## RDCK FLOODPLAIN AND STEEP CREEK STUDY

# Slocan River

**Final**
**March 31, 2020**

BGC Project No.:
**0268007**

BGC Document No.:
**RDCK2-CW-006F**

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

## TABLE OF REVISIONS

| ISSUE | DATE | REV | REMARKS |
|---|---|---|---|
| DRAFT | March 31, 2020 | | Draft issue. |
| FINAL | March 31, 2020 | | Final issue. |

## LIMITATIONS

BGC Engineering Inc. (BGC) prepared this document for the account of Regional District of Central Kootenay. 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.

As a mutual protection to our client, the public, and ourselves, all documents and drawings are submitted for the confidential information of our client for a specific project. Authorization for any use and/or publication of this document or any data, statements, conclusions or abstracts from or regarding our documents and drawings, through any form of print or electronic media, including without limitation, posting or reproduction of same on any website, is reserved pending BGC's written approval. A record copy of this document is on file at BGC. That copy takes precedence over any other copy or reproduction of this document.

# EXECUTIVE SUMMARY

This report and its appendices provide a detailed flood hazard assessment of the Slocan River between Slocan Lake and the Kootenay River. This river was chosen as a high priority clear-water hazard amongst hundreds in the Regional District of Central Kootenay (RDCK) from a risk perspective because of its comparatively high hazards and consequences from flooding. This report describes hydrological conditions and details the methods applied to create scenario and hazard maps for the Slocan River. This work is the foundation for possible future quantitative risk assessments or conceptualization of mitigation measures such as potential upgrades to existing dikes.

Flood mapping is used for estimating the extent and depth of different magnitude floods for application in community planning, policy development, and emergency response planning in areas subject to flood hazards. Results from a two-dimensional (2D) hydraulic model developed for about a 58 km length of the Slocan River provides potential flood inundation extents and establishes flood construction levels (FCLs) based on the 200-year return period event or annual exceedance probability (AEP) of 0.5% with consideration for climate change and include a freeboard allowance for planning purposes.

The following types of maps were produced for the Slocan River:

- Flood depth, velocity and intensity maps for the 20-, 50-, 100-, 200- and 500-year return period events
- Designated floodplain maps depicting the 200-year flood levels including a freeboard allowance 0.6 m (200-year)
- Aerial photograph interpretation and channel change mapping.

Flood mapping developed by BGC provides an update to historical floodplain mapping previously conducted for the Slocan River. Flood extents are similar to the 1989 designated floodplain maps created by the BC Ministry of Forests, Lands and Natural Resource Operations (BC MFLNRO); however, FCLs are higher due to the increased 200-year return period flood event that accounts for climate change, and the application of more advanced modelling methods. Implementation of the Slocan River FCLs and community planning for development outside of high hazard areas will lead to greater flood resiliency within the communities adjacent to the river. Flood mapping results are also provided digitally through a BGC web application called Cambio™.

Furthermore, the assumptions made on changes in runoff due to climate change will likely need to be updated periodically as scientific understanding evolves.

Table E-1 provides key observations derived from the hazard assessment.

**Table E-1. Summary of key hazard assessment results.**

| Process | Key Observations |
|---|---|
| **Bank erosion and channel changes** | • Fluvial landforms were identified and delineated in the different sets of photographs and high-resolution imagery (Drawings 04 and 05). From a bank erosion and channel change perspective, the most laterally unstable reaches identified are the lower 5 km of Little Slocan River and a 5.5 km reach of the Slocan River downstream of Lemon Creek. Both these reaches are characterized by a wandering river planform, indicating a moderate to high sediment supply. Average bank erosion rates in these two areas are on the order of 1 to 2 m/year for the past 60 years.<br>• As both areas are sparsely populated, no immediate erosion hazard assessment is deemed necessary. However, this situation could change over time, particularly on the Little Slocan River, where there are buildings on the floodplain. In contrast, the floodplain of the Slocan River downstream of Lemon Creek is of lesser risk, as the area is used for agriculture with no structures located on the floodplain. |
| **Clear-water inundation** | <u>Village of Slocan and Slocan Lake</u><br>• The Village of Slocan is impacted by flooding from Slocan Lake. The simulated 200-year lake level is 539.58 m (without freeboard and wave allowance).<br>• Flooding during the 20-year flood is predicted on properties west of Main Street that borders the lake outlet. Flooding during the 200-year flood is predicted between Park Ave and Lake Ave with depths up to 1 m.<br>• The 500-year event raises the 200-year lake level by 0.23 m to a value of 539.81 m causing a marginal increase in flooding extent (10 to 30 m horizontally).<br>• Properties inside or near the impacted area are subject to additional hazard from the wave runup expected in Slocan Lake (outside the scope of current study).<br><u>Between Slocan Lake and Lemon Creek</u><br>• At flood return periods of 20 years and greater, the Slocan Valley Rail Trail is overtopped downstream of the Logging Bridge (Gravel Pit Road). Agricultural lands are also flooded on both sides of Slocan River.<br><u>Lemon Creek</u><br>• Upstream of the Highway 6 Bridge on Lemon Creek, banks and dikes are overtopped during the 20-year flood. Water flows along the highway south embankment and overtops the highway to flow on the fan to reach Slocan River.<br>• Both floods are not contained in the channel upstream of the Slocan Valley Rail Trail Bridge and the water level rises against the embankment until it is overtopped.<br>• Lemon Creek is an active alluvial fan and flooding is likely exacerbated by sediment transport, although these flood concerns are beyond the scope of this study. |

| Process | Key Observations |
|---|---|
| | <u>Between Lemon Creek and Little Slocan River</u><br>• Perrys Back Road is flooded during the 20-year flood at the junction of Avis Road and the Perry Bridge.<br>• During the 200-year flood, Highway 6 is flooded approximately 500 m downstream of the Winlaw Bridge.<br>• During the 20-year flood, Filipoff Road and the Slocan Valley Rail Trail are flooded in the left (west) floodplain between the communities of Winlaw and Lebahdo.<br>• During the 20-year flood, flooding extents reach the Highway 6 embankment on the left (southeast) floodplain approximately 300 m downstream of Lebahdo.<br><u>Little Slocan River</u><br>• Properties along the left bank (north) of Little Slocan River are flooded by the 200-year flood event starting at the end of Arrow Road and more importantly in the vicinity of Point Road.<br>• During the 50-year flood, the left (north) approach of the Little Slocan River Bridge is overtopped. Water flows along old channels visible in the lidar and water level rises until Kickwillie Road is overtopped.<br><u>Between Passmore and the Kootenay River</u><br>• Approximately 1 km downstream of the Passmore bridge, the 200-year event causes flooding over the Slocan Valley Rail Trail and Highway 6 located on the left (north) floodplain. Several properties and buildings along Old Passmore Road are flooded by this magnitude of event.<br>• Downstream of the Slocan Park Bridge, the Slocan Valley West Road on the right (southwest) bank is flooded during the 20-year flood.<br>• At flood return periods of 20 years and greater, floods extend to the left (northeast) floodplain of the Slocan River at the community of Slocan Park. The streets that are flooded by those events include the following (from upstream to downstream): Bower Road, Kirby Road, Price Road, Slocan Valley East Road, Evin Road, and the Slocan Valley Rail Trail. Water flows along the Highway 6 embankment and multiple properties are impacted by the floods.<br>• The 50-year event floods Highway 6 near Cunningham Road. The left (east) floodplain is low in this area.<br>• Goose Creek Road is flooded on the section along the river during the 20-year event. |
| **Hydraulic Structures (Bridges)** | • The water surface elevation for the 200-year flood does not reach the low chord of the bridges in this study as verified through 1D modelling (Table 5-13).<br>• The Logging Road Bridge has a negligible freeboard of 2 cm during the 200-year event. The 500-year flood will likely overtop the bridge and cause damage.<br>• Perry Bridge approaches in the floodplain are overtopped during the 20-year flood. |
| **Hydraulic Structures (Dikes)** | • Dikes along Lemon Creek are composed of river boulders and log cribs (Figure 3-4 and Figure 3-5). Severe deterioration of the dikes was observed during the field visit and they are not expected to provide any protection during a flood. |

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

## LIST OF APPENDICES



## LIST OF DRAWINGS

# 1. INTRODUCTION

The Regional District of Central Kootenay (RDCK, the District) is located in a mountainous region in southeastern British Columbia (BC) that is subject to damaging floods, which have resulted in impacts to communities and infrastructure. In 2018, RDCK retained BGC Engineering Inc. (BGC) to carry out a regional geohazard risk prioritization study for the District (BGC, March 31, 2019). Supported by National Disaster Mitigation Program (NDMP) Stream 1 funding, the objective of the study was to characterize and prioritize clear-water flood and steep creek (debris-flood and debris-flow) geohazards. Through the regional study, BGC identified and prioritized 427 flood and steep creek hazard areas within the RDCK, of which six floodplains and ten steep creeks in the District were selected for further detailed assessment (Table 1-1, Figure 1-1).

**Table 1-1. List of study areas.**

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

The six clear-water hazard areas were prioritized either for development of new flood maps or modernization of existing historical flood maps. Flood maps provide information on the hazards associated with defined flood events, such as water depth, flow velocity, and the probability of occurrence. These maps are critical decision-making tools for local and regional governments to inform flood mitigation, land use planning, emergency management, and public awareness. Generally, the historical flood maps in the District are at least twenty years out-of-date and lack consideration of more robust hydraulic models, additional hydrological data, changes in land use such as urban development or the impacts of climate change. In response, updated floodplain mapping was conducted by BGC for each of the six prioritized clear-water hazard areas and provided under separate cover along with digital deliverables through a BGC web application called Cambio™[1].

This report details the approach used by BGC to conduct detailed floodplain mapping for the Slocan River originating near the Village of Slocan (Slocan), BC (Drawing 01). The Slocan River is a major tributary to the Kootenay River and has an approximate watershed area of 3,412 km$^2$ as described in Section 2. The Slocan River poses a flood hazard to properties and infrastructure constructed on the adjacent floodplain and low-gradient alluvial fan of the river. The Slocan River has a long history of past damaging flood events and is mitigated in areas as described in Section 3.

Flood mapping developed by BGC provides an update to historical floodplain mapping conducted previously for the Slocan River in 1989 (Northwest Hydraulic Consultants Ltd., February 1989). A two-dimensional (2D) hydraulic model was developed for about a 58 km length of the river using methods described in Section 4.4. Modelling results described in Section 5.3 provide potential flood inundation extents and establishes flood construction levels (FCLs) based on the 200-year return period event or annual exceedance probability (AEP) 0.005 and includes a freeboard allowance of 0.6 m for planning purposes.

An outcome of the study is an improved basis for community planning, bylaw development, and emergency response planning in developed areas subject to flood hazards, with consideration of climate change. Recommendations are provided in Section 6 and include considerations for next steps from the study such as possible future quantitative risk assessments (QRAs) or conceptualization of mitigation measures such as potential upgrades to existing dikes.

BGC is providing a summary report for the entire assessment, *RDCK Floodplain and Steep Creek Study Summary Report* (referred to herein as the "Summary Report"). Readers are encouraged to read the Summary Report to obtain context about the objectives, scope of work, deliverables, and recommendations of the larger study.

[1] *www.cambiocommunities.ca.*

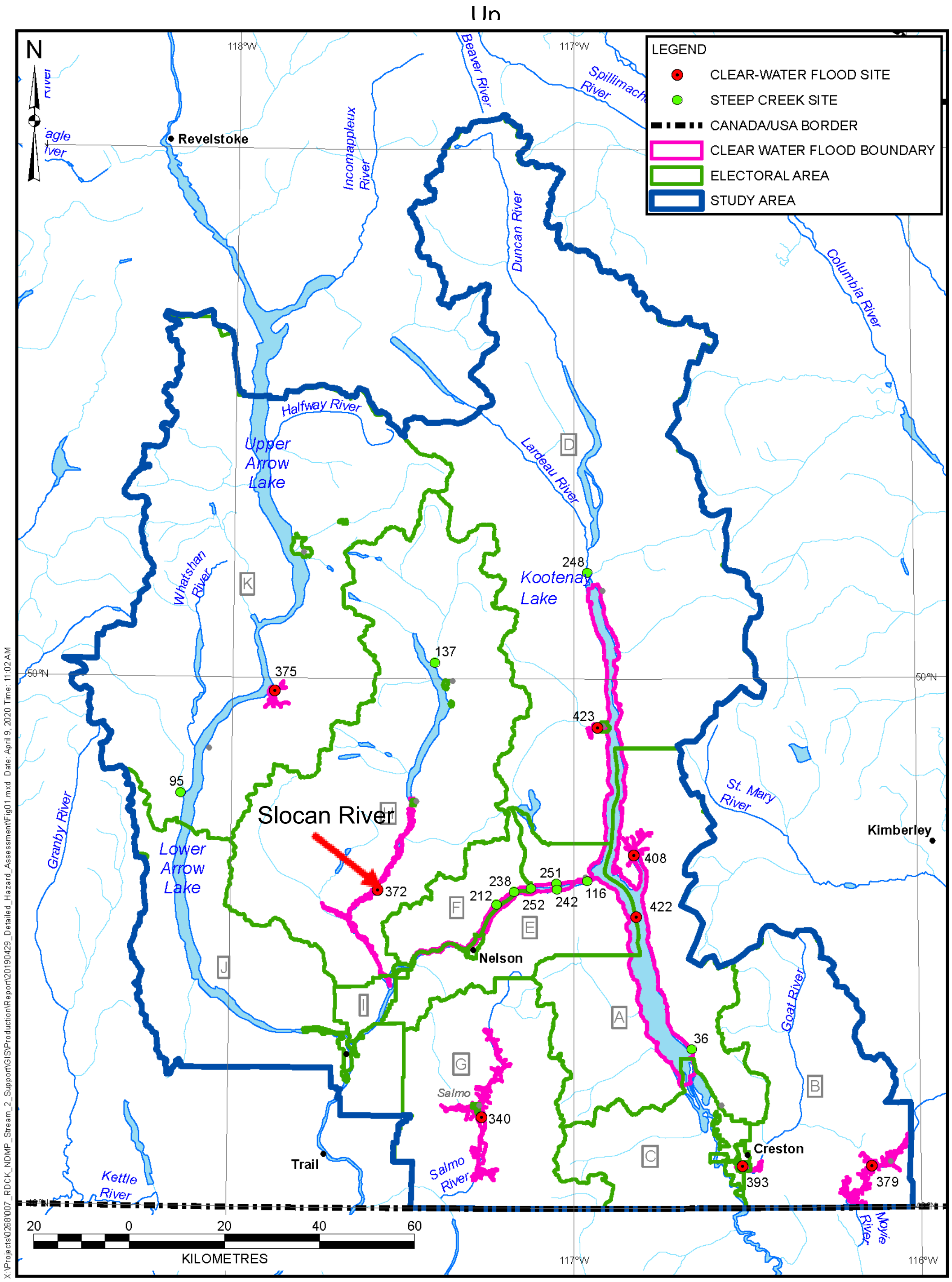



**Figure 1-1.** **Hazard areas prioritized for detailed flood and steep creek mapping. Site labels correspond to hazard identification numbers in Cambio. Slocan River (No. 372) is labelled on the figure (red arrow).**

## 1.1. Scope of Work

BGC's scope of work is outlined in the proposed work plan (BGC, May 24, 2019), which was refined to best meet RDCK's needs as the project developed (BGC, November 15, 2019). The work was carried out under the terms of contract between RDCK and BGC dated June 20, 2019. The work scope was funded by Emergency Management BC (EMBC) and Public Safety Canada under Stream 2 of the NDMP.

For the Slocan River, the scope of work included:

- Characterization of the study area including regional physiography and hydroclimate, and local watershed characteristics, geology and site characteristics.
- Development of a comprehensive site history of floods and mitigation activity.
- Compilation of data and baseline analyses required as inputs for flood geohazards assessment. This includes topographic and river bathymetry data collection including terrain, hydrologic, hydraulic, fluvial geomorphologic analyses and consideration of climate change impacts.
- Complete hazard mapping and assessment according to provincial and national standards including mapping of inundation areas, flow velocity, and flow depth for a spectrum of return periods. Dike and dam breach scenarios were not included.
- Integrate flood mapping results with the regional study and disseminate flood hazard mapping and data in web-accessible formats amenable to incorporation into policy and risk-informed decision making.

The study scope was informed by Engineers and Geoscientists of British Columbia (EGBC, 2018) professional practice guidelines, *Legislated Flood Assessments in a Changing Climate in BC,* and EGBC (2017) guidelines for flood map preparation. The assessment is consistent with the *Federal Floodplain Mapping Framework* (Natural Resources Canada [NRCan], 2017). Within the NRCan framework, this study provides the foundation to risk assessment and mitigation (Figure 1-2).

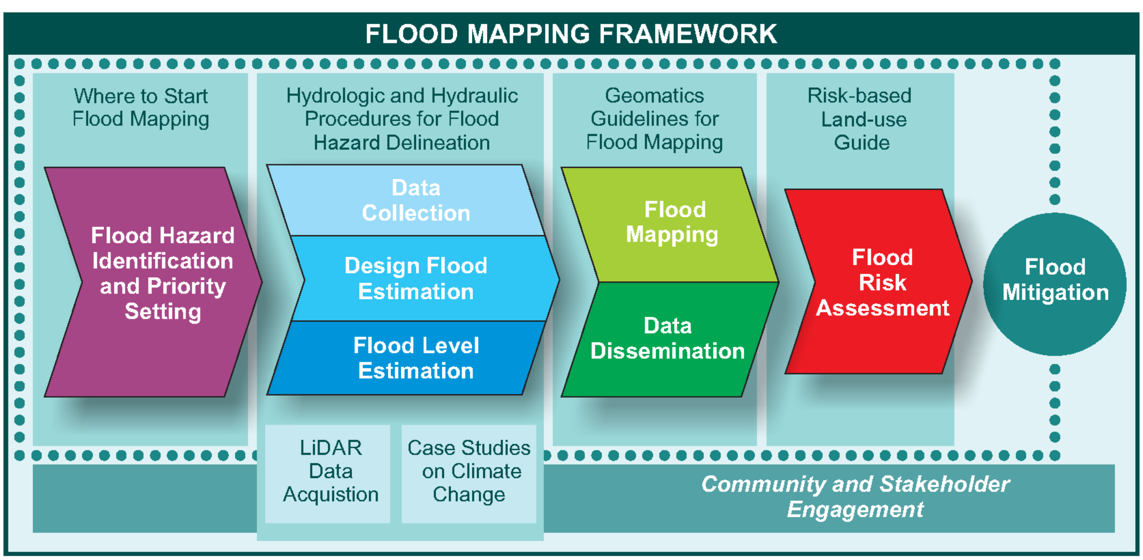



**Figure 1-2. Federal flood mapping framework (NRCan, 2017).**

## 1.2. Terminology

This assessment uses specific hazard terminology provided in Appendix A.

