where the user can select the type of priority rating most appropriate for their objective.

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

Table C-1. Weightings applied to elements at risk within the hazard area.

Asset Group	Element at Risk	Description	Value	Weight
Community	People	Total Census (2016) Population (Census Dissemination Block)[1]	0	0
			1-10	5
			11 – 100	10
			101 – 1,000	20
			1,001 – 10,000	40
			>10,000	80
	Buildings	Building Improvement Value[2] (summed by parcel)	$0	0
			<$100k	1
			$100k - $1M	5
			$1M - $10M	10
			$10M - $50M	20
			>$50M	40
	Critical Facilities	Critical Facilities[3] (point locations)	Emergency Response Services	36
			Emergency Response Resources	10
			Utilities	30
			Communication	18
			Medical Facilities	36
			Transportation	22
			Environmental	18
			Community	36
	Businesses	Business annual revenue (summed)	0$ Annual Revenue or 0 Businesses	0

Asset Group	Element at Risk	Description	Value	Weight
		(point locations)	<$100k Annual Revenue or 1 Business	1
			$100k - $1M Annual Revenue or 2-5 Businesses	5
			$1M - $10M Annual Revenue or 6-10 Businesses	10
			$10M - $50M Annual Revenue or 11-25 Businesses	20
			$50M - $100M Annual Revenue or 26-100 Businesses	40
			>$100M annual revenue or >100 businesses	80
	Environmental Values	Active Agricultural Area	Presence of	15
		Fisheries	Presence of	15
		Species and Ecosystems at risk	Presence of	15
Lifelines	Lifelines[3]	Roads (centerline)	Road present; no traffic data	1
			Highway present; no traffic data	5
			0-10 vehicles/day (Class 7)	1
			10-100 vehicles/day (Class 6)	5
			100-500 vehicles/day (Class)	10
			500-1000 vehicles/day (Class 4)	20
			> 1000 vehicles/day (Class <4)	40
		Railway	Presence of	10
		Petroleum Infrastructure	Presence of	15
		Electrical Infrastructure	Presence of	10

Asset Group	Element at Risk	Description	Value	Weight
		Communication Infrastructure	Presence of	10
		Water Infrastructure	Presence of	10
		Drainage Infrastructure	Presence of	10
		Sanitary Infrastructure	Presence of	10

Notes:

1. Census population was scaled according to the proportion of census block area intersecting a hazard area. For example, if the hazard area intersected half the census block, then half the population was assigned. The estimate does not account for spatial variation of population density within the census block.
2. Large parcels with only minor outbuildings or cabins, typically in remote areas, were not included in the assessment.

C.2. COMMUNITY ASSET GROUP

C.2.1. Buildings (Improvements)

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

Titled and Crown land parcels in British Columbia were defined using Parcel Map BC (BC, 2018) and joined to 2021 BC Assessment (BCA) data to obtain data on building improvements and land use. For this study, the 2018 BCA data was updated with BCA data from 2020 provided by CRD (March 17, 2021). No changes to the parcel layer were made as part of this update.

BGC applied the following steps to join these data and address one-to-many and many-to-one relationships within the data:

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

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

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

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

C.2.2. Population

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

[2] A dissemination block (DB) is defined as a geographic area bounded on all sides by roads and/or boundaries of standard geographic area. The dissemination block is the smallest geographic area for which population and dwelling counts are determined. (Statistics Canada, 2016). Census blocks are not defined based on administrative boundaries, and therefore extend into and account for populations in First Nations reserves.

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

C.2.3. Critical Facilities

Critical facilities were defined as facilities that:

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

BGC distinguished between “critical facilities” and “lifelines”, where the latter includes linear transportation networks and utility systems. While both may be important in an emergency, linear infrastructure can extend through multiple geohazard areas and were inventoried separately (see Section C.3).

Critical facilities were classified according to categories and criteria shown in Table C-3. Facility locations were determined based on BC Assessment predominant use codes for cadastral parcels in CRD (Section C.1). Facility locations are shown on the web map. Table C-4 provides a more detailed breakdown of how weightings were assigned to critical facilities based on the BCEMS response goals (Government of BC, 2016).

Table C-3. Critical facility descriptions.

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

Notes:

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

Table C-4. Basis for weightings applied to critical facilities.

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

Note:

1. The actual use value descriptions shown in this table were a starting point to compile an inventory of critical facilities. They should be considered representative, but not exhaustive descriptions of facilities in each category.