## 1.3. Deliverables

The deliverables of this study include this assessment report and digital deliverables (hazard maps) provided via the Cambio web application and as geospatial data provided to the RDCK.

This report is best read with access to Cambio. Cambio displays the results of both the NDMP Stream 1 and Stream 2 studies. The application can be accessed at www.cambiocommunities.ca, using either Chrome or Firefox web browsers. The Summary Report provides a Cambio user guide.

## 1.4. Study Team

This study was multidisciplinary. Contributors are listed below, and primary authors and reviewers are listed in Table 1-2.

- Kris Holm, M.Sc., P.Geo., Principal Geoscientist
- Sarah Kimball, M.A.Sc., P.Eng., P.Geo., Senior Geological Engineer
- Rob Millar, Ph.D., P.Eng., P.Geo., Principal Hydrotechnical Engineer
- Hamish Weatherly, M.Sc., P.Geo., Principal Hydrologist
- Patrick Grover, M.A.Sc., P.Eng., Senior Hydrotechnical Engineer
- Elisa Scordo, M.Sc., P.Geo., P.Ag., Senior Hydrologist
- Pascal Szeftel, Ph.D., P.Eng., Senior Hydrotechnical Engineer
- Marc Olivier Trottier, M.A.Sc., P.Eng., Intermediate Hydrotechnical Engineer
- Melissa Hairabedian, M.Sc., P.Geo., Senior Hydrologist
- Hilary Shirra, B.A.Sc., EIT, Junior Hydrotechnical Engineer
- Toby Perkins, M.A.Sc., P.Eng., Senior Hydrotechnical Engineer
- Kenneth Lockwood, Ph.D., EIT, Junior Civil Engineer
- Beatrice Collier-Pandya, B.A.Sc., EIT, Geological Engineer
- Matthias Busslinger, M.A.Sc., P.Eng., Senior Geotechnical Engineer
- Carie-Ann Lau, M.Sc., P.Geo., Intermediate Geoscientist
- Phil LeSueur, M.Sc., P.Geo., Geological Engineer
- Lauren Hutchinson, M.Sc., P.Eng., Intermediate Geotechnical Engineer
- Anna Akkerman, B.A.Sc., P.Eng., Senior Hydrotechnical Engineer
- Matthew Buchanan, B.Sc., GISP, A.D.P., GIS Analyst
- Betsy Waddington, M.Sc., P.Geo., Senior Geoscientist
- Vanessa Cuervo, M.Sc., Geohazard Specialist
- Sophol Tran, B.A., A.D.P., GIS Analyst
- Lucy Lee, B.A., A.D.P., GISP, GIS Analyst/Developer
- Matthew Williams, B.Sc., A.D.P., GIS Analyst.
- Alistair Beck, B.S.F., Dip CST, Database/Web Application Developer
- Michael Porter, M.Eng., P.Eng., Director, Principal Geological Engineer

**Table 1-2. Study team.**

| | | |
|---|---|---|
| **Project Director** | Kris Holm | |
| **Project Manager** | Sarah Kimball | |
| **Overall Technical Reviewer(s)** | Rob Millar<br>Hamish Weatherly | |
| **Section** | **Primary Author(s)** | **Peer Reviewer(s)** |
| **1** | Elisa Scordo | Kris Holm |
| **2** | Marc Olivier Trottier<br>Melissa Hairabedian | Elisa Scordo<br>Betsy Waddington |
| **3** | Marc Olivier Trottier<br>Elisa Scordo | Melissa Hairabedian |
| **4.1** | Elisa Scordo | Patrick Grover |
| **4.2** | Vanessa Cuervo | Betsy Waddington |
| **4.3** | Melissa Hairabedian | Patrick Grover<br>Elisa Scordo |
| **4.4** | Marc Olivier Trottier | Patrick Grover |
| **4.5** | Marc Olivier Trottier | Patrick Grover |
| **5.1** | Vanessa Cuervo | Betsy Waddington |
| **5.2** | Marc Olivier Trottier | Patrick Grover |
| **5.3 – 5.5** | Marc Olivier Trottier | Patrick Grover |
| **6.0** | Marc Olivier Trottier | Patrick Grover<br>Melissa Hairabedian |
| **Appendix A** | Hilary Shirra | Elisa Scordo |
| **Appendix B** | Kenneth Lockwood | Elisa Scordo |
| **Appendix C** | Melissa Hairabedian<br>Patrick Grover | Pascal Szeftel |
| **Appendix D** | Melissa Hairabedian<br>Patrick Grover | Pascal Szeftel |
| **Appendix E** | Marc Olivier Trottier | Patrick Grover<br>Pascal Szeftel |

# 2. STUDY AREA CHARACTERIZATION

The following section provides a characterization of the study area, including aspects such as physiography, glacial history and surficial geology, and floodplain morphology of the Slocan River, Lemon Creek and Little Slocan River. It also describes hydroclimatic conditions and projected impacts of climate change.

## 2.1. Physiography

The Slocan River watershed lies in the Northern Columbia Mountains Ecoregion. This ecoregion is a mountainous area with the Southern Rocky Mountain Trench to the east and the Columbia Highlands to the west. More specifically, the watershed extends across a portion of the Central Columbia Mountains Ecosection. High ridges and narrow valleys and trenches characterize this area. The Slocan River originates at Slocan Lake flowing approximately 156 km south past communities such as the Village of Slocan, Winlaw, Passmore and Crescent Valley before joining the Kootenay River near Shoreacres, BC, located between Nelson and Castlegar, BC. The Kootenay River is a major tributary to the Columbia River. The valleys and lower slopes are dominated by Interior Cedar-Hemlock forests while the middle mountain slopes have an Engelmann Spruce – Subalpine Fir forest. Moist vegetation is present in the alpine with barren rock present in the highest areas (Demarchi, 2011). The area is underlain by a variety of rocks including sedimentary, metamorphic, gneiss, and granitic batholiths (Demarchi, 2011).

The Slocan River has an upstream watershed area of 3,412 $km^2$ that has a north-south orientation. The watershed includes the tributaries of Lemon Creek, which has a watershed area of 203 $km^2$, Little Slocan River, which has a watershed area of 818 $km^2$, and Goose Creek, which has a watershed area of 86 $km^2$. The Slocan River watershed boundary is presented in Drawing 01 and key physiographic parameters of the watershed are listed in Table 2-1. The embankment of the Slocan Valley Rail Trail and Highway 6 runs parallel to the river in sections (Drawing 02).

**Table 2-1. Watershed characteristics of Slocan River.**

| Characteristic | Value |
|---|---|
| Watershed area ($km^2$) | 3,412 |
| Maximum watershed elevation (m) | 2,857 |
| Minimum watershed elevation (m) | 445 |
| Watershed relief (m) | 2,382 |
| Average channel gradient (%) | 0.14 |

## 2.2. Alluvial Fan and Floodplain Morphology

The Slocan River is generally confined in a 0.5 to 1 km wide valley bottom and displays a single-thread, low sinuosity meandering planform for most of its length. Alluvial fans have developed where tributaries such as Lemon Creek, Little Slocan River and Goose Creek enter the Slocan River valley. The depositional fans have restricted the floodplain width in some of these sections. At the confluence with Lemon Creek, approximately 7 km downstream (south) of the Village of Slocan, the Slocan River is narrowed to a 40 m wide floodplain between the Lemon Creek fan to the east and exposed bedrock to the west. Similarly, at the confluence with the Little Slocan River, the Slocan River is constricted to a 60 to 100 m wide channel. South of Slocan Park, the Slocan River becomes partially confined by fluvial terrace deposits. Downstream of Crescent Valley, the Slocan River flows in a canyon formed by terraces to its confluence with Kootenay River at Shoreacres, BC. The Slocan River is a relatively stable, irregular channel for most of its length. An exception to this is south of the confluence with Lemon Creek, where the channel forms a wandering pattern with numerous gravel bars. For much of its length, Little Slocan River flows in a narrow valley with an irregular channel pattern, and changes to a wandering river morphology where the valley opens to the Slocan River valley.

## 2.3. Hydroclimatic Conditions

Large-scale airflows moving in from the Pacific Ocean bring moist, marine air to the BC Interior. The Columbia Mountains, lying perpendicular to the prevailing winds, influence the distribution of precipitation and temperatures within the Columbia River watershed. Air masses rising over the Columbia Mountains produce an area of increased precipitation. Precipitation takes the form of rain in the summer and deep snow in the winter. Cold air from the arctic infrequently enters this area because it is protected by mountain ranges from all sides (Demarchi, 2011).

The upper watershed of the Slocan River rises to a maximum elevation of 2857 m. Based on climate normals (1961 to 1990), this high elevation area receives a maximum annual average precipitation of approximately 2300 mm. In comparison, Shoreacres is located at an elevation of approximately elevation 445 m and received an average annual precipitation of approximately 650 mm for the same period (Wang et al., 2016).

Averaged across the watershed, the mean annual precipitation (MAP) is 1224 mm, of which approximately 666 mm (54%) is snowfall (precipitation as snow [PAS]) (Table 2-2). The mean annual temperature (MAT) in the watershed is approximately 3.0ºC. The spatial distribution of historical average MAP, MAT, and PAS is depicted in Figure 2-1 based on climate data from Wang et al. (2016). Precipitation occurs primarily as snowfall from November to April, and as rain throughout the remainder of the year. Historical precipitation has been highest on average in December and lowest in August.

**Table 2-2. Historical (1961 to 1990) annual climate statistics for the Slocan River watershed (Wang et al., 2016)**

| Variable | Mean Annual Total | Percent of total annual precipitation (%) |
|---|---|---|
| Mean Annual Temperature | 3.0 ºC | - |
| Mean Annual Precipitation | 1224 mm | 100 |
| Precipitations as Snow | 666 mm | 54 |
| Precipitation as Rainfall | 558 mm | 46 |

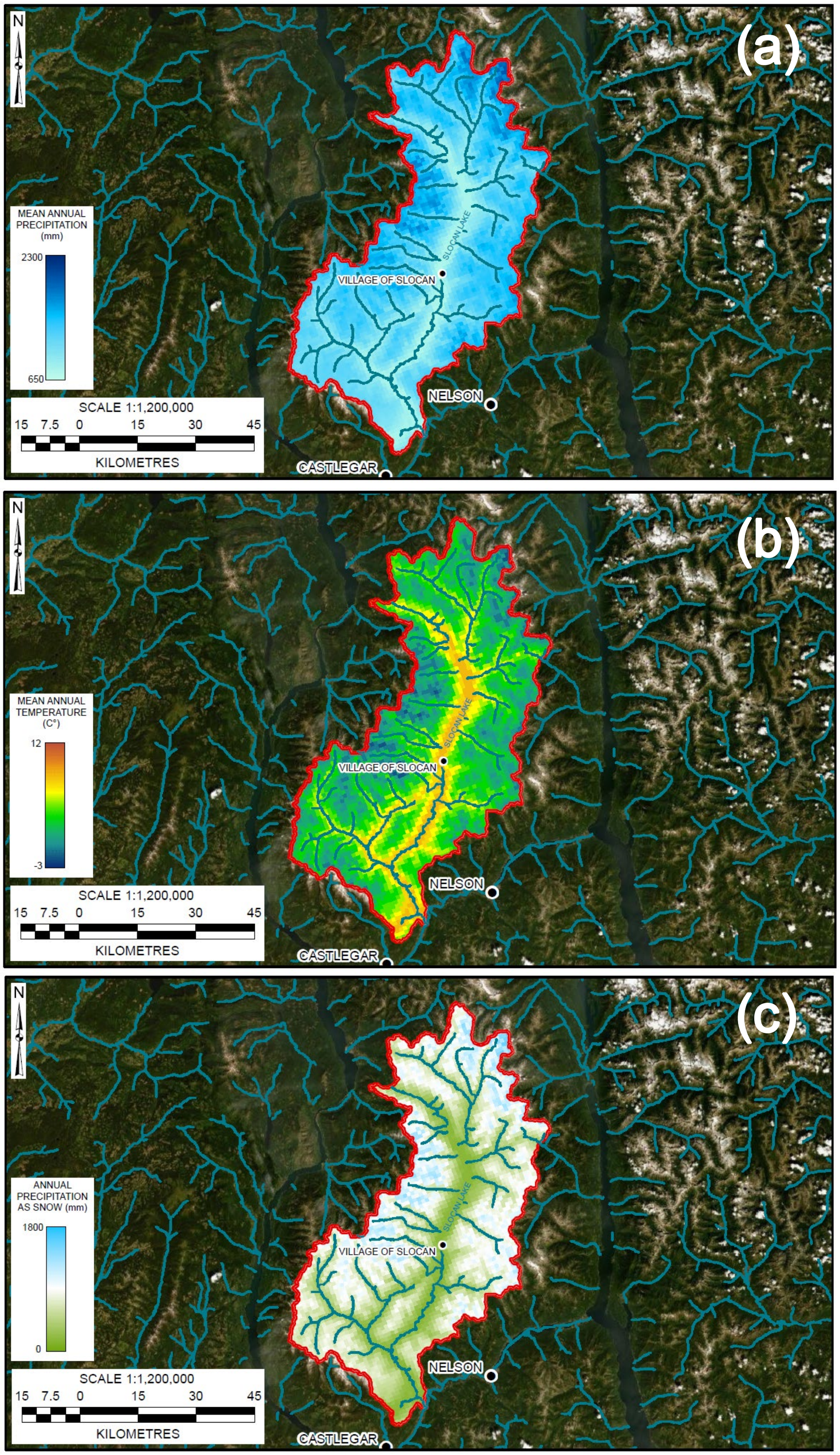



**Figure 2-1. Historical (1961 to 1990) mean annual precipitation (MAP) (a), mean annual temperature (MAT) (b), and precipitation as snow (PAS) (c) averaged over the Slocan River watershed.**

The Slocan River is gauged by the Water Survey of Canada's (WSC) hydrometric station *Slocan River near Crescent Valley* (08NJ013) from 1914 to present. The hydrometric station is located 40 km downstream from the Village of Slocan, BC (Drawing 02). The annual maximum peak instantaneous discharge is shown in Figure 2-2. The Slocan River is not regulated through the study reach. Peak flows occur in early May to late June corresponding with snowmelt or rain-on-snow events. The historical peak flows ($Q_2$ to $Q_{500}$) plotted in Figure 2-2 were used in the determination of the design flows, as detailed in Section 4.3.

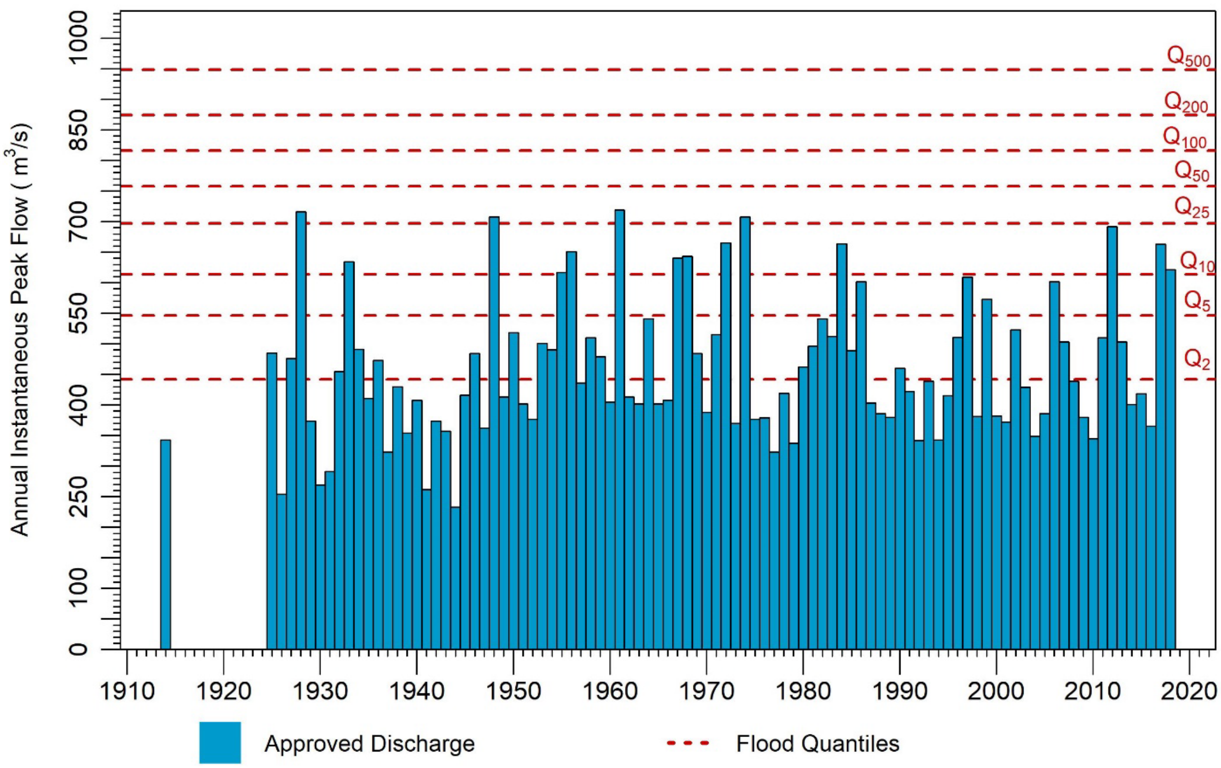



**Figure 2-2. Annual maximum peak instantaneous flows at Slocan River near Crescent Valley (08NJ013).**

Lemon Creek is gauged at WSC's *Lemon Creek above South Lemon Creek* (08NJ160) hydrometric station located 3.5 km upstream from its confluence with the Slocan River (Drawing 02). The historical annual maximum peak instantaneous discharge records on Lemon Creek are shown in (Figure 2-3). Based on 40 years of concurrent data, the timing of the peak flows on Lemon Creek coincide with the timing on Slocan River. In approximately 50% of the years on record, flows on Lemon Creek peaked the day before, or the same day as the flows on the Slocan River.