C.2.4. Business Activity

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

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

Table C-5. Business data uncertainties.

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

C.2.5. Environmental Values

C.2.5.1. Agriculture

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

C.2.5.2. Fisheries

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

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

C.2.5.3. Species and Ecosystems at Risk

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

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

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

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

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

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

C.3. LIFELINES ASSET GROUP

Lifelines considered in this assessment are shown on the web map and include: highways, roads, railways; and petroleum, electrical, communication, water, sanitary, and drainage infrastructure. Table C-6 provides a more detailed breakdown of the utility classes shown in Table C-1 (BC Land Title and Survey, 2018). BGC also obtained traffic frequency data from BC Ministry of Transportation and Infrastructure (MoTI), which were used to assign relative weights to different road networks as part of the prioritization scheme.

Table C-6. Utility systems data obtained from BC Land Title and Survey (2018).

Id	Classified Type (BGC)	Description (BC Land Title and Survey, 2018)	Position
1	Electrical Infrastructure	Electrical Duct Bank	Surface
2	Electrical Infrastructure	Electrical Junction	Surface
3	Electrical Infrastructure	Electrical Main	Surface
4	Electrical Infrastructure	Electrical Manhole	Surface
5	Electrical Infrastructure	Electrical Overhead Primary	Surface
6	Electrical Infrastructure	Electrical Overhead Secondary	Surface
7	Electrical Infrastructure	Electrical Overhead Transmission Line	Surface
8	Electrical Infrastructure	Electrical Pole	Surface
9	Electrical Infrastructure	Electrical Pull Box	Surface
10	Electrical Infrastructure	Electrical Service Box	Surface
11	Electrical Infrastructure	Electrical Street Light	Surface
12	Electrical Infrastructure	Electrical Switching Kiosk	Surface
13	Electrical Infrastructure	Electrical Transmission Circuit	Surface
14	Electrical Infrastructure	Electrical Transmission Low Tension Substation	Surface
15	Electrical Infrastructure	Electrical Transmission Structure	Surface
16	Electrical Infrastructure	Electrical Underground Primary	Subsurface
17	Electrical Infrastructure	Electrical Underground Secondary	Subsurface
18	Electrical Infrastructure	Electrical Underground Structure	Subsurface
19	Electrical Infrastructure	Electrical Underground Transformer	Subsurface
20	Electrical Infrastructure	Electrical Vault	Subsurface
39	Sanitary Infrastructure	Municipal Combined Sewer and Stormwater	Subsurface
40	Sanitary Infrastructure	Municipal Sanitary Sewer Main	Subsurface
41	Drainage Infrastructure	Municipal Stormwater Main	Subsurface
21	Petroleum Infrastructure	Petroleum Distribution Pipe	Subsurface
22	Petroleum Infrastructure	Petroleum Distribution Station	Subsurface
23	Petroleum Infrastructure	Petroleum Distribution Valve	Subsurface

Id	Classified Type (BGC)	Description (BC Land Title and Survey, 2018)	Position
24	Petroleum Infrastructure	Petroleum Facility Site	Surface
25	Petroleum Infrastructure	Petroleum Kilometer Post	Surface
26	Petroleum Infrastructure	Petroleum Methane Main	Subsurface
27	Petroleum Infrastructure	Petroleum Pipeline	Subsurface
28	Petroleum Infrastructure	Petroleum Transmission Pipe	Subsurface
29	Petroleum Infrastructure	Petroleum Transmission Pipeline Facility	Subsurface
30	Petroleum Infrastructure	Petroleum Transmission Valve	Subsurface
31	Communication Infrastructure	Telecom Broadband Cable Line	Subsurface
32	Communication Infrastructure	Telcom Cable Line	Surface
33	Communication Infrastructure	Telcom Facility	Surface
34	Communication Infrastructure	Telcom Main	Surface
35	Communication Infrastructure	Telcom Manhole	Surface
36	Communication Infrastructure	Telcom Pole	Surface
37	Communication Infrastructure	Telcom Structure	Surface
38	Communication Infrastructure	Telcom Underground Line	Subsurface
39	Water Infrastructure	Water Distribution	Subsurface

C.4. HAZARD EXPOSURE RATINGS

BGC used the following steps to assign a hazard exposure rating to each area:

1. Identify the presence of elements at risk, divided into Community or Lifelines asset groups and for all assets combined.
2. Calculate their value and weight according to the categories listed in Appendix C.
3. Sum the weightings to achieve a total for each area.
4. Assign exposure ratings to areas based on their percentile rank compared to other areas.

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

Exposure scores for all flood hazard areas were grouped by percentiles and assigned exposure ratings per the criteria listed in Table C-7. Exposure ratings equal to zero were excluded from the percentile distributions.

For consistency and application at provincial scale, BGC has applied the same ratings criteria (percentile thresholds) across multiple risk prioritization studies for Regional Districts in BC[3]. However, BGC notes that the distribution of exposure scores is relative to the study area (TNRD), to compare the level of development between different hazard areas inside this study area. Different choices of study area would affect this relative rating.

Table C-7. Hazard exposure rating.

Hazard Exposure Rating	Criteria
Very High	Greater than 95th percentile
High	Between 80th and 95th percentile
Moderate	Between 60th and 80th percentile
Low	Between 20th and 60th percentile
Very Low	Smaller 20th percentile

[3] To date, this includes the TNRD, Regional District of Central Kootenay, Columbia Shuswap Regional District, Regional District of North Okanagan, Cariboo Regional District, and Squamish-Lillooet Regional District.

REFERENCES

BC Assessment. (2021). *BC Assessment Custom Report.* Provided by CRD via email attachment dated December 2020.

BC Land Title and Survey. (2018). Parcel Map BC. Cadastral data provided by the Integrated Cadastral Information (ICI) Society, dated September 2018.

Government of BC. (2016). British Columbia Emergency Management System Guide. Web location: https://www2.gov.bc.ca/gov/content/safety/emergency-preparedness-response-recovery/emergency-management-bc/bcems

InfoCanada Business File. (2018). Canada Business Points. Provided by Geografx Digital Mapping Services, dated September 29, 2018.

Ministry of Environment (MOE). (2018a). Fisheries Inventory. Web location: https://www2.gov.bc.ca/gov/content/environment/plants-animals-ecosystems/fish

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

Statistics Canada. (2016). Census Profile, 2016 Census. Catalogue No. 98-316-X2016001.

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)
Asset	Anything of value, including both anthropogenic and natural assets.	BGC
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
Base Level Flood Mapping	Simplified flood plain mapping that provides flood hazard maps based on desktop hydraulic models. Suitable for limited application in planning, policies, and bylaws at individual parcel (property boundary) level of detail, and emergency response & mitigation planning. Can be refined to prepare detailed flood hazard maps.	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

Term	Definition	Source
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
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
Detailed Flood Mapping	Detailed flood plain mapping that provides local flood hazard maps and hydraulic models at a high level of detail. Mapping is suitable for parcel scale risk management, including risk assessment & bylaw enforcement, hazard monitoring, and detailed emergency response & mitigation planning	BGC
Elements at Risk (E)	Assets exposed to potential consequences of geohazard events. 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

Term	Definition	Source
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)
Exposure model	A type of data model describing the location and characteristics of elements at risk.	BGC
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

Term	Definition	Source
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)
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

Term	Definition	Source
Geohazard	Geophysical process that is the source of potential harm, or that represents a situation with a potential for causing harm. Note that this definition is equivalent to Fell et al. (2005)'s definition of Danger (threat), defined as an existing or potential natural phenomenon that could lead to damage, described in terms of its geometry, mechanical and other characteristics. Fell et al. (2005)'s definition of danger or threat does not include forecasting, and they differentiate Danger from Hazard. The latter is defined as the **probability** that a particular danger (threat) occurs within a given period of time.	Adapted from CSA (1997), Fell et al. (2005).
Geohazard 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)

Term	Definition	Source
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)
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.).
Lifeline	Linear infrastructure that provides access and services to the community. May include roads, utilities, railways, pipelines, powerlines, drainage infrastructure, water infrastructure, communication infrastructure, etc.	BGC
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

Term	Definition	Source
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
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

Term	Definition	Source
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
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

REFERENCES

American Geological Institute. (1972). *Glossary of Geology*. Washington, DC.: Author.

American Geosciences Institute. (2011). *Glossary of Geology* (5th ed.). Virginia: Author.

Bates, R.L. & Jackson, J.A. (1995). *Glossary of Geology* (2nd ed.). Virginia: American Geological Institute.