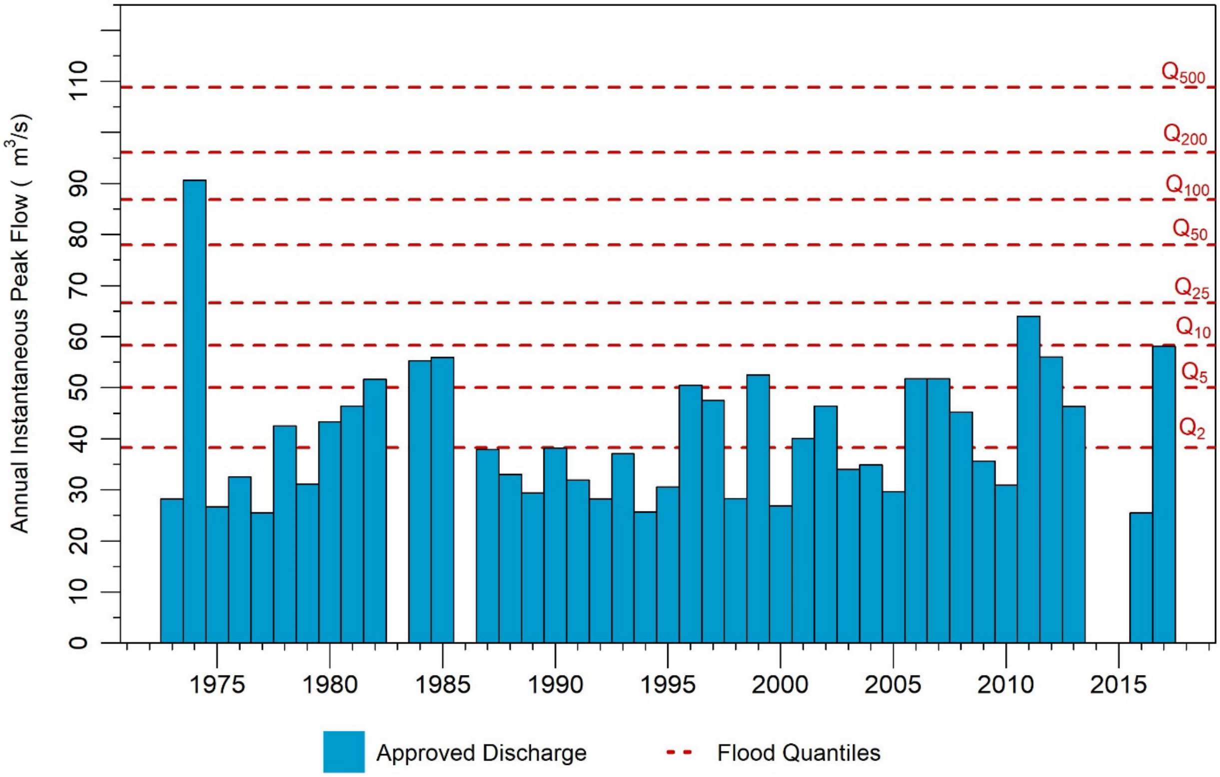



**Figure 2-3. Annual maximum peak instantaneous flows at Lemon Creek above South Lemon Creek (08NJ160).**

## 2.4. Climate Change Impacts

The MAT in the Slocan River watershed is projected to increase from 3.0°C (based on historical period 1961 to 1990) to 6.6°C by 2050 (based on period 2041 to 2070) assuming representative carbon pathway 8.5 (RCP 8.5). The MAP is projected to increase to 1,297 mm while PAS is projected to decrease to 446 mm by 2050 in the Slocan River watershed. Projected changes by 2050 (2041 to 2070) in climate variables from historical (1961 to 1990) conditions for the Slocan River watershed are presented in Table 2-3 (Wang et al., 2016).

**Table 2-3. Projected change (RCP 8.5, 2050) from historical (1961 to 1990) conditions for the Slocan River watershed.**

| Climate Variable | Projected Change |
|---|---|
| Mean Annual Temperature | +3.5 ºC |
| Mean Annual Precipitation | +74 mm |
| Precipitation as Snow | -220 mm |

Extreme flood events in the Montane Cordillera are often associated with rain-on-snow events in the spring (Harder et al., 2015). Although the effects of climate change on precipitation are not clear, projected increases in temperature are expected to have the largest impact on annual minimum temperatures occurring in the winter months (Harder et al., 2015). The effects of temperature change differ throughout the region. High elevation regions throughout parts of the

Montane Cordillera (e.g., Upper Columbia River watershed) are projected to experience increases in snowpack, limiting the response in high elevation watersheds while lower elevations are projected to experience a decrease in snow water equivalent (Loukas & Quick, 1999; Schnorbus et al., 2011).

Changes in streamflow vary spatially and seasonally based on snow and precipitation changes and topography-based temperature gradients. Researchers anticipate that streamflow will increase in the winter and spring in this region due to earlier snowmelt and more frequent rain-on-snow events, while earlier peak flow timing is expected in many rivers (Schnorbus et al., 2014; Farjad et al. 2016). Peak flows may increase or decrease depending on the watershed characteristics and the balance of temperature and precipitation changes described above.

## 2.5. Glacial History and Surficial Geology

Between 2 million and 10,000 years ago, ice sheets advanced and retreated into the Kootenay region (Turner et al., 2009). The final glaciation which ended approximately 10,000 years ago is responsible for many of the surficial materials in the area. South-flowing glaciers carved deep troughs which now hold Kootenay, Arrow and Slocan Lakes. Ice dammed the lakes during deglaciation. This resulted in lake levels approximately 150 m higher than present, and the deposition of silts and clays in isolated terraces near the lake shores. Processes of erosion and deposition have continued since deglaciation creating the younger deposits, such as the fluvial materials found along the streams. Near the Slocan River, the valley sides are bedrock with a thin discontinuous cover of till and colluvium (Fulton et al., 1984). Glaciofluvial and glaciolacustrine terraces are present in several locations along Slocan River and the south end of Slocan Lake. Thicker fluvial sediments are deposited along the Slocan River valley (Fulton et al., 1984).

# 3. SITE HISTORY

## 3.1. Area Development

Prior to European arrival, the Slocan Valley was part of the traditional territory of the Sinixt Nation, a hunting and fishing people that lived in the area of West Kootenays that included Slocan, Arrow, and Kootenay Lakes. Mining provided the impetus for European settlements in the Slocan River valley. The Village of Slocan grew rapidly, supported by the mining boom that originated in the late 1800s. Silver-lead ore mining was predominantly centered around the areas of New Denver, Slocan and Nakusp, BC. Mining production slowly declined due to increasing recovery costs and unfavorable market conditions and came to a halt in the 1920s. Today, agriculture, forestry, and tourism remain the dominant economic drivers in the Slocan River valley and support a population of 387 in the Village of Slocan (Statistics Canada, 2017). The estimated total improvement value of parcels intersecting the Slocan River hazard area based on the 2018 BC Assessment Data is $74,668,900 (BGC, March 31, 2019).

## 3.2. Historical Flood Events

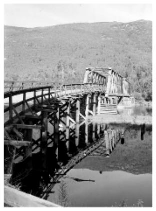
Slocan River and Lemon Creek have overtopped their channel banks on numerous occasions since the start of historical records in the late 1800s (Figure 3-1). The first major flood recorded on the Slocan River occurred in 1894 and washed out bridges and caused damage to property and railway lines. In 1933, regional flooding resulted in flooding on the Slocan River where water extents reached the Highway 6 embankment, located on the left (southeast) bank of the channel. In May 1948, flooding on the Slocan River and Lemon Creek reached a 25-year event resulting in channel maintenance on Lemon Creek following flood recession. On June 4, 1986, the Slocan River water level peaked resulting in a 10-year flood (approximately 600 $m^3/s$). Historical high-water marks were collected following the flood event on June 5, 1986 by members of the community. These high-water marks are summarized in Appendix E. The next major flood on the Slocan River took place in June 2012 resulting in a 25-year event (approximately 700 $m^3/s$) causing debris flows on tributaries. The next year, a flood event was recorded in May 2013 with a return period of 2 to 5 years (approximately 500 $m^3/s$). The most recent major flood event on the Slocan River was recorded in June 2017 with a return period of 10 to 25 years (approximately 650 $m^3/s$).

The provincial floodplain mapping program began in BC in 1974 aimed at identifying flood risk areas. This was in part due to the large Fraser River flood of 1972, which resulted in damage in the BC Interior. From 1975 to 2003, the province managed development in designated floodplain areas under the Floodplain Development Control Program. In 2003, the Program ended resulting in a significant change in how MFLNRO participated in land use regulation in flood-prone areas. The responsibility for developing and applying floodplain mapping tools was transferred to local governments, with the requirement that provincial guidelines be taken into consideration (EGBC, 2017).

The historical event inventory is based upon a variety of sources including newspaper articles, government records and consulting reports. Some sources may not be completely accurate or only provide partial records of flood events but are provided to present an overview of historical events.

## Flood History


***Slocan River flooding, May 2017 (Photo by Bruce Fuhr, The Nelson Daily)***



***Slocan River at Perry Siding, 1946 (BC Archives)***

***Slocan River near Vallican, ca. 1930 (Nelson Museum)***

**May - June 2017** - Flooding of Slocan River prompted evacuation alert
**February 2015** - Flooding and debris flow resulted in property damage, road closures, and evacuation alerts
**May 23, 2013** - Slocan River flowed at higher than normal level and reached 5-year peak
**June 2012** - Slocan River at a 25-year high, causing flooding and debris flow
**May 2006** - Flooding on the Slocan River and Little Slocan River forced evacuation of residents in Passmore Area
**May 2005** - Flooding along the Slocan River prompted evacuation orders for 78 homes in communities of Passmore and Slocan Park
**January 24, 2005** - Ice build-up in the Little Slocan River resulted in localized flooding
**April 2000** - Landslide occurred on private land on the upslope side of Highway 6 (approximately 20 km north of the Highway 3A/Highway 6 junction) releasing approximately 75,000 $m^3$ of material and blocking the river for nearly five minutes; phone and power lines knocked out
**June 1999** - Flooding along Slocan River resulted in erosion damage to local roads
**1997** - Large landslide occurred during spring freshet on south side of Little Slocan River near Passmore; other landslides in the area included one into the Slocan River
**October 30, 1996** - Channel migration resulted in bank erosion
**October 3-14, 1996** - Landslide near Appledale affected 3 properties resulting in structural damage and formed a small island in the river
**1995** - Landslide entered Slocan River
**September 15, 1986** - Erosion along Slocan River caused 100 m of bank slumping
**June 4, 1986** - Slocan River flood levels peaked
**June 1982** - Flooding along Slocan River
**June 11, 1981** - Flooding and erosion along the Slocan River
**December 16, 1974** - Flooding along Slocan River inundated low-lying land
**June 6, 1974** - Flooding drainage of low marshy area
**June 1972** - Flooding along the Slocan River and Lemon Creek; Slocan River reached a peak of 645.62 $m^3/s$; floods affected farmland and roads; banks were eroded
**March 24, 1969** - Debris flow near Slocan blocked a road, destroyed part of CPR track, and flowed into the Slocan River
**June 13, 1964** - Flooding in low lying areas near Slocan River
**1961** - Flooding along Slocan River
**June 21, 1956** - Flooding along Slocan River, with peak flow measuring at a rate of 566.33 $m^3/s$
**June 25, 1955** - Flooding on the Slocan River near Winlaw resulted in property damage
**May 1948** - Flooding along Slocan River and Lemon Creek, with peak flow along Slocan River measuring at a rate of 679.60 $m^3/s$
**June 1933** - Slocan River flooded highway
**June 1916** - Flooding washed out rail lines and approach to CPR bridge at Lemon Creek
**June - July 1909** - Flooding along the Slocan River caused extensive damage to property, including sawmills and railway lines; Lemon Creek left its channel, flowing north and carrying away farm buildings on two ranches
**March 1900** - Landslide carried 30.48 m of CP rail track into the Slocan River
**June 1894** - Flooding along the Slocan River washed out bridges, causing damage to property and railway lines

2020
2010
2000
1990
1980
1970
1960
1950
1940
1930
1920
1910
1900
1890

## Mitigation

**May 2005** - Instream structure and riparian restoration project undertaken by Slocan River Streamkeepers and Selkirk College
**May 1999** - Anchors installed along Little Slocan River at the toe of 1997 landslide
**August 31, 1998** - Large wood debris relocated to the toe of 1997 landslide along Little Slocan River and secured by piles
**September 5, 1991** - Channel modified through gravel bar scalping and channel diversion
**February 23, 1990** - Bridge removal resulted in debris entering Slocan River
**1984** - Riprap installed along section of the Slocan River
**1948** - Channel maintenance along Lemon Creek instigated by the CPR following spring flooding

## Development

**September 2012** - 1.6 acres of Shoreacres beach property along the Slocan River donated to the community and dedicated as the "Kieran Galbraith Memorial Park Shoreacres Beach"
**October 2011** - Crescent Valley Beach property on the shore of the Slocan River donated to RDCK
**November 2009** - Columbia Basin Trust and The Nature Trust of British Columbia purchased 142-acre Slocan Island conservation property, located on the Slocan River floodplain
**2009** - Columbia Basin Trust partnered with non-profit, government, and private citizens to purchase the Valhalla Mile, 155 acres of shoreline along the Slocan River, ensuring its protection as a new addition to Valhalla Provincial Park
**2006** - Slocan Valley Rail Trail celebrated grand opening along former CP Railway line
**September 1993** - The last CP Rail train travelled the Slocan Valley rail line
**March 3, 1983** - Valhalla Provincial Park established adjacent to the Slocan River
**1954** - Slocan Park Bridge constructed over the Slocan River, replacing suspension bridge
**1940s** - Three internment camps built in the Slocan Valley during WWII at Lemon Creek, Bay Farm, and Popoff Farm
**1932** - Replacement bridge constructed at Appledale over the Slocan River
**1928** - Winlaw Bridge constructed over the Slocan River
**April 1913** - Mapping of Slocan River watershed undertaken by provincial government
**1911** - Bridges constructed across the Slocan River at Slocan City and at Perry Siding
**1909** - Bridge constructed over the Slocan River near the junction with the Little Slocan River
**April 1904** - Railway bridge constructed over the Slocan River
**December 1897** - Slocan River branch of the CPR completed
**Early development history** - Slocan is the anglicized version of the Sinixt word slhu7kíń, meaning "to pierce, strike on the head," referring to the local first nations practice of spearing salmon

Flood (major flood)
Landslide
Debris flow or debris flood
Channel location
Mitigation
Development event

**Figure 3-1. Summary of recorded flood history, mitigation, and development history at the Slocan River and Lemon Creek.**

## 3.3. Flood Protection and Hydraulic Structures

### 3.3.1. Bridges

A total of twelve bridge crossings of the Slocan River (nine), Little Slocan River (one) and Lemon Creek (two) were identified within the study area (Figure 3-2). Bridges located on smaller tributaries were not included in this study. Midwest Surveys Inc. (Midwest) conducted surveys along the Slocan River to capture bridge and pier dimensions, as well as low chord (bottom-of-deck) and top-of-deck elevations (Table 3-1). Additional photos and bridge details are provided in Appendix E.

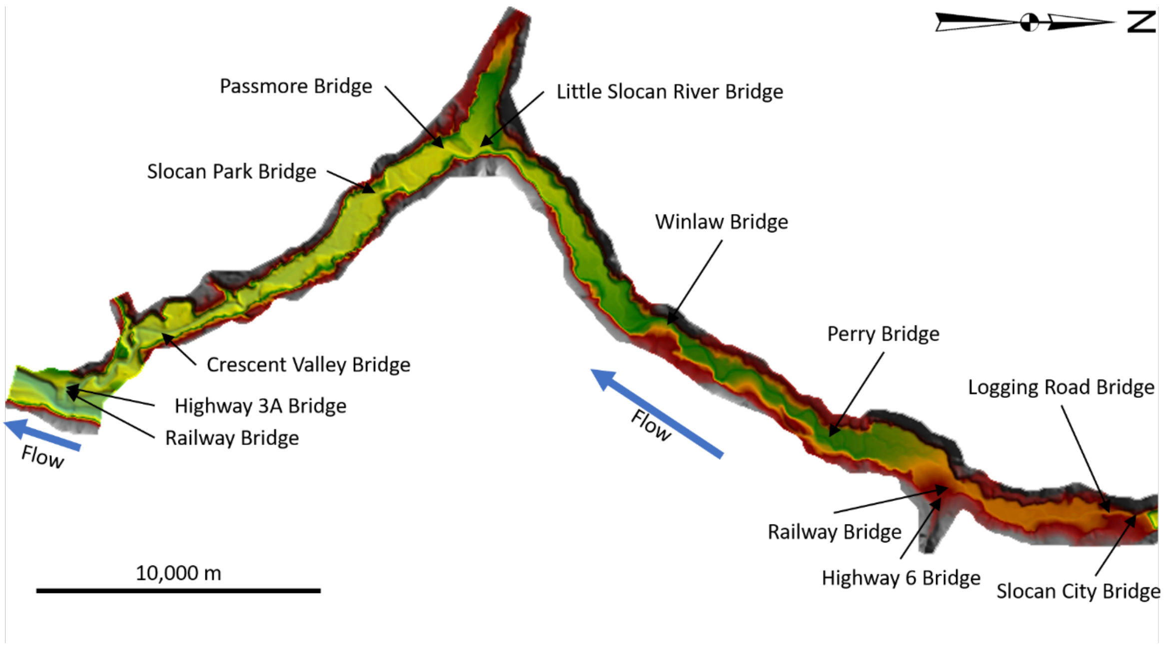



**Figure 3-2. Bridge crossings within the study area.**

**Table 3-1. Bridge crossings along the Slocan River, Little Slocan River, and Lemon Creek within the study area.**

| Bridge Crossing | Latitude (°) | Latitude (°) | Length (m) | Width (m) | Deck orientation to flow (°) | Low chord elevation (m)[1] | No. of Bridge Piers |
|---|---|---|---|---|---|---|---|
| **Slocan River** | | | | | | | |
| Village of Slocan Bridge | 49.7660 | -117.4732 | 80 | 8 | 80 | 539.90 | 2 |
| Logging Road Bridge (Gravel Pit Road) | 49.7545 | -117.4751 | 64 | 4 | 90 | 538.38 | 2 |
| Perry Bridge | 49.6647 | -117.5113 | 100 | 4 | 90 | 523.10 | 3 |
| Winlaw Bridge | 49.6157 | -117.5665 | 80 | 9 | 90 | 521.60 | 2 |
| Passmore Bridge | 49.5405 | -117.6535 | 90 | 6 | 90 | 494.31 | 2 |
| Slocan Park Bridge | 49.5188 | -117.6302 | 70 | 6 | 90 | 484.63 | 0 |
| Crescent Valley Bridge | 49.4511 | -117.5607 | 96 | 10 | 90 | 474.87 | 1 |
| Highway 3A Bridge | 49.4199 | -117.5312 | 123 | 10 | 90 | - | 0 |
| Railway Bridge | 49.4199 | -117.5307 | 107 | 7 | 90 | - | 0 |
| **Lemon Creek** | | | | | | | |
| Highway 6 Bridge | 49.7017 | -117.4796 | - | - | 90 | - | 1 |
| Slocan Valley Rail Trail Bridge | 49.7048 | -117.4889 | - | - | 90 | - | 0 |
| **Little Slocan River** | | | | | | | |
| Little Slocan Bridge | 49.5505 | -117.6570 | 67 | 11 | 90 | 499.99 | 1 |

Note:

1. Vertical datum: CGVD 2013.

### 3.3.2. Dikes

Approximately 600 m of non-regulated dikes have been constructed on the left (south) bank of Lemon Creek (Figure 3-3). Dike construction initially used streambed sediments dredged from the channel and anchored with log cribs (Figure 3-4). The Canadian Pacific Railway (CPR) built dikes to contain the creek in the channel and prevent washouts of the railway bridge as previously the creek had washed out the railway tracks in 1909 and 1916. The creek has remained in the current channel alignment, partly due to past maintenance to remove accumulated gravel from the channel (MoE, 1979). These dikes are considered an orphan flood protection structure that is not being maintained by an owner or diking authority (Boyer, 2009). Additional bank alterations are visible in lidar that are not listed in the database and were not surveyed (shown as unlisted dike in Figure 3-3). The origin of those features is unknown but could be attributed to bed material removal and placement along the banks. Surveyed dike locations are shown in Figure 3-3. In addition to the log cribbage shown in Figure 3-4, bank armouring with boulders was observed further downstream as shown in Figure 3-5.