Canadian Avalanche Association (CAA). (2016). Technical Aspects of Snow Avalanche Risk Management – Resources and Guidelines for Avalanche Practitioners in Canada (C. Campbell, S. Conger, B. Gould, P. Haegeli, B. Jamieson, & G. Statham Eds.). Revelstoke, BC, Canada: Canadian Avalanche Association.

Canadian Standards Association (CSA). (1997). *CAN/CSA – Q859-97 Risk Management: Guideline for Decision Makers*. CSA Group, Toronto, ON, pp. 55.

Fell, R., Ho., K.K.S., LaCasse, S., & Leroi, E. (2005). A framework for landslide risk assessment and management. In Hungr, O., Fell, R., Couture, R. (Eds.) *Landslide Risk Management:* Proceedings *of the International Conference on Landslide Risk Management.* Vancouver, BC.

Fell, R., Whitt, G. Miner, A., & Flentje, P.N. (2007). Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning. *Australian Geomechanics Journal* 42: 13-36.

International Organization for Standardization (ISO). (2018). *ISO 31000:2018 Risk Management – Guidelines*. Retrieved from https://www.iso.org/standard/65694.html

Ministry of Water, Land and Air Protection. (MWLAP). (2004). *Flood Hazard Area Land Use Management Guidelines*.

National Oceanic and Atmospheric Administration. (n.d.) What is LIDAR? [Web page]. Retrieved from https://oceanservice.noaa.gov/facts/lidar.html

Oxford University Press. (2008). *A dictionary of Earth Sciences* (3rd ed.). Oxford, England: Author.

Porter, M., Jakob, M., & Holm, K. (2009, September). Proposed Landslide Risk Tolerance Criteria. *GeoHalifax 2009*. Paper presented at the meeting of the Canadian Geotechnical Society, Halifax, Canada.

Whitfield, P.H., Cannon, A.J., & Reynolds, C.J. (2002). Modelling Streamflow in Present and Future Climates: Examples from the Georgia Basin, British Columbia. *Canadian Water Resources Journal, 27(*4), 427 – 456. https://doi.org/10.4296/cwrj2704427

APPENDIX E
DATA GAPS AND UNCERTAINTIES

Table E-1. Summary of data gaps and recommended actions.

Input	Description	Implication (Factor Affected)	Recommended Actions to Resolve Gaps
Topography	• The lack of detailed topography (lidar) in the CRD is a limitation for detailed clear-water flood hazard area delineation and characterization.	• Lidar topography is a prerequisite for completing detailed flood hazard mapping. Because of the time required for acquisition and processing, there can also be a time lag between the acquisition and processing of lidar and commencing work that requires these data as inputs.	• Lidar acquisition and processing. • Consider completing additional flood hazard mapping once lidar data are available.
Bathymetry	• Available topographic data does not extend below the water level at the time of survey. As river bathymetry was not available, assumptions were incorporated in the model to account for the channel geometry below the surveyed water elevation.	• Precision and accuracy of estimated geohazard location/extents and intensity.	• Complete bathymetric surveys in preparation for or as part of detailed flood hazard mapping.
Stream network	• Not all watercourses present within the CRD are contained within provincial (TRIM) or national river networks, and some have changed location since mapping (i.e., due to channel avulsion or migration). Mapped watercourses may or may not be consistent with the definition of watercourse contained in Floodplain Management Bylaws. In this study, District-wide floodplain identification was based on "Height Above Nearest Drainage" (HAND) modelling that involved topographic-based modelling of stream flow. The HAND modelling was performed on the 30 m resolution DEM produced by the Shuttle RADAR Topography Mission (SRTM) (Farr et al., 2007). The flow networks defined using HAND modelling may not be consistent with TRIM or national river networks. This may be particularly the case in topographically gentle areas of the CRD where the topographic data is not at a sufficient resolution to capture subtle elevation changes, and the stream network is poorly represented/defined in some areas.	• Watercourses that have moved since the original stream network mapping may lead to an apparent inconsistency between HAND modelling outputs and mapped river channels. • Low resolution of the DEM used in the HAND modelling may also result in inconsistencies between the HAND modelling outputs and the mapped river channels.	• Manual revisions to stream networks may be required to facilitate hydrologic, hydraulic, and geomorphic analyses required for geohazard risk management. • Consider running algorithms on region-wide lidar, once available, to identify watercourse and bank locations, and to identify stream segments that are consistent with the bylaw definition for watercourse.
Geohazard Sources / Controls / Triggers	• Gaps exist in the inventory of geohazards within the CRD that represent sources, controls, or triggers for flood-related geohazards. For example, ice jams and landslides act as flood-related event triggers, and wildfires alter watershed hydrology in ways that can temporarily affect flood response and sediment transport. Ice jams and landslides can also create temporary dams and associated inundation and outburst floods, as well as floods from waves triggered by landslides into lakes and reservoirs. Those have not been considered.	• Ability to identify sources, controls, or triggers for flood-related geohazards.	• Given that hazard inventories are often completed piecemeal over long periods of time, maintain a data information management system that integrates existing knowledge, with tools to grow an accessible knowledge base as funding permits. Organizing geospatial data in a common resource will greatly reduce the costs of data compilation. • Require future assessments to provide results in geospatial formats when generated during a study and provide data standards that facilitate their inclusion in a larger data model. • Initiate citizen science initiatives[1] to capture geohazards information, particularly events, in near-real time.
Flood Protection Measures, and Flood Conveyance Infrastructure	• Dikes, bank erosion protection, and appurtenant structures, in addition to culverts and bridges were excluded from the evaluation due to the limited data available on the location, geometries and condition of these facilities. • Locations modelled using airborne lidar will implicity contain the elevations of bridge embankments (minus the decks), dikes and other structures however these were not explicitly modelled within the models.	• Precision and accuracy of estimated geohazard location/extents, likelihood, and intensity where affected by structural flood mitigation.	• Develop data collection standards and sharing agreements between the various facility owners to facilitate their inclusion in a larger data model. • More detailed inventories and characterization of assets based on consistent data standards would improve and reduce the cost of hydraulic assessments. • Apply the results of this assessment to prioritize characterization of risk reduction measures and consideration in further, more detailed geohazards assessments.