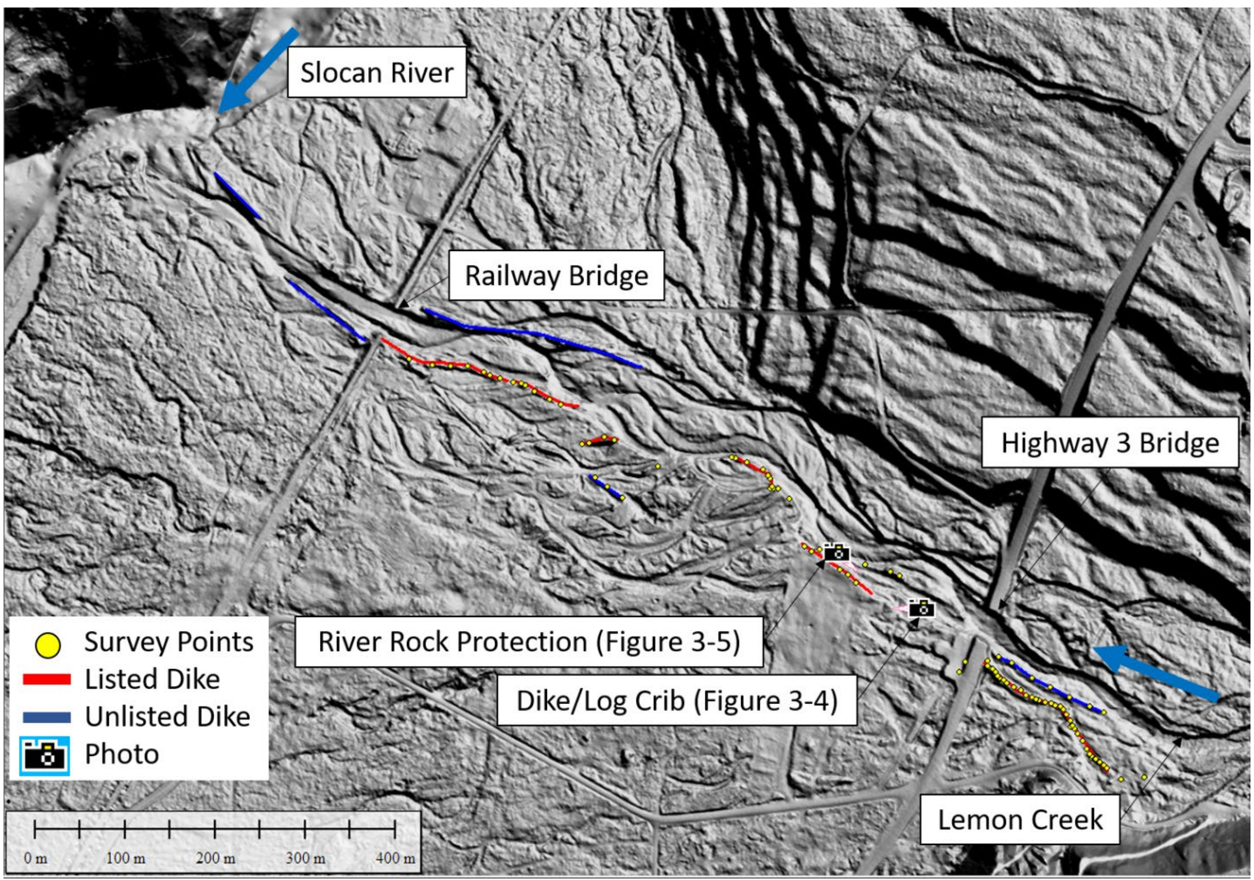



**Figure 3-3. Dike locations (red line) and survey points (yellow dots) along Lemon Creek. Photos referenced are shown in figures below.**

**Figure 3-4. Failed log cribbing with gravel and cobbles along left bank of Lemon Creek. Photo: BGC, July 2, 2019.**

**Figure 3-5. Boulders along left bank of Lemon Creek. Photo: BGC, July 2, 2019.**

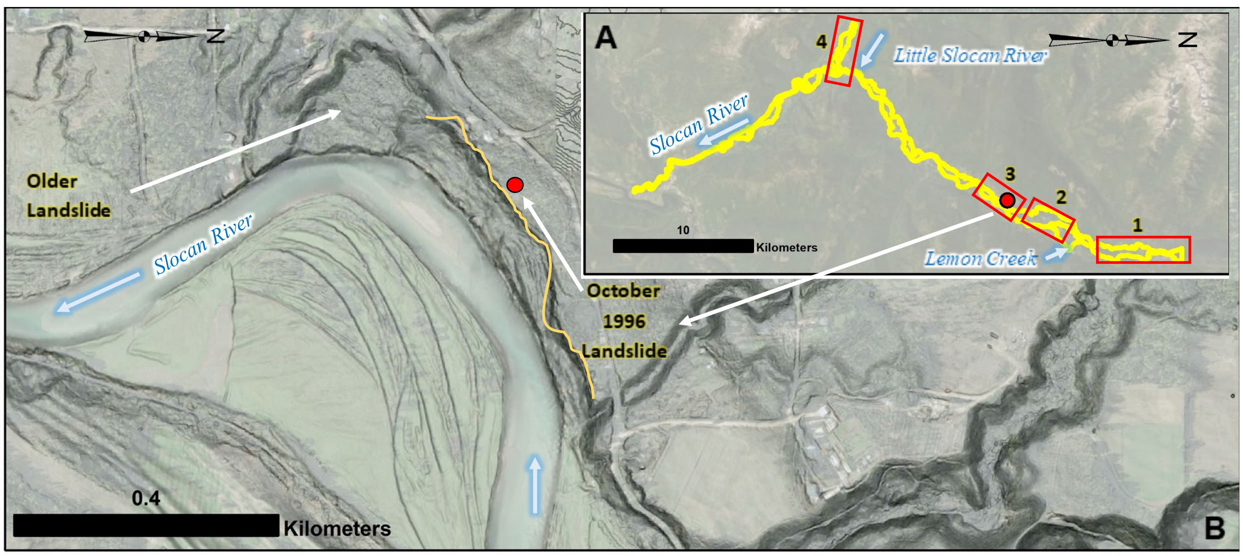
## 3.4. Landsliding, Bank Erosion and Avulsion History

Lateral channel migration resulting from bank erosion and sediment deposition is a natural process in alluvial rivers. Channel migration may occur as gradual erosion at the outside of river bends, or as sudden widening of the river during floods. Gradual channel migration generally results from sediments being eroded along the outer bank of a meander bend and deposited as a point bar along the inside of the meander bend (Charlton, 2007).

Variations in the geometry of a channel may impact flooding by decreasing its capacity of conveying flows or adding uncertainty to channel path during high-flow conditions. Several factors contribute to changes in channel morphology and pattern. These factors include physical characteristics (channel confinement and river slope, for instance) and geomorphic processes (aggradation, bank erosion, including hillslope processes).

Within the study area, the Slocan River has significantly changed at specific sections following high-flow events and as a result of progressive geomorphic processes (e.g., landslides and bank erosion). Investigations into flooding, avulsion, bank erosion and landsliding problems within the Slocan River study area were initiated following requests from the Slocan Valley Agricultural and Development Association in 1970 (MoE, 1979). Since then, further studies have been conducted to understand the dynamics of these processes and the potential mitigation alternatives. A summary of these studies is provided in Table 3-2. The areas where geomorphic processes have been historically active include (Figure 3-6):

- Upstream of the confluence with Lemon Creek (Area 1 in Figure 3-6). The active geomorphic processes at this area have been mostly related to flooding and fluctuations in water level (long periods of high water-levels).
- Downstream of the confluence with Lemon Creek (Area 2 in Figure 3-6). Active bank migration has caused the channel to meander in the floodplain leading to loss of agricultural land.
- Further downstream of the confluence with Lemon Creek (Area 3 in Figure 3-6). Several landslides are visible within this area along the glaciolacustrine materials. Some examples are provided in Boyer (1996), VanDine (1996) and Apex Geoscience (1998).
- Little Slocan River (Area 4 in Figure 3-6). This area has been historically unstable due to slope instabilities (e.g., Klohn- Crippen, 2000) and bank erosion.




Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

**Figure 3-6. Areas within the Slocan River floodplain where geomorphic processes have been historically active. (A) Red dot illustrates the location of the October 1996 landslide; (B) Areas of historical activity: 1= Upstream of the confluence with Lemon Creek; 2= Downstream of the confluence of Lemon Creek; 3= Approximately 18 km upstream of the confluence with Little Slocan River; and, 4= Little Slocan River.**

**Table 3-2. Historical bank erosion and avulsion information.**

| Year | Reported Observations | Proposed or Completed Mitigation works | Reference |
|---|---|---|---|
| 1971 | Property owner downstream of Lemon Creek reported that the main channel of Slocan River has moved to a relict channel and is eroding the banks at a rate of about 5 feet per year. | Proposal for the rehabilitation and reclamation of land in the vicinity of Lemon Creek by removing the Lemon Creek dam. | BC Department of Lands Forests and Water Resources, 1971 |
| 1975 | Bank erosion downstream of Lemon Creek resulted in loss of agricultural land. The cause of bank erosion was attributed to the steep gradient and high velocity of the Slocan River. | None | Northwest Hydraulic Consultants, 1975 |
| 1979 | Erosion problems noted along the Lemon Creek fan, due to sediment accumulation at the outlet of Lemon Creek and higher gradients downstream of Lemon Creek. | None | BC Ministry of Environment, Water Investigation Branch, 1979 |
| 1984 | Bank erosion on the east bank of Slocan River downstream of Lemon Creek. | None | BC Ministry of Environment. Slocan River – Lemon Creek study |
| 1996 | A landslide occurred on October 3, 1996, on the right bank (west) of the Slocan River between Lemon Creek and Winlaw (Figure 3-6). The ground movement caused a small island to form at the toe of the slope. River erosion at the meander bend was identified as a possible contributor to instability. | Mitigation was not completed at this point. | Boyer, 1996; VanDine, 1996 |
| 1997 | A series of slope failures occurred approximately 6 km north of Crescent Valley on the west side of the Slocan River | The debris deposited in the river were removed. Remediation of the slope was recommended. | EBA Engineering, 1997 |
| 1997 | Landslide along the right (south) bank of the Little Slocan River approximately 2 km from its confluence with the Slocan River | Recontouring of the slide scarp and bioengineering. | Timberland Consultants, 1999 |
| 2000 | In April 2000, a landslide occurred on private land on the upslope side of Highway 6 (approximately 20 kilometers north of the Highway 3A/Highway 6 junction). During the months before the failure, the slope was creeping 1 to 2 meters, with most of the activity concentrated on the toe of the slope. The landslide consisted of several slump blocks, released about 75000 m3 of material, and blocked the river for nearly five minutes. | Mitigation included groundwater management on the slope. | Walsh, 2000 |

# 4. METHODS

This section summarizes the assessment methodology applied to at the Slocan River. Additional details on the methodology applied are summarized in Appendices C, D, and E.

## 4.1. Field Data, Topographic Data and River Bathymetric Surveys

### 4.1.1. Fieldwork and Site Investigations

Fieldwork on the Slocan River was conducted on July 2, 7 and 30, 2019 by BGC personnel (Elisa Scordo, P.Geo., Marc Olivier Trottier, P.Eng., and Rob Millar, P.Geo., P.Eng.). Field work included measurement of grain size diameters (Wolman sampling) to characterize the grain size distribution of in-channel materials, and observations at bridge and other infrastructure crossing locations and flood protection structures (e.g., dikes, riprap armouring). Field work was also conducted to coordinate the survey extent and data collection with the survey crews.

### 4.1.2. Topographic Mapping

Detailed topographic data of the floodplain were available from a classified high-resolution lidar dataset obtained from RDCK and flown in August 2018. BGC was provided with tiles containing the classified point cloud and a 1 m bare-earth Digital Elevation Model (DEM). Lidar coverage provided by RDCK for the entire study area is shown in Figure 4-1.

The lidar data were provided with the following coordinate system:

- Horizontal Datum: NAD83 CSRS
- Projection: UTM Zone 11 North
- Vertical Datum: CGVD 2013
- Geoid Model: CGG2013.

As part of the lidar acquisition, orthophotos were not collected. As a result, the classification of the raw lidar point cloud contained inaccuracies particularly around gravel bars and the location of the river shoreline. In order to account for this, BGC collected additional ground and bathymetric survey data to capture in-channel features that were not classified in the lidar survey.

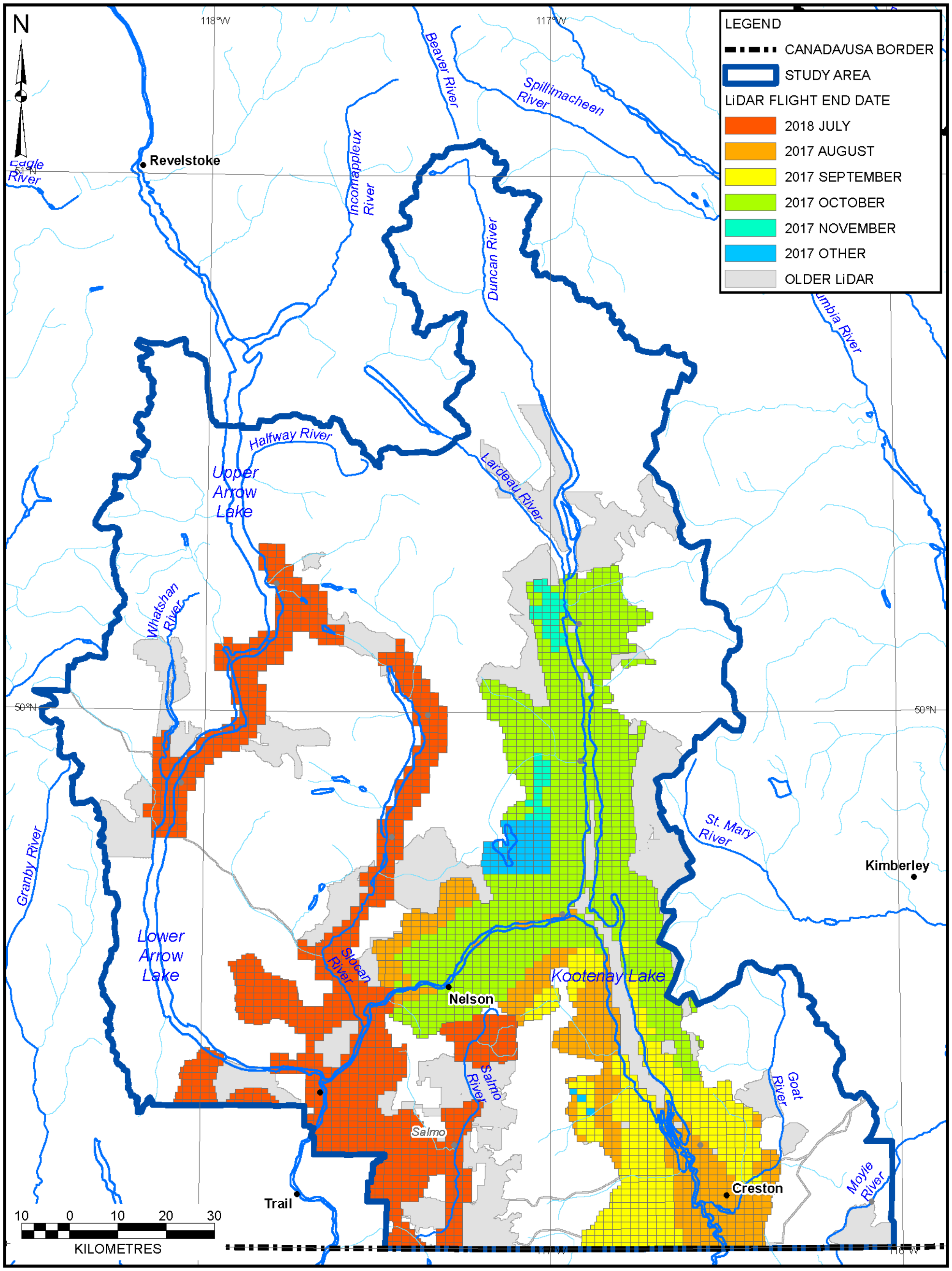



**Figure 4-1. Lidar coverage for clear-water study sites.**

### 4.1.3. Ground and Bathymetric Surveying

BGC contracted Midwest to conduct a detailed survey of the Slocan River, Lemon Creek and Little Slocan River (Drawing 03). The scope of work included surveying of the channel bed, bridges, and dikes. A combination of Static Global Navigation Satellite System (GNSS) techniques, real-time kinematic (RTK) and real-time network (RTN) techniques were used to establish a precise, reliable Survey Control Network (SCN) for the length of the project. The SCN was integrated with existing BC Survey Control and/or the Canadian Base Network. The survey data were provided in the 3TM NAD 83 (CSRS) UTM 11 North coordinate system with elevation in the CGVD2013 Vertical Datum.

The survey was conducted from July 2 to September 22, 2019. The survey covered approximately 60 km of the Slocan River, 5 km of Little Slocan River, and 1.5 km of Lemon Creek. Surveying of the channels was completed using GNSS RTK GPS and in locations where the water depth was too deep to be waded safely, hydrographic surveying (sonar) from a boat was used. A summary of locations collected using survey and sonar techniques is presented in Drawing 03. Channel cross sections, extending from bank to bank and approximately perpendicular to the channel, were collected at a typical spacing of 200 to 300 m. Cross-section spacing was reduced to 50 to 100 m in areas of rapid channel changes. Bridges were surveyed to collect details such as the length of the span, width of the bridge, top of curb elevation, bottom of deck (low chord) elevation and width of piers (e.g., Figure 4-2).


**Figure 4-2. Example of bridge structure features collected during the Slocan River survey.**

### 4.1.4. Survey Equipment, Accuracy and Processing Software

Table 4-1 provides a list of survey equipment and the reported accuracy. Hypack 2018 Hydrographic Software was used to correlate global position system (GPS) and hydrographic data together.

**Table 4-1. Summary of survey equipment.**

| Equipment Type | Reported Accuracy |
|---|---|
| **GPS** | |
| Trimble R10 GNSS | • Single Baseline: <30 km<br>• Horizontal (RTK): 8 mm + 1 ppm RMS<br>• Vertical (RTK): 15 mm + 1 ppm RMS<br>• Horizontal (Static GNSS): 3 mm + 0.1 ppm RMS<br>• Vertical (Static GNSS): 3.5 mm + 0.4 ppm RMS |
| **Total Station** | |
| Leica TCR 403<br>Trimble SX3 Robotic Scanning Total Station | • Angular Accuracy: +/- 3"<br>• EDM Range: 1 m – 2,500 m to single prism<br>• Reflectorless EDM Range: 1 m – 100 m<br>• Distance Accuracy: 2 mm + 2 ppm<br>• Distance Accuracy Scanning: 2 mm + 1.5 ppm |
| **Hydrographic Equipment** | |
| Odom Echotrac CV-100 | • Depth Range: <0.30 m to 600 m<br>• Accuracy (Corrected for Sound Velocity): 0.01 m +/-0.1 % depth |

### 4.1.5. Terrain Creation

Following completion of the survey, BGC integrated the bathymetry data with the lidar bare-earth DEM to generate a continuous terrain model for use in hydraulic modelling. The process to generate the terrain model from the topographic modelling and the bathymetric survey was as follows:

1. A mask was defined in the channel to remove pulse returns from the water surface from the lidar point collection.
2. A continuous terrain surface of the ground and bathymetry was created from the bathymetric survey points and the classified ground points from the lidar using the Kriging gridding method within the Surfer software package from Golden Software.

The resulting terrain was reviewed, and adjustments made to remove artifacts from the process. Many of the artifacts encountered were due to changes in the channel alignment between the period of the lidar collection and the survey.

Hydraulic structures were not included in the terrain. Bridge decks were removed from the DEM so as to not artificially dam the flows. The flow hydraulics at bridge crossings are detailed in Appendix E.

## 4.2. Channel Change and Bank Erosion Analysis

Floods induce high shear stresses on channel banks, which can promote bank erosion. Non-cohesive materials such as sands and gravels are more susceptible to this process than cohesive banks. Standard hydraulic models to simulate floods do not consider bank erosion and assume the channel geometry is static. BGC conducted a separate analysis to assess changes in the floodplain and channel, and their potential influence on flooding.

Channel change mapping and bank erosion approaches using remote sensing have been widely used to detect variations in the position of channel geomorphology features (e.g., channels, banks, and bars) (Trimble & Cook, 1991; Marcus, 2012). These methods have been reviewed and considered suitable to quantify the rate of change over a study period (Lawler, 2006).

This section briefly describes the study area, data and methods used to document planform channel changes within the floodplain and analyze the bank erosion processes observed between 2003 and 2014. It also outlines the limitations and uncertainties of the methodology.

### 4.2.1. Channel Change and Bank Erosion Study Area

The analysis focused on two areas where historical channel changes, bank erosion and other geomorphic processes such as landslides were evident within the reviewed timeframe and are expected to impact flood hazards within the Slocan River (Table 4-2 and Figure 4-3). The first area includes a 4.6 km segment downstream of the confluence of Slocan River with Lemon Creek (Figure 4-3C). The second section comprises a 4.8 km long reach of Little Slocan River (Figure 4-3B). These areas were divided into reaches to facilitate the analysis of the channel changes. The main characteristics of the identified reaches are described in Section 5.1.

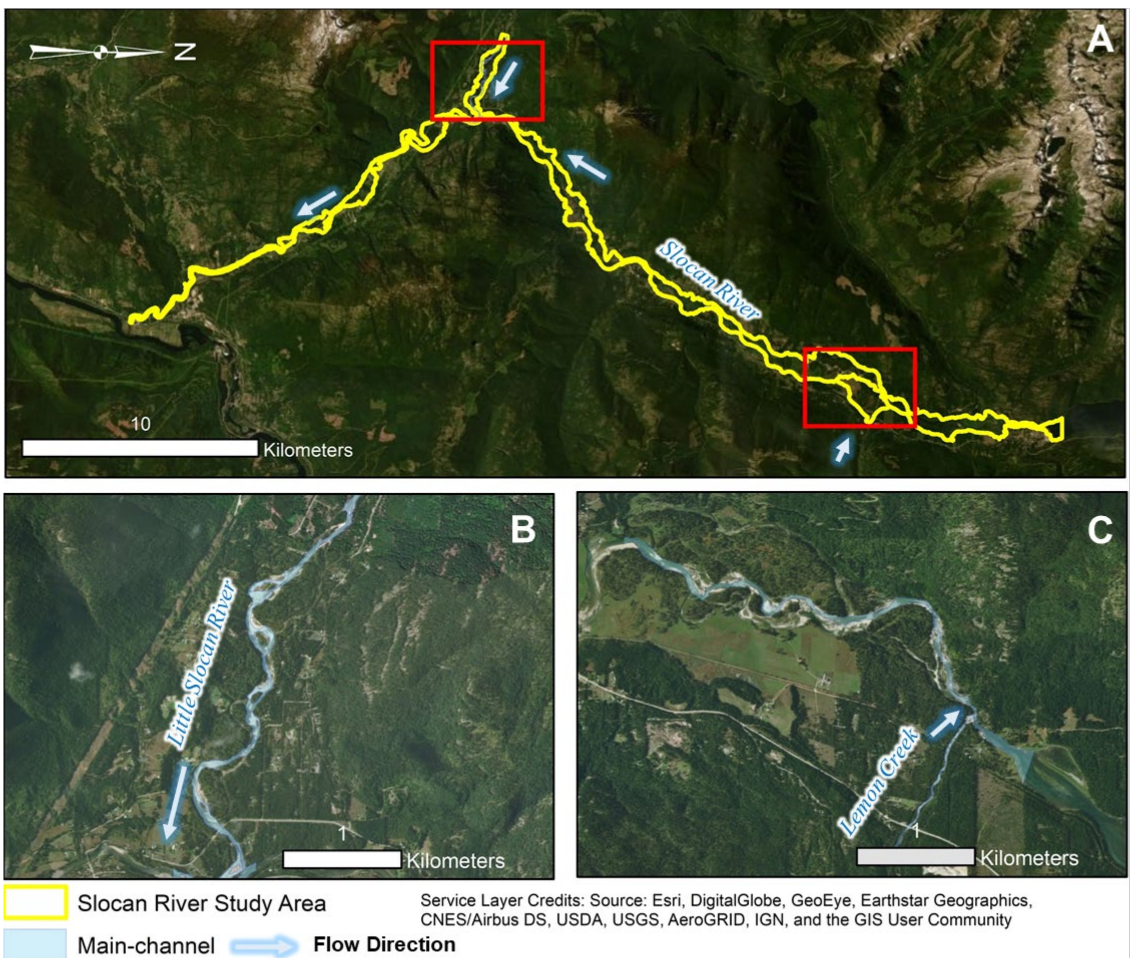



**Figure 4-3. Channel change and bank erosion study areas. (A) Slocan River study area overview; (B) Little Slocan River; and (C) Slocan River south of Lemon Creek.**

### 4.2.2. Data Sources

The data sources for this analysis consisted of high-resolution satellite imagery supported with lidar. The characteristics of these data are described in Table 4-2. The channel mapping was also informed by the river bathymetric survey described in Section 4.1.3.

**Table 4-2. Aerial photographs and satellite imagery used in the analysis.**

| Type | Year | Roll/Frame | Nominal Scale | Source |
|---|---|---|---|---|
| Aerial Photograph | 1954 | BC167: 14, BC165:39 | 1:31,680 to 1:40,000 (Medium) | BC Government |
| Aerial Photograph | 1980 | BC80138:048 | 1:40,000 | BC Government |
| Aerial Photograph | 1990 | BCB90132: 189-190 | 1:15,000 | BC Government |
| High-resolution imagery | 2003 | N/A | 1:10,000 | Google Earth Pro (v 7.3.2.5776) |
| High resolution imagery | 2004 | N/A | 1:10,000 | Google Earth Pro (v 7.3.2.5776) |
| High resolution imagery | 2005 | N/A | 1:10,000 | Google Earth Pro (v 7.3.2.5776) |
| High-resolution imagery | 2009 | N/A | 1:10,000 | Google Earth Pro (v 7.3.2.5776) |
| High-resolution imagery | 2012 | N/A | 1:10,000 | Google Earth Pro (v 7.3.2.5776) |
| High-resolution imagery | 2014 | N/A | 0.5 m resolution | Digital Globe from ESRI World Imagery |

### 4.2.3. Method

In this analysis, the following tasks were completed:

<u>Data preparation</u>:

This task involved the acquisition of historical aerial photographs and imagery for georeferencing and mosaics creation. All the imagery and photographs were georeferenced to the same coordinate systems (NAD 1983 CSRS UTM, Zone 11N).

<u>Geomorphic analysis</u>:

The geomorphic analysis involved three steps. First, distinct channel reaches were delineated (i.e., length of the channel with similar physical characteristics). These reaches were then used to quantify the average net erosion recorded in the analyzed period.

Second, the channel thalweg and planform were delineated. The channel planform refers to the form of a river as viewed from above (Charlton, 2007). The 2019 thalweg was generated from the river bathymetric survey data. The historical channel thalwegs were interpreted from the historical photographs and manually digitized on-screen.

Third, geomorphic features were mapped using defined geomorphic criteria developed by BGC based on Wheaton et al. (2015), Howes and Kenk (1997), and Church (2006) (Table 4-3 and Table 4-4).

**Table 4-3. Geomorphic features used for geomorphic floodplain and channel mapping.**

| Feature | Type | Map Symbol | Description |
|---|---|---|---|
| **Channel** | Main-channel | Fmc | Flowing channel with distinct banks that carries most of the river discharge. This feature is always active. |
| | Side-channel | Fsc | Flowing channel with distinct banks that carries a portion of the river discharge less than the main-channel. This feature is active. |
| | Back-channel | Fbc | Abandoned channel with distinct banks whose downstream end is connected to the river but whose upstream end is plugged. This feature is always active. |
| | Flood-channel | Ffc | Channel with distinct banks connected to a main or side channel only in overbank flood conditions. |
| **Bars** | Abandoned-channel | Fac | Inactive channel remnant(s). No longer directly connected to active flow (e.g., oxbow lake). It can become active during high- flow events. |
| | Lateral and point bars | Flb | Deposition and accumulation of sediments against the bank (lateral or side bars) and on the inside of a meander bend (point bars). |
| | Mid-channel bar | Fmb | Feature characterized by the accumulation of sediments within the main channel. When the position of the bar become stable and vegetated during decades, they are commonly called islands. |
| **Plain** | Floodplain | Fp | Includes the level-ground area susceptible to overbank flow or flooding during high-flow events. |
| **Fan** | Alluvial fan/delta | Ff | A fan is a relatively smooth sector of a cone with a slope gradient from apex to toe up to and including 15°, and a longitudinal profile that is either straight, or slightly concave or convex (Howes and Kenk, 1997). |
| **Terrace** | Terrace | Ft, FGt LGt | Flat or gently sloping areas bounded by an adjacent scarp. Fluvial terrace (Ft) deposits consist of channel deposits that may include some overbank materials. |

**Table 4-4. Levels of activity assigned to the geomorphic features.**

| Activity Class | Map Symbol | Description |
|---|---|---|
| Active | A | This indicates that the fluvial processes were active on the identified geomorphic feature at the time when the remote sensing data were collected. The floodplain and lateral, point or mid-channel bars are considered active until vegetation cover is established. Less than 75% of vegetation coverage or isolated patches of vegetation were classified as active. |
| Dormant/ Inactive | D | This indicates that there is no observable evidence of fluvial processes being active on the identified feature at the time when the remote sensing data was collected. The floodplain and lateral, point or mid-channel bars are considered dormant when at least 75% of the mapped feature is covered by vegetation. |

Channel Change and Bank Erosion Analysis

The channel banks and geomorphic features delineated in the previous stage were used to quantify net bank erosion between the analyzed periods. A spatial analysis using ArcGIS software by ESRI (version 10.6.1) was applied to estimate the net change in riverbank positions between each set of imagery. The following steps were completed:

- A numerical value of 1 (active) or 2 (dormant/inactive) was assigned to each mapped feature in the shapefile attribute table. The values were determined as per the activity criteria described in Table 4-4. The general assumption was that unvegetated bars are active and would be submerged during bankfull conditions and, therefore, part of the active channel. A raster layer consisting of 1 and 2 values was created for each year of analysis.
- Then, the map algebra tool was used to subtract any two raster layers and estimate net change within the period. Negative values indicate bank erosion or channel migration, zero values indicate no change within the period, and positive values indicate either bar stabilization or deposition (Table 4-5).

**Table 4-5. Channel change classes.**

| Map Algebra Results | Class | Definition |
|---|---|---|
| -1 | Bank Erosion, Channel Migration | Lateral migration of the channel due to the removal of bank material has occurred at the raster cell. |
| 0 | No Change | The channel features remained the same at the raster cell between the reviewed periods |
| 1 | Stabilization, Bank Accretion | Two conditions are possible for this result. First, pre-existing channel bars have remained stable during the period, allowing for vegetation to grow (stabilization). Second, the fluvial processes acting during the reviewed timeframe have promoted the sideway deposition along channel meanders (lateral accretion). |

### 4.2.4. Limitations and Uncertainties

Some limitations of the interpretation of remote sensing data to the quantification of channel change include:

- The scale and resolution of available aerial photographs, which affects the level of detail that can be identified for a given year.
- The geometric distortion that results from terrain and imagery acquisition method (e.g., camera tilt in aerial photographs). These factors may result in a displacement of the geomorphic features from its true position.
- The degree to which the historical photographs represent relevant channel changes within the investigated timeframe to within tolerable levels of accuracy.
- Challenges related to the quantification of the error during the process. Possible sources of error in this analysis include scanning, georeferencing error and on-screen digitizing errors.
- The discharge at the time of image capture. At higher discharges, most gravel bars would be inundated.

These errors were reduced in this study by applying common procedures including:

- Focusing on the central part of each aerial photograph.
- Scanning the paper photographs at a high resolution.
- Conducting geometric corrections on ArcGIS 10.6.1 software using the spline transformation tool which is commonly used when local accuracy is required.

## 4.3. Hydrological Analysis

### 4.3.1. Flood Frequency Analysis

For this study, peak discharge estimates for select return periods needed to be determined at three locations within the Slocan River watershed. From upstream to downstream, these locations include 1) Slocan Lake, 2) Lemon Creek, and 3) Little Slocan River.

Peak discharge estimates for the Slocan River, Lemon Creek, and Little Slocan River were calculated by pro-rating the peak discharges obtained from a flood frequency analysis (FFA) of the Annual Maximum Series (AMS) from a single hydrometric station located on the watercourses. In this approach, the maximum peak instantaneous discharge is considered for each year on record. The Generalized Extreme Value (GEV) probability distribution function was fit to peak discharge records. The parameters of the distribution were calculated using the L-moments method of inference.

The FFA from two streamflow gauges were used to estimate the peak discharges for the three watercourses: *Slocan River near Crescent Valley* (08NJ013) and *Lemon Creek above South Lemon Creek* (08NJ160). The information for these two gauges is listed in Table 4-6. The estimates for the Slocan River were compared with historical estimates published by previous studies (e.g., NHC, 1989). The *Slocan River near Crescent Valley* (08NJ013) station was used to estimate the peak discharges for the Slocan and Little Slocan rivers and *Lemon Creek above South Lemon Creek* (08NJ160) was used to estimate the peak flows for Lemon Creek.

**Table 4-6. Hydrometric station information used to determine the peak discharges.**

| Station Name | Slocan River near Crescent Valley | Slocan River at Slocan Lake | Lemon Creek above South Lemon Creek |
|---|---|---|---|
| **Station ID** | 08NJ013 | 08NJ014 | 08NJ160 |
| **Watershed Area (km$^2$)** | 3330 | 18211 | 181 |
| **Real-time recordings** | Yes | No | No |
| **Latitude** | 49°27'36" N | 49°46'8.0¨ N | 49°41'49" N |
| **Longitude** | 117°33'53" W | 117°28'23.0¨ W | 117°26'45" W |
| **Record Period** | 1914 to 2020 | 1911 to 1968 | 1973 to 1998 |
| **Record Length (Complete years of data)** | 95 | 28 | 41 |
| **# Years of published peak instantaneous flows** | 92 | 0 | 41 |
| **Approximate Elevation (m)** | 477 | 538 | 667 |
| **Hydrologic Regime** | Natural | Natural | Natural |
| **Location with Respect to the Village of Slocan** | 40 km downstream (south) | 0 km | 7 km downstream (south) |

Note:

1. WSC estimate is 1660 km$^2$. Current estimate is based on modern GIS analysis of the watershed.

The peak discharge estimated at the two hydrometric stations were transferred to the desired locations along the Slocan River, Lemon Creek and Little Slocan River by pro-rating the annual maximum peak instantaneous discharges at the hydrometric station to the ungauged site using watershed area. The equation used for this relation is as follows:

$$\frac{Q_U}{Q_G} = \left(\frac{A_U}{A_G}\right)^n \qquad \text{[Eq. 4-1]}$$

where $Q_U$ and $Q_G$ are the annual maximum peak instantaneous discharges (m$^3$/s) at the ungauged site and the hydrometric station respectively, $A_U$ and $A_G$ are the watershed areas (km$^2$) for the ungauged and gauged sites respectively, and $n$ is a site-specific exponent related to peak discharges data at both sites (Watt 1989). Typically, a value for n is chosen based on the watershed area size (Watt, 1989). In the case of the Slocan River, an exponent of 0.5 was used in the calculation at the mouth of the river and a value of 0.6 was used to prorate discharges from Little Slocan River at the confluence with Slocan River. A value of 1 was used to estimate the peak discharges from Slocan Lake based on a comparison of annual daily maximum discharges between gauges 08NJ013 and 08NJ014 (*Slocan River at Slocan City*), the latter of which is located just below Slocan Lake. Further details are provided in Appendix E. The site-specific estimated exponent was only used to estimate the peak discharges at Slocan Lake. The lake flood propagation creates a particular response compared to the typical exponent values proposed by Watt (1989). In the case of Lemon Creek, an exponent of 0.65 was used in the calculation.

#### 4.3.2. Climate Change Considerations

Engineers and Geoscientists British Columbia (EGBC) offer guidelines that include procedures to account for climate change when flood magnitudes for protective works or mitigation procedures are required (EGBC, 2018). The impacts of climate change on peak discharge estimates in Slocan River were assessed using statistical and processed-based methods (Appendix D). The statistical methods included a trend assessment on historical flood events using the Mann-Kendall test as well as the application of climate-adjusted variables (mean annual precipitation, mean annual temperature, and precipitation as snow) to the Regional FFA model. The process-based methods included the trend analysis for climate-adjusted flood data offered by the Pacific Climate Impacts Consortium (PCIC).

### 4.4. Hydraulic Modelling

#### 4.4.1. General Approach

The preparation of flood hazard maps requires the development of a hydraulic model. The two-dimensional (2D) hydraulic model HEC-RAS 2D (Version 5.0.7) was used to simulate the flood scenarios summarized in Table 4-7. HEC-RAS is a public domain hydraulic modelling program developed and supported by the United States Army Corps of Engineers (Brunner & CEIWR-HEC, 2016). Each scenario was modelled with a climate-change adjusted peak discharge to represent projected future conditions as described below.

**Table 4-7. Return period classes for flood scenarios evaluated.**

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

Further details on the development of the model and modelling methods are presented in Appendix E. A summary is provided in the sections below.

#### 4.4.2. Model Inputs

Key model inputs include: (1) the topographic model to represent the floodplain and in-channel bathymetry, and (2) the boundary conditions at the upstream and downstream ends of the study area. Table 4-8 summarizes the key numerical modelling inputs selected for the HEC-RAS 2D model.

**Table 4-8. Summary of numerical modelling inputs.**

| Variable | HEC-RAS |
|---|---|
| Topographic Input | Lidar (2018); bathymetry (2019) |
| Mesh Resolution | Variable (10 - 15 m) |
| Manning's n | 0.03 to 0.04 (in-channel); varied based on landcover data (NRCan, 2015), (out of channel), Manning's n values from Chow (1959). |
| Upstream boundary condition | Steady flow (Q20, Q50, Q200, and Q500) |
| Downstream boundary condition | Stage hydrographs |

#### 4.4.2.1. Terrain Model

Following completion of the survey, BGC integrated the bathymetry data and surveyed cross sections with the lidar to generate a DEM for use in hydraulic modelling using the process described in Section 4.1.5.

#### 4.4.2.2. Hydraulic Structures

<u>Bridges</u>

A total of twelve bridge crossings of the Slocan River (nine), Little Slocan (one) and Lemon Creek (two) were identified within the study area. Bridges were surveyed by Midwest Surveys in July – September 2019 to capture bridge and pier dimensions, as well as low chord (bottom-of-deck) and top-of-deck elevations. Additional details on the bridges is presented in Appendix E.

Bridge crossings cannot be readily modelled with HEC-RAS 2D v5.0.7. Bridge decks were removed from the terrain model for 2D simulations and separate HEC-RAS 1D models of the bridge crossings were developed. While the model can accommodate box culverts, the 2D module cannot model high-flow conditions (e.g., when the water surface elevation is greater than the low chord of the bridge). Incorporation of bridge piers can be accomplished within the 2D model but at significant computational cost. To address this, one-dimensional (1D) models of the bridge crossings were developed. The water surface elevations resulting from the 1D bridge models were then checked against the water surface elevations resulting from the 2D model.

<u>Culverts</u>

No culverts were explicitly included in the HEC-RAS model. The mesh was modified at one location near Lebahdo Road (approximately 7 km upstream of the confluence with Little Slocan River) to allow water to flow through the railway embankment on the left bank of the Slocan River.

<u>Breaklines</u>

Breaklines are linear features created to locally orient the computational mesh and improve the representation of terrain features. Breaklines were introduced in the computational mesh to capture dike crests, road embankments, ditches and channels, and local high-ground features (e.g., terraces). An illustration of how breaklines capture terrain feature and influence mesh orientation is provided in Appendix E.

#### 4.4.2.3. Model Domain and Boundary Conditions

The model domain covers the entire Slocan River from Slocan Lake to the Kootenay River, 4.5 km of Little Slocan River and 2.3 km of Lemon Creek (Figure 4-4). The upstream model boundary is located at the outlet of Slocan Lake extending upstream approximately 500 m into the lake to avoid effects from the model inlet from affecting the flow into the river. The downstream boundary of the model domain extends approximately 500 m into the Kootenay River downstream of the confluence. The upstream boundary was set as an inflow hydrograph and the downstream boundary was set as a steady stage hydrograph. The edges of the modelled domain were set sufficiently far from the area of interest so as to not influence the results. Additional details about the boundary conditions are provided in the Appendix E.

#### 4.4.2.4. Development of Flooding Scenarios

To develop complete flood hazard maps for the Slocan River study area, two separate flooding scenarios were modelled; flooding on the Slocan River, and flooding on the Little Slocan River and Lemon Creek. The results of these two scenarios were then combined to determine the final flood hazards.

## 4.5. Hazard Mapping

BGC prepared hazard maps based on the results from the numerical flood modelling. Specifically, BGC prepared two types of maps for the Slocan River study: hazard scenario maps and an FCL map. The scenario maps support emergency planning and risk analyses, and the FCL map supports communication and policy implementation, as described further below.

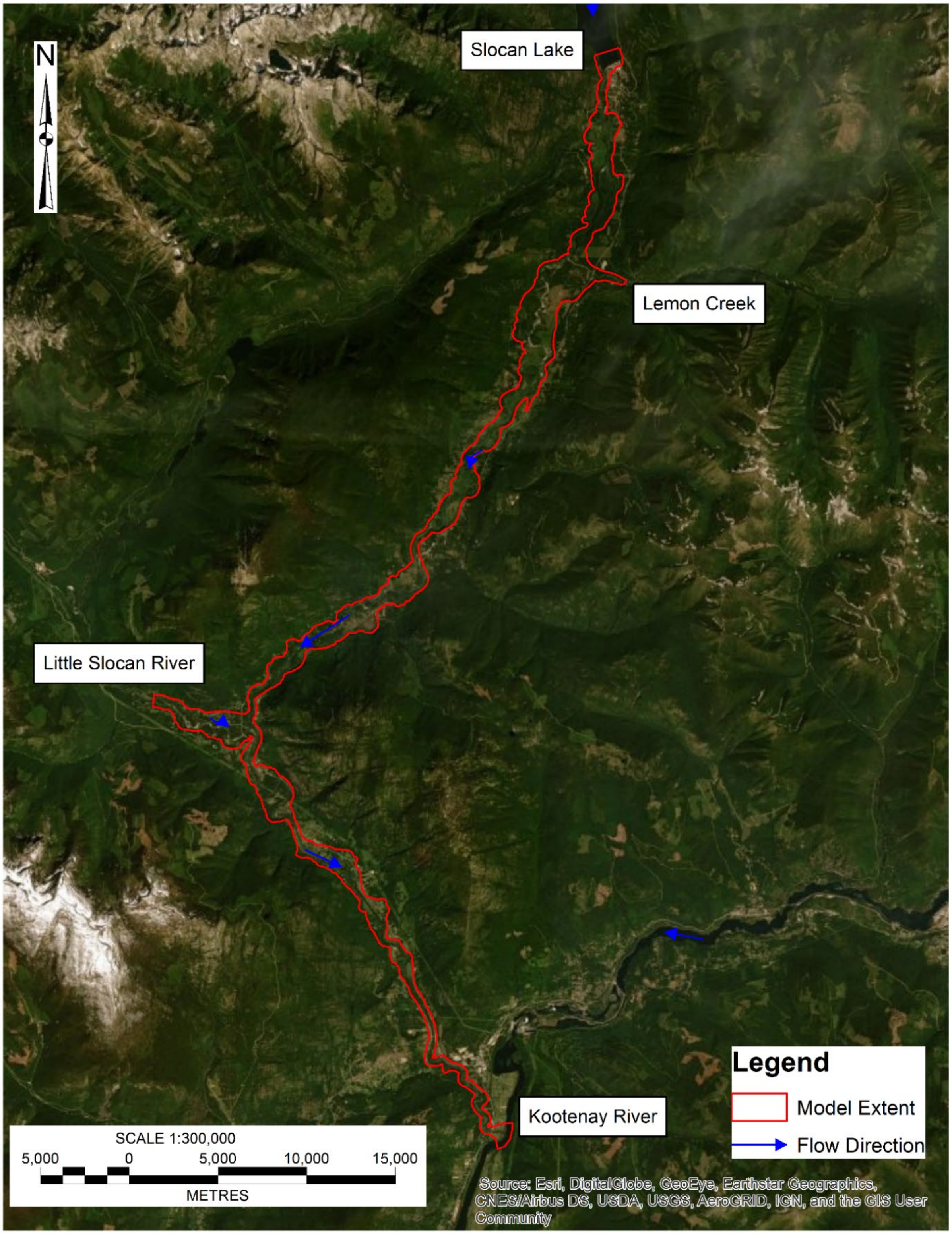



**Figure 4-4. Slocan River study area modelling domain.**

### 4.5.1. Hazard Scenario Maps

Hazard scenario maps display the hazard intensity (destructive potential) and extent of inundated areas for each scenario assessed. Two versions of the hazard scenario maps for each return period are provided: i) maps showing flood depth, and ii) maps showing flow impact force ($IF$) defined as the combination of fluid bulk density ($\rho$), area of impact ($A$) and velocity ($v$) shown in Equation 4-2:

$$IF \propto \rho\, A\, v^2 \qquad \text{[Eq. 4-2]}$$

For clearwater flooding, 1000 kg/m$^3$ was assumed for $\rho$ as shown Equation 4-2. The area of impact represents the area of the object that is impacted or the portion thereof. For this level of study, depth of flow from modelling results is used as a proxy for the height of the area and the impact force is then represented as an impact force per unit width, in this case 1 m.

Maps displaying flow depth support assessments where inundation is the primary mechanism of damage. Flow impact force maps highlight locations where a combination of higher flow velocity and depth may warrant additional assessment (i.e., analyses of bank stability, erosion, or life safety). Table 4-9 provides a description of the flow impact force ranges and their impacts on life safety and impacts on the built environment. A flow depth map for the 200-year peak discharge is provided in this report in Drawing 06. Flow depth and flow impact force maps for all return periods are displayed on Cambio.

**Table 4-9. Flow intensity values shown on the flood hazard scenario maps (Cambio)**

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

Note:
1. Flow intensities greater than 100 kN/m in clear water creeks are generally confined to the main channel.

### 4.5.2. Flood Construction Level Mapping

FCLs are required for areas adjacent to river floodplains for consideration during planning. An FCL can be incorporated into regulation by authorities to provide guidance for new constructions on the extent and elevation of possible flooding in the area. In BC, FCLs have historically been calculated as the higher of the followings:

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

The freeboard is applied to the estimated water surface profile to account for uncertainties in the calculation of the water surface. As noted in EGBC (2017; 2018), for many BC rivers freeboard has been set higher than these minimum values to account for sediment deposition, debris jams, and other factors. Recently, several studies have recommended using 0.6 m of freeboard above the design peak instantaneous flow (KWL, 2014; 2017; NHC, 2008; 2014; 2016; 2018). As such, we have selected to use this approach as well for the Slocan River study area.

The presence of dikes needs to be considered when defining the FCLs. Depending on the situation, the presence of a dike may lead to a local rise in the flood levels as the dike constrains the flow within the channel. Should a dike fail through overtopping or geotechnical failure, the resulting flooding depth and extent of flooding may be greater than if the dike was not present due to the elevated flood level (e.g., Figure 4-5). Dikes were only present along Lemon Creek. Dike breach scenarios were excluded for the flood hazard assessment, so the FCL in the vicinity of Lemon Creek where protected by dikes will be conservative.

For the Slocan River study area, FCLs were generated by extending the predicted 200-year water surface elevation plus a 0.6 m freeboard across the floodplain. The FCL maps are presented in Drawing 07.

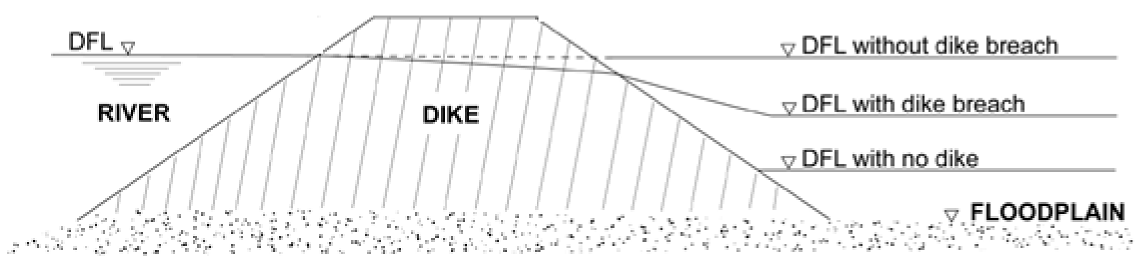



**Figure 4-5. Definition of design flood levels (DFL) in the presence of a dike. DFL refers to the estimated water levels from a design flood event such as the 200-year return period flood (Modified from Water Management Consultants, March 19, 2004).**

# 5. RESULTS

## 5.1. Channel Change Mapping and Bank Erosion

The objective of the geomorphic and bank erosion analysis was to document historical changes in channel width, fluvial landforms, and related geomorphic processes using aerial photographs and high-resolution imagery. The geomorphic units were mapped for the successive years and were considered in the channel change analysis. The resulting aerial photograph comparison maps are presented in Drawing 04-A and Drawing 04-B. The changes estimated over the reviewed timeframe are shown in Drawing 05-A for the reach around Lemon Creek and Drawing 05-B for the Little Slocan River reach. A description of the observed channel changes as it relates to flood hazard follows.

### 5.1.1. Slocan River at Lemon Creek

The channel reaches identified within this area are shown in Figure 5-2. The main characteristics of these reaches are provided in Table 5-1.

**Table 5-1. Channel reaches characterization**

| Reach | Length[1] (m) | Bankfull Width Variation[2] (m) | Channel Pattern | Average Slope (%) |
|---|---|---|---|---|
| LC-1 | 1400 | 19-30 | Straight | 2.4 |
| LC-2 | 185 | 30-40 | Straight | 0.02 |
| SR-1 | 660 | 40 - 100 | - | - |
| SR-2 | 3975 | 60 - 150 | Wandering[3] | 0.35 |

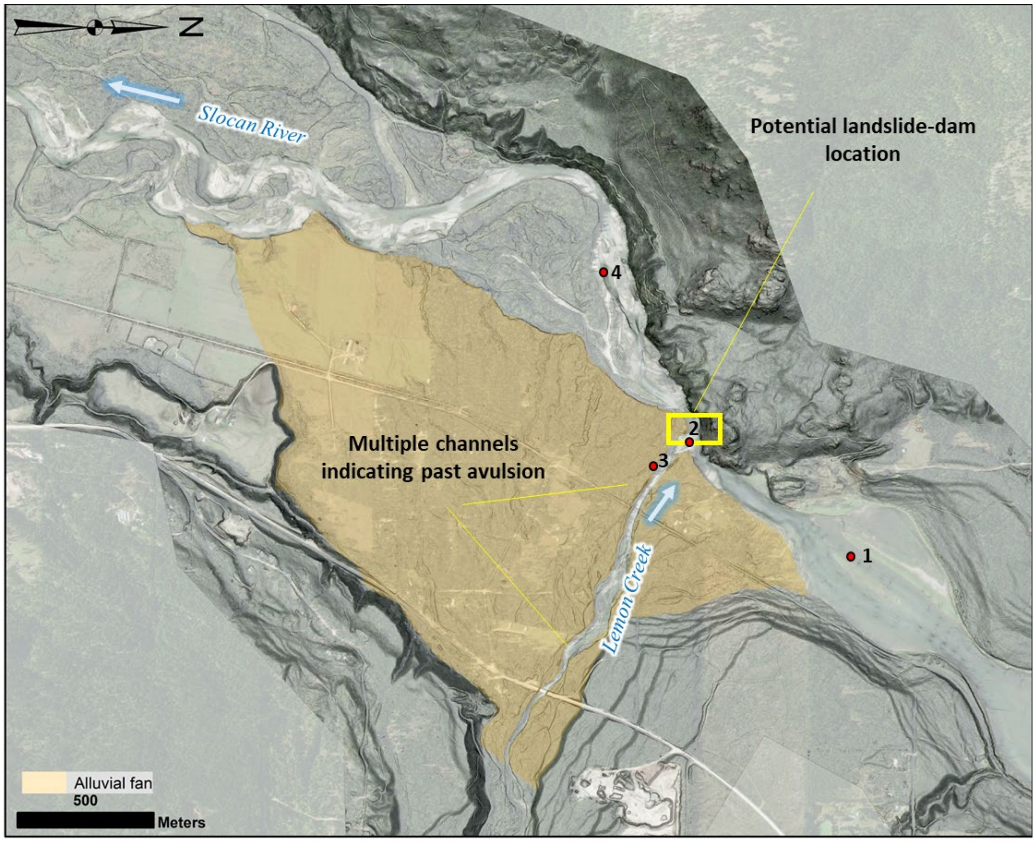
Notes:

1. Based on 2018 lidar and 2019 bathymetry data.
2. Accuracy is +/- 2 m.
3. Wandering implies the watercourse is transitional between meandering (single-thread) and braided (multiple-thread).

The morphology of the Slocan River in this reach is affected by geomorphic processes in Lemon Creek. Upstream of the Lemon Creek confluence, the Slocan River is slow-flowing (s ~ 0.08%) and back watered by the Lemon Creek alluvial fan during periods of high flow (Figure 5-1, SR-1 in Figure 5-2). Downstream of the fan, the Slocan River steepens (s ~ 0.35%) and exhibits a wandering channel pattern (SR-2 in Figure 5-2) for a distance of about 5.5 km, before reverting to a single-thread meandering channel. The wandering channel planform can be attributed to sediment inputs from Lemon Creek.

On the alluvial fan, Lemon Creek is a steep channel (the average slope is 2.3 %) with a straight pattern that has remained unchanged in the last several decades likely due to the orphan flood protection (dikes) installed in the early 1900s (see Section 3.3.2). However, the 1954 imagery shows fresh in-channel deposits from the mid-fan to the creek outlet, indicating that a high-sediment concentration hydrogeomorphic event had recently occurred on the fan, contributing sediment to the Slocan River. Lemon Creek is therefore likely prone to episodic debris floods that transport sediment to the fan and beyond, contributing to the wandering channel planform of the

Slocan River. On review of the lidar data, multiple historic channel avulsion paths are also visible on the Lemon Creek fan (Figure 5-1), providing further evidence of significant hydrogeomorphic events.




Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

**Figure 5-1. Lemon Creek fan at the confluence with Slocan River. The lidar displays a morphology consistent with landslide dam formation and temporary channel blockages. (1) Location of the temporary lake (reservoir). (2) Constrained section of the Slocan River that is susceptible to the formation of a landslide dam. (3) Recent fan deposits. (4) Changes in channel pattern.**

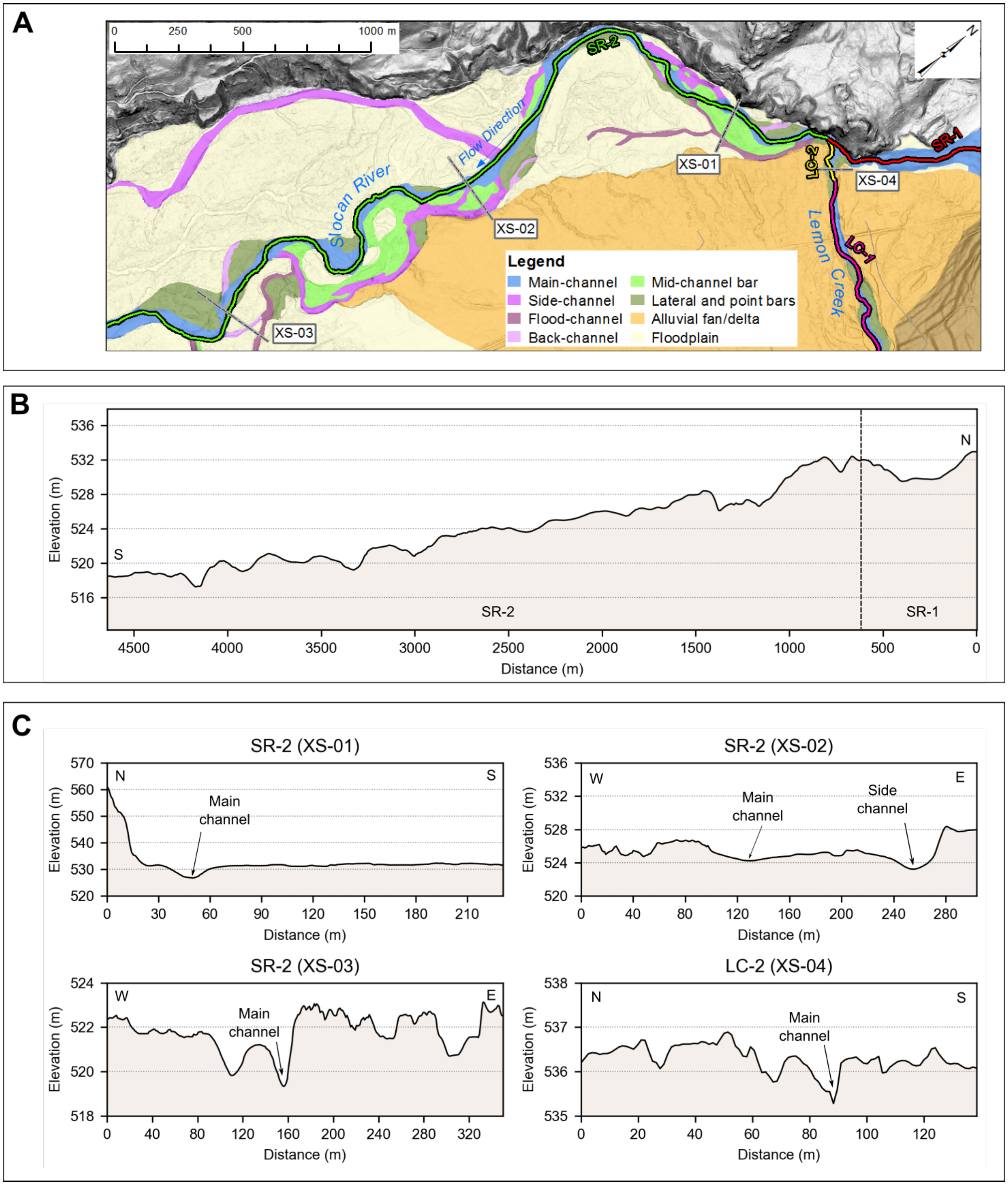



**Figure 5-2. Channel reaches within the Slocan River floodplain downstream of Lemon Creek. (A) Plan view of the river and floodplain. (B) Channel longitudinal profile. (C) Examples of cross sections within the Slocan River (SR-2) and Lemon Creek (LC-2) reaches. Cross section lines are from left to right bank.**

From a geomorphic perspective, the main observations are summarized as follows:

Channel aggradation:

The Slocan River downstream of the confluence with Lemon Creek is aggrading as observed by the formation and growth of numerous gravel bars and islands for a distance of about 5.5 km (SR-2 in Figure 5-1 and Drawing 04-A). Channel aggradation in this section is promoting channel avulsion. Although aggradation is a typical process on the distal part of alluvial fans and adjacent areas, it often requires management to restore channel flow capacity.

Landslide-dam and potential for landslide dam outbreak floods (LDOFs):

The review of the lidar and high-resolution imagery showed evidence of past landslide dams forming at the confluence of Lemon Creek with the Slocan River (Figure 5-1). Here, the Slocan River is narrowed to a 40 m width with Lemon Creek fan on the left (east) bank and exposed bedrock on the right (west) bank. The morphology of this area suggests that this narrow section of the river has been blocked (possibly on multiple occasions) by steep creek processes on Lemon Creek. A breach of a landslide dam at this location could lead to an outbreak flood. Depending on the dam failure mechanism, and water volume retained in the breach, this flood could range from a catastrophic flood to channel scour with smaller peak flow. This potential scenario (i.e., steep creek processes in Lemon Creek fan resulting in the formation of a temporary landslide dam and subsequent outbreak flood) was not considered in the context of the flood hazard assessment conducted in this study.

Progressive erosion of the outer bank of meander bends:

Gradual erosion was identified at channel meander bends on both banks along the SR-2 reach, promoting an increase of the meander curvature (Drawing 04-A). Bank retreat under this mechanism has caused erosion of agricultural land at several locations on the left (east) bank (Drawing 05-A). During the 1990-2005 timeframe, the left (east) bank retreated more than 50 m, followed by a further maximum retreat of 40 m between 2005 and 2014. About 900 m downstream of the Lemon Creek confluence, the Slocan River has also move laterally towards the right (west) bank, eroding and reworking fluvial sediment (Drawing 05-B). Average bank retreat in the various reaches is summarized in Table 5-2 for the period 1954-2014. Over this period, the average annual erosion rate was 0.6 m/year in reach SR-1 and 2.0 m/year in reach SR-2.

**Table 5-2. Average bank retreat for the Slocan River south of Lemon Creek.**

| Reach | Average Bank Retreat (m) | | | |
|---|---|---|---|---|
| | 1954 – 1980 | 1980 – 1990 | 1990 – 2005 | 2005 – 2014 |
| LC-1 | 3 | 2 | - | 1 |
| LC-2 | 5 | 16 | 8 | 2 |
| SR-1 | 20 | 18 | - | 0 |
| SR-2 | 48 | 29 | 34 | 14 |

Bank erosion and channel migration in this reach is an active on-going process, having initially been reported in 1975 by Northwest Hydraulic Consultants and then by the BC Ministry of Environment in 1984.

Reoccupation of former flood channels and avulsions:

The high-resolution imagery and lidar show evidence of past channel avulsion and relic flood channel re-occupation within the floodplain of the Slocan River and Lemon Creek alluvial fan. The BC Department of Lands, Forests and Water Resources (1971) reported channel shifting of the Slocan River, resulting in channel widening and bank erosion of up to 1.5 m (5 feet) per year.

Summary

While the reach below Lemon Creek is very active from a geomorphic perspective (aggradation, bank erosion and avulsion), the adjacent floodplain is sparsely populated and is mostly used for agriculture. BGC only identified two buildings in this reach that could be directly impacted by bank erosion.

### 5.1.2. Little Slocan River

Little Slocan River is a wandering channel with numerous islands and gravel bars. Three channel reaches were identified along the lower river: LR-1, LR-2, and LR-3 (Figure 5-3). Significant changes in channel planform were recognized throughout the 1954 to 2014 period, with an average bank erosion rate that varied between 1 m/year in LR-2 to 1.6 m/year in LR-3 (Table 5-3).

**Table 5-3. Channel reaches characterization and average bank retreat for Little Slocan River.**

| Reach | Length[1] (m) | Bankfull Width Variation[2] (m) | Channel Pattern | Average Slope (%) | Average Bank Retreat (m) | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 1954 - 1990 | 1990 - 2004 | 2004 - 2009 | 2009 - 2014 |
| LR-1 | 1170 | 35-75 | Wandering[3] | 1.2 | 27 | 51 | 1 | 5 |
| LR-2 | 3165 | 70-100 | Wandering[3] | 0.5 | 37 | 4 | 10 | 13 |
| LR-3 | 525 | 70-150 | Wandering[3] | 0.3 | 71 | 16 | 4 | 4 |

Notes:

1. Based on 2018 lidar and 2019 bathymetry data.
2. Accuracy is +/- 5 m.
3. Wandering implies the watercourse is transitional between meandering (single-thread) and braided (multiple-thread).

While the floodplain of the Lower Little Slocan River is sparsely populated, ongoing bank erosion has the potential to impact several properties.

### 5.1.3. Other Reaches of Slocan River

Other than the sections identified south of Lemon Creek and at Little Slocan River, the main channel of Slocan River has remained relatively constant throughout the 1954-2014 record.

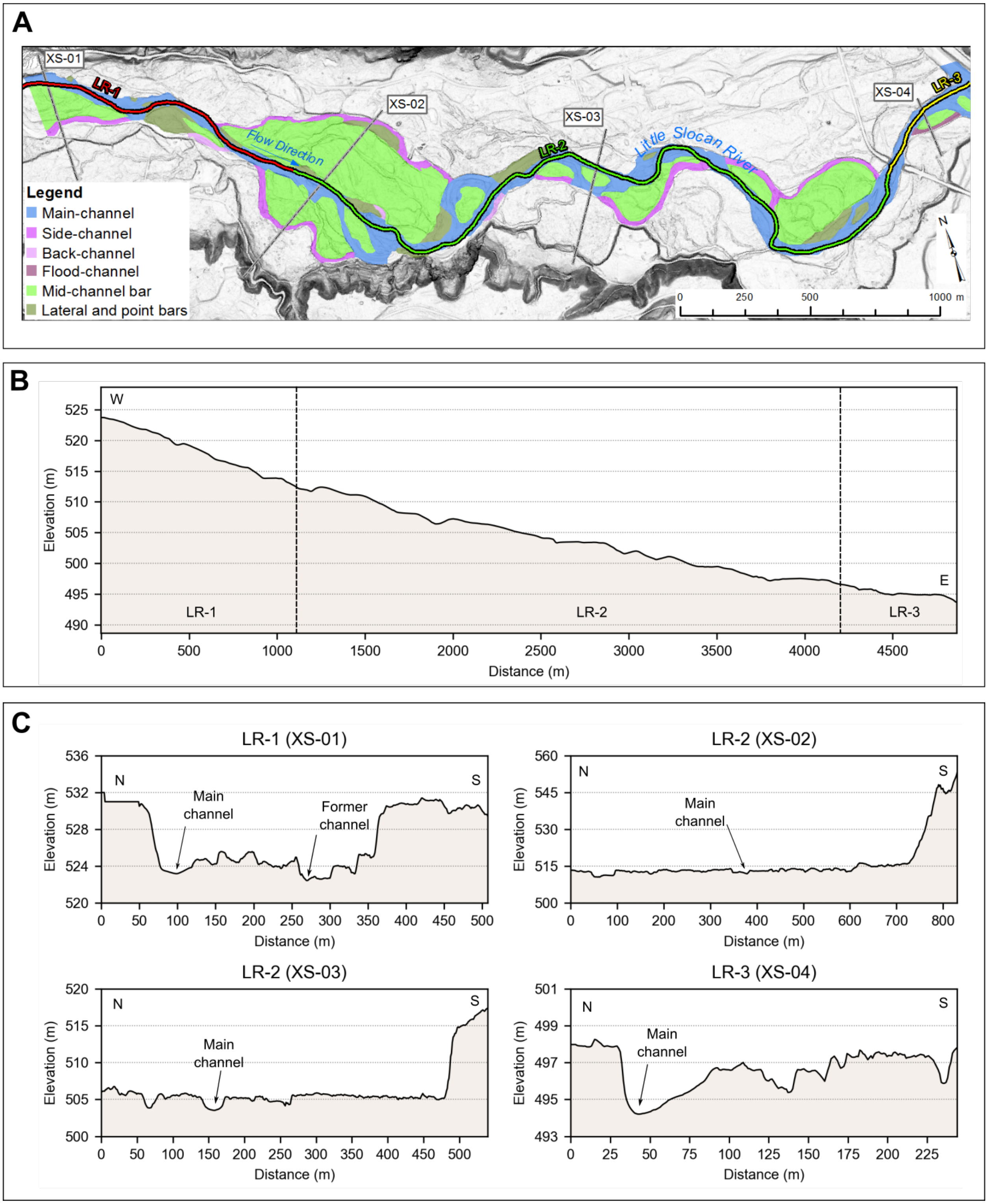



**Figure 5-3. Channel reaches within the Lower Little Slocan River. (A) Plan view of the river and floodplain. (B) Channel longitudinal profile. (C) Examples of cross sections within the Little Slocan River reaches. Cross section lines are from left to right bank.**

## 5.2. Hydrological Modelling

### 5.2.1. Historical Peak Discharge Estimates

Peak discharge estimates for select return periods were determined at three locations within the Slocan River watershed. These three locations were necessary to generate the different flood scenarios presented in Section 5.2.4. The historical peak discharges for Slocan River, Lemon Creek, and Little Slocan River are based on a pro-rating an FFA from analysis of a single gauge on the watercourse (Section 4.3.1). The peak discharge estimates based on analysis of historical streamflows are listed in Table 5-4.

**Table 5-4. Historical peak discharge estimates for Slocan River, Little Slocan, and Lemon Creek.**

| Return Period (years) | AEP | Slocan River ($m^3/s$) | Little Slocan River ($m^3/s$) | Lemon Creek ($m^3/s$) |
|---|---|---|---|---|
| 20 | 0.05 | 685 | 292 | 72 |
| 50 | 0.02 | 767 | 326 | 84 |
| 200 | 0.005 | 884 | 352 | 104 |
| 500 | 0.002 | 960 | 408 | 117 |

For comparison, NHC estimated the 20-year flood was estimated to be 708 $m^3/s$ while the 200-year flood event was estimated to be 900 $m^3/s$ for the Slocan River (NHC, 1989). NHC also estimated the peak discharge for the Little Slocan River. The 20-year flood was estimated to be 244 $m^3/s$ while the 200-year flood was estimated to be 310 $m^3/s$ (NHC, 1989).

### 5.2.2. Accounting for Climate Change

Statistical trend analysis results show that there is no significant trend in the historical peak flow time series for both *Slocan River near Crescent Valley* (08NJ013) and *Lemon Creek Above South Lemon Creek* (08NJ160) (Table 5-5). Trend analysis results for the PCIC climate-adjusted 200-year flood event (process-based prediction) show that the mean of the for *Slocan River Near Crescent Valley* (08NJ013) hydrometric station remains the same (compared to the historical 1955 to 2009 period) for the 2009 to 2038 period (-0.1%) followed by a small decrease for the 2039 to 2068 period (-5%).

**Table 5-5. Trend analysis results.**

| Hydrometric Station | Name | Start Year | End Year | p-value[1] | Trend Direction | Sen's Slope[2] |
|---|---|---|---|---|---|---|
| 08NJ013 | Slocan River Near Crescent Valley | 1914 | 2018 | 0.18 | - | 0.48 |
| 08NJ160 | Lemon Creek Above South Lemon Creek | 1973 | 2017 | 0.23 | - | 0.17 |

Notes:

1. A p-value of less than 0.05 is considered significant.
2. A positive Sen's slope indicates an increasing trend in the flow.

While these results suggest that the flood record may be stationary at these two hydrometric stations, the results of the statistical and process-based evaluation methods to assess climate change impacts on peak flows were found to be inconsistent across the RDCK by 2050. The climate change impact assessment results were difficult to synthesise in order to select climate-adjusted peak discharges on a site-specific basis. The assessment of the trends in the discharge records was inconclusive. The results of the statistical flood frequency modelling generally show a small decrease in the flood magnitude, while the results of the process-based discharge modelling generally show an increase with a wide range in magnitude. As a result, peak discharge estimates were adjusted upwards by 20% to account for the uncertainty in the impacts of climate change in the RDCK as per Appendix D.

### 5.2.3. Slocan River

The pro-rated FFA transfers peak discharge information from hydrometric stations to ungauged locations by relating peak discharge to watershed area using Equation 4-1. The results of the pro-rated peak discharges are presented in Table 5-6 along with the watershed areas and exponent used at different locations along the Slocan River.

The attenuation of Slocan Lake on the peak discharge estimates was incorporated through a site-specific estimation of the exponent n for the equation 4-1. The estimation was perform using historical discharges at gauges 08NJ014 (*Slocan River at Slocan City*) and 08NJ013 (*Slocan River near Crescent Valley*). The gauge at Slocan Lake was discontinued in 1968 and provides 24 years of concurrent data with the downstream gauge. The exponent *n* was determined using the maximum annual daily mean discharge at both gauges and the values varied between 0.93 and 1.36 with an average of 1.13. BGC adopted of a value of 1 to prorate peak discharges to Slocan Lake and to the Slocan River below Lemon Creek. The choice of 0.5 for the exponent at Little Slocan River and the Slocan River at the mouth was based on the watershed area size (Watt, 1989).

**Table 5-6. Historical and climate-adjusted peak instantaneous discharge estimates along the Slocan River.**

| Location | Watershed Area ($km^2$) | *n* | Peak Discharge ($m^3/s$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | AEP=0.05 | | AEP=0.02 | | AEP=0.005 | | AEP=0.002 | |
| | | | Historical | Climate-Adjusted | Historical | Climate-Adjusted | Historical | Climate-Adjusted | Historical | Climate-Adjusted |
| Slocan River upstream boundary | 1821 | 1.0 | 370 | 445 | 414 | 495 | 478 | 575 | 519 | 620 |
| Slocan River below Lemon Creek | 2185 | 0.65 | 444 | 535 | 497 | 595 | 573 | 690 | 622 | 750 |
| Slocan River below Little Slocan River | 3224 | 0.6 | 666 | 800 | 745 | 895 | 860 | 1030 | 933 | 1120 |
| Slocan River at gauge 08NJ013 | 3330 | - | 677 | 810 | 757 | 910 | 874 | 1050 | 948 | 1140 |
| Salmo River at mouth (downstream boundary) | 3412 | 0.5 | 685 | 820 | 767 | 920 | 884 | 1060 | 960 | 1150 |

### 5.2.4. Lemon Creek

The historical and climate-adjusted peak instantaneous discharges estimated based on the pro-rated FFA at gauge 08NJ160 (*Lemon Creek above South Lemon Creek*) are listed in Table 5-7. The discharges were pro-rated using Equation 4-1 with a watershed area of 181 $km^2$ at the gauge location and 203 $km^2$ at the mouth. Based on the watershed area size, an exponent of 0.65 was used (Watt, 1989).

**Table 5-7. Historical and climate-adjusted peak instantaneous discharge estimates for Lemon Creek based on the pro-rated FFA.**

| Return Period (years) | AEP | Historical Discharge ($m^3/s$) | Climate-adjusted Peak Discharge ($m^3/s$) |
|---|---|---|---|
| 20 | 0.05 | 72 | 85 |
| 50 | 0.02 | 84 | 100 |
| 200 | 0.005 | 104 | 125 |
| 500 | 0.002 | 117 | 140 |

### 5.2.5. Little Slocan River

The historical and climate-adjusted peak instantaneous discharges estimated based on the pro-rated FFA at gauge 08NJ013 (*Slocan River near Crescent Valley*) are listed in Table 5-8. The discharges were pro-rated using Equation 4-1 with a watershed area of 818 $km^2$ at the confluence with the Slocan River. Based on the watershed area size, an exponent of 0.6 was used (Watt 1989).

**Table 5-8. Historical and climate-adjusted peak instantaneous discharge estimates for Little Slocan River based on the pro-rated FFA.**

| Return Period (years) | AEP | Historical Discharge ($m^3/s$) | Climate-adjusted Peak Discharge ($m^3/s$) |
|---|---|---|---|
| 20 | 0.05 | 292 | 350 |
| 50 | 0.02 | 326 | 390 |
| 200 | 0.005 | 352 | 450 |
| 500 | 0.002 | 408 | 490 |

### 5.2.6. Flood Scenarios

The climate-adjusted peak discharge estimates were used to determine the inflows to the hydraulic model for the two flood scenarios presented in Section 4.4.2.4. The model domain included three inflow boundary conditions: Little Slocan River, Lemon Creek, and Slocan Lake.

For Flood Scenario 1, Slocan River flood scenario, the climate-adjusted peak discharges used as inflows to the model are listed in Table 5-9. For this scenario, the climate-adjusted peak discharge estimates for Slocan River were used directly from Table 5-6. The peak discharge estimates for

Lemon Creek were estimated by subtracting the peak discharge estimates at Slocan Lake to the estimates on the Slocan River below Lemon Creek. The peak discharges at Little Slocan River were estimated by subtracting the peak discharge estimates on the Slocan River below Lemon Creek to the estimates at the Slocan River mouth for all return periods. This procedure allows for the inclusion of flows from non-modelled tributaries and lateral contributions not directly modelled.

For Flood Scenario 2, the tributaries flood scenario, the climate-adjusted peak discharges are listed in Table 5-10. For this scenario, the climate-adjusted peak discharge estimates for the Little Slocan River and the Lemon Creek were used directly from Table 5-7 and Table 5-8. The peak discharge estimates for Slocan Lake were estimated by subtracting the Little Slocan River and Lemon Creek flows from the Slocan River estimates at the mouth for all return periods.

A comparison of Table 5-9 and Table 5-10 shows that peak discharge proportions assigned to Lemon Creek and Little Slocan River differ from the peak discharges estimated from the pro-rated FFA (Table 5-7 and Table 5-8). The peak discharges for Lemon Creek and Little Slocan River are higher in Flood Scenario 2 than for Flood Scenario 1 as expected. The results of these two flood scenarios were combined to determine the final flood hazards.

**Table 5-9. Climate-adjusted peak discharge used for Flood Scenario 1 (Slocan River flood scenario).**

| Location | Peak Discharge (m³/s) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | AEP=0.05 (20-year) | | AEP=0.02 (50-year) | | AEP=0.005 (200-year) | | AEP=0.002 (500-year) | |
| | Slocan River | Tributary | Slocan River | Tributary | Slocan River | Tributary | Slocan River | Tributary |
| Slocan River upstream boundary | 445 | - | 495 | - | 575 | - | 620 | - |
| Lemon Creek | - | 89 | - | 99 | - | 115 | - | 124 |
| Slocan River below Lemon Creek | 535 | - | 595 | - | 690 | - | 745 | - |
| Little Slocan River | - | 290 | - | 325 | - | 373 | - | 405 |
| Slocan River at mouth | 820 | - | 920 | - | 1060 | - | 1150 | - |

**Table 5-10. Climate-adjusted peak discharge used for Flood Scenario 2 (Tributaries flood scenario).**

| Location | Peak Discharge (m³/s) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | AEP=0.05 (20-year) | | AEP=0.02 (50-year) | | AEP=0.005 (200-year) | | AEP=0.002 (500-year) | |
| | Slocan River | Tributary | Slocan River | Tributary | Slocan River | Tributary | Slocan River | Tributary |
| Slocan River upstream boundary | 385 | - | 430 | - | 485 | - | 520 | - |
| Lemon Creek | - | 85 | - | 100 | - | 125 | - | 140 |
| Slocan River below Lemon Creek | 470 | - | 530 | - | 610 | - | 660 | - |
| Little Slocan River | - | 350 | - | 391 | - | 450 | - | 490 |
| Slocan River at mouth | 820 | - | 920 | - | 1,060 | - | 1150 | - |

## 5.3. Hydraulic Modelling

The simulated flood profiles for the scenarios are shown in Appendix E (Figure E-38 to Figure E-49). The profiles represent the water surface elevation along the thalweg of the Slocan River during the peak of the floods.

### 5.3.1. Slocan Lake Levels

Slocan Lake is the upstream boundary of the study area and the lake levels govern the discharge at the lake outlet into the Slocan River. Details from previous studies are provided in Appendix E.

The present study used the peak flows listed in Table 5-6 as steady-state inflow hydrographs into the lake within the HEC-RAS 2D model. The simulated lake levels (without freeboard) are shown in Table 5-11. The lake levels for each return period cannot be compared to previous studies because the peak-discharges were adjusted upwards for climate change.

**Table 5-11. Simulated Slocan Lake levels.**

| Return Period (years) | AEP | Slocan Lake Outflow ($m^3/s$) | Slocan Lake Levels (m) |
|---|---|---|---|
| 20 | 0.05 | 445 | 538.92 |
| 50 | 0.02 | 495 | 539.20 |
| 200 | 0.005 | 575 | 539.58 |
| 500 | 0.002 | 620 | 539.81 |

The Slocan Lake stage-discharge relationship (provided in the Appendix E) was built using concurrent data from WSC gauges 08NJ014 (*Slocan River at Slocan City*) and 08NJ137 (*Slocan Lake at Slocan City*). The gauges were operational until 1968 and 31 years of concurrent data are available. Because the most recent data at the gauge are five decades old, they were not used to estimate Slocan Lake levels for the current study. Further details are provided in Appendix E.

#### 5.3.1.1. Wave Height Prediction

Wave analysis are out of the scope of the current study. NHC (1989) analyzed the wave runup for Slocan Lake and concluded that for a combined joint frequency of 200-year return period, the 200-year daily lake level plus a 1-year storm wave height (0.72 m) govern flooding conditions on the lake.

### 5.3.2. Summary of Modelling Results and Bridges

A summary of the key observations from the hydraulic modelling is included in Table 5-12 and results from the bridge analyses are included in Table 5-13.

**Table 5-12. Summary of modelling results.**

| Process | Key Observations |
|---|---|
| **Clear-water inundation** | <u>Village of Slocan and Slocan Lake</u><br>• The Village of Slocan is impacted by flooding from Slocan Lake. The simulated 200-year lake level is 539.58 m (without freeboard and wave allowance).<br>• Flooding during the 20-year flood is predicted on properties west of Main Street that borders the lake outlet. Flooding during the 200-year flood is predicted between Park Ave and Lake Ave with depths up to 1 m.<br>• The 500-year event raises the 200-year lake level by 0.23 m to a value of 539.81 m causing a marginal increase in flooding extent (10 to 30 m horizontally).<br>• Properties inside or near the impacted area are subject to additional hazard from the wave runup expected in Slocan Lake (outside the scope of current study).<br><u>Between Slocan Lake and Lemon Creek</u><br>• At flood return periods of 20 years and greater, the Slocan Valley Rail Trail is overtopped downstream of the Logging Bridge (Gravel Pit Road). Agricultural lands are also flooded on both sides of Slocan River.<br><u>Lemon Creek</u><br>• Upstream of the Highway 6 Bridge on Lemon Creek, banks and dikes are overtopped during the 20-year flood. Water flows along the highway south embankment and overtops the highway to flow on the fan to reach Slocan River.<br>• Both floods are not contained in the channel upstream of the Slocan Valley Rail Trail Bridge and the water level rises against the embankment until it is overtopped.<br>• Lemon Creek is an active alluvial fan and flooding is likely exacerbated by sediment transport, although these flood concerns are beyond the scope of this study.<br><u>Between Lemon Creek and Little Slocan River</u><br>• Perrys Back Road is flooded during the 20-year flood at the junction of Avis Road and the Perry Bridge.<br>• During the 200-year flood, Highway 6 is flooded approximately 500 m downstream of the Winlaw Bridge.<br>• During the 20-year flood, Filipoff Road and the Slocan Valley Rail Trail are flooded in the left (west) floodplain between the communities of Winlaw and Lebahdo.<br>• During the 20-year flood, flooding extents reach the Highway 6 embankment on the left (southeast) floodplain approximately 300 m downstream of Lebahdo.<br><u>Little Slocan River</u><br>• Properties along the left bank (north) of Little Slocan River are flooded by the 200-year flood event starting at the end of Arrow Road and more importantly in the vicinity of Point Road.<br>• During the 50-year flood, the left (north) approach of the Little Slocan River Bridge is overtopped. Water flows along old channels visible in the lidar and water level rises until Kickwillie Road is overtopped. |

| Process | Key Observations |
|---|---|
| | Between Passmore and the Kootenay River<br>• Approximately 1 km downstream of the Passmore bridge, the 200-year event causes flooding over the Slocan Valley Rail Trail and Highway 6 located on the left (north) floodplain. Several properties and buildings along Old Passmore Road are flooded by this magnitude of event.<br>• Downstream of the Slocan Park Bridge, the Slocan Valley West Road on the right (southwest) bank is flooded during the 20-year flood.<br>• At flood return periods of 20 years and greater, floods extend to the left (northeast) floodplain of the Slocan River at the community of Slocan Park. The streets that are flooded by those events include the following (from upstream to downstream): Bower Road, Kirby Road, Price Road, Slocan Valley East Road, Evin Road, and the Slocan Valley Rail Trail. Water flows along the Highway 6 embankment and multiple properties are impacted by the floods.<br>• The 50-year event floods Highway 6 near Cunningham Road. The left (east) floodplain is low in this area.<br>• Goose Creek Road is flooded on the section along the river during the 20-year event. |
| **Hydraulic Structures (Bridges)** | • The water surface elevation for the 200-year flood does not reach the low chord of the bridges in this study as verified through 1D modelling (Table 5-13).<br>• The Logging Road Bridge has a negligible freeboard of 2 cm during the 200-year event. The 500-year flood will likely overtop the bridge and cause damage.<br>• Perry Bridge approaches in the floodplain are overtopped during the 20-year flood. |
| **Hydraulic Structures (Dikes)** | • Dikes along Lemon Creek are composed of river boulders and log cribs (Figure 3-4 and Figure 3-5). Severe deterioration of the dikes was observed during the field visit and they are not expected to provide any protection during a flood. |

**Table 5-13. Bridge crossings along the Slocan River, Little Slocan River, and Lemon Creek within the study area.**

| Bridge Crossing[1] | Latitude (°) | Longitude (°) | Low Chord Elevation (m) | 200-year Flood WSE (m)[2] | Freeboard (m) |
|---|---|---|---|---|---|
| **Slocan River** | | | | | |
| Village of Slocan Bridge | 49.7660 | -117.4732 | 539.90 | 539.29 | 0.61 |
| Logging Road Bridge (Gravel Pit Road) | 49.7545 | -117.4751 | 538.38 | 538.35 | 0.02 |
| Perry Bridge | 49.6647 | -117.5113 | 523.10 | 522.75 | 0.35 |
| Winlaw Bridge | 49.6157 | -117.5665 | 521.60 | 520.37 | 1.2 |
| Passmore Bridge | 49.5405 | -117.6535 | 494.31 | 492.82 | 1.5 |
| Slocan Park Bridge | 49.5188 | -117.6302 | 484.63 | 483.11 | 1.5 |
| Crescent Valley Bridge | 49.4511 | -117.5607 | 474.87 | 470.56 | 4.3 |
| Highway 3A Bridge | 49.4199 | -117.5312 | N/A | 454.09 | - |
| Railway Bridge | 49.4199 | -117.5307 | N/A | 453.56 | - |
| **Lemon Creek** | | | | | |
| Highway 6 Bridge | 49.7017 | -117.4796 | N/A | - | - |
| Slocan Valley Rail Trail Bridge | 49.7048 | -117.4889 | N/A | - | - |
| **Little Slocan River** | | | | | |
| Little Slocan Bridge | 49.5505 | -117.6570 | 499.99 | 498.78 | 1.1 |

Notes:

1. Bridge crossings are listed in a downstream direction.
2. Vertical Datum is CGVD 2013.

## 5.4. Flood Hazard Mapping

Hazard scenario results from the range of return periods modelled are presented in Cambio. Drawing 06 provides modelled water depths for the 200-year return period event.

## 5.5. Flood Construction Level Mapping

FCL results for the 200-year water surface elevation plus 0.6 m freeboard are presented on Drawing 07. Note that elevations from the FCLs have not been surveyed in the field and should not be relied upon for accuracy of ground levels at the building lot scale.

# 6. SUMMARY AND RECOMMENDATIONS

This report provides a detailed flood hazard assessment of the Slocan River study area, which includes the Slocan River, the Little Slocan River, and Lemon Creek floodplains. This area was chosen as a high priority site amongst hundreds in the RDCK due to its comparatively high risk. The results of this study are presented on digital hazard maps that provide the basis quantitative risk assessment, if required. This study also provides the basis to inform the conceptualization and potential design and construction of mitigation measures should those be found to be required for the Slocan River study area. A variety of analytical desktop and field-based tools and techniques were combined to understand the geomorphological and hazard history, hydrology, and hydraulics of the Slocan River study area.

## 6.1. Flood Hazard Assessment

### 6.1.1. Channel Change Mapping and Bank Erosion

Channel change mapping and bank erosion analyses were completed to assess historical geomorphic changes in the study area and how these changes influence channel migration and flood hazards. Detailed analysis was focused on the reach in the immediate vicinity of the confluence of Lemon Creek with Slocan River and the Little Slocan River.

In summary:

- Fluvial landforms were identified and delineated in the different sets of aerial photographs and high-resolution imagery (Drawing 04-A and Drawing 04-B). This analysis is useful to understand the geomorphic evolution of the channel and how these processes may influence flooding in the area. For instance, bed aggradation and mid-bar formation can divert water overbank and form new paths (avulsion). The data for Lemon Creek and Little Slocan River indicates that avulsion has occurred in several instances leading to the reoccupation of previous flood channels. Also, the Lemon Creek fan at the confluence with Slocan River section shows evidence consistent with landslide dam formation and channel blockages. Temporary damming of the river could result in outbreak flooding.
- The channel change maps (Drawing 05-A and Drawing 05-B) illustrate the areas of recorded change between the reviewed photographs and high-resolution imagery (e.g., bank erosion, channel shifting, and stabilization or deposition). These variations were quantified to determine average bank retreat rates within the 1954-2014 period (Table 5-4 and Table 5-6). In general, it was found that both Little Slocan River and Lemon Creek are laterally unstable, with average erosion rates on the order of 1 to 2 m/year.

The resulting maps depict channel geomorphology dynamics within the studied areas and their possible influence on flood hazards.

### 6.1.2. Adjustment for Projected Climate Change

Historical peak discharges estimated for the Slocan River, Little Slocan River, and Lemon Creek were adjusted to account for future climate change. Key findings applied to flood mapping are:

- The climate change impact assessment results were difficult to synthesize to select climate-adjusted peak discharges on a site-specific basis. Consequently, a 20% increase in peak discharge was adopted (Appendix D).
- The climate-change adjusted 200-year peak discharges for Slocan River range from 575 $m^3/s$ at the upstream end of the study area (Slocan Lake) to 1060 $m^3/s$ at the mouth.
- The climate-change adjusted 200-year peak discharge for Lemon Creek was 125 $m^3/s$ at the confluence with the Slocan River.
- The climate-change adjusted 200-year peak discharges for Little Slocan River was 450 $m^3/s$ at the confluence with the Slocan River.

### 6.1.3. Hydraulic Modelling

A 2D numerical model developed using HEC-RAS was used to simulate selected hazard scenarios. Table 5-12 provides key observations derived from the numerical modelling. The water surface profiles for the Slocan River are presented in Appendix E (Figure