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

Input	Description	Implication (Factor Affected)	Recommended Actions to Resolve Gaps
Climate Change	• Justification for adjustments made to streamflow to account for climate change were based on a coarse-resolution general circulation model. Finer resolution climate change information could be obtained by downscaling the results and/or nesting a regional climate model over the region. • Climate data paucity remains a significant concern for accurately characterizing climate-related risks in the region. The limited number of observing stations for the large area inhibit identification and validation of fine-scale climate variations across the area. While certain satellite data may supplement the data sources, those estimates themselves contain inherent uncertainties.	• Accuracy of hydrologic estimates of streamflow discharge at a given frequency. • Potential for over- or under-estimation of flood hazard, if actual flows exceed or are less than the factor adjustment applied to stream flows in this project to account for climate change.	• Low-cost climate sensors co-located with stream gauges in the area would enhance understanding of climate-related risk and support the validation of model outputs.
Hydraulic Modelling	• Flow conveyance infrastructure (i.e., bridges and culverts) were not incorporated into hydraulic models nor was the topography of the built environments considered. • The CDEM does not have sufficient resolution to distinguish bridge and roadway embankments. • The airborne lidar does have sufficient resolution to distinguish bridge and roadway embankments however information regarding the geometry of the bridges/culverts (e.g., culvert diameter, bridge soffit elevation etc.) was not collected as part of the project so could not be included. • Structural flood protection (i.e., dikes) was not incorporated into models and the CDEM DEM 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, for example, may not be modelled accurately. • 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 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. • Failure of structural flood protection during a flood would result in different flow pathways and behaviors than the modelling results presented herein.	• Address as part of detailed flood hazard mapping. • Consider examining the stability of structural flood protection and the impacts of failure during a flood event.
	• Breaklines were used only to delineate river centerlines and/or banks and increase resolution within that region.	• 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.	• Address as part of detailed flood hazard mapping.
	• The terrain used to define the model only includes 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.	• Address as part of 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) as well as the representative period of collection.	• 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).	• Obtain lidar topography where gaps exist, and update hydraulic models and map deliverables.
	• 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.	• Complete periodic review and updates to address changing conditions. • Collect high water marks after high water events to assist in the model calibration.

Input	Description	Implication (Factor Affected)	Recommended Actions to Resolve Gaps
	• 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.	• Consider addressing as part of detailed flood hazard mapping.

APPENDIX F
RISK PRIORITIZATION SPREADSHEET
(PROVIDED SEPARATELY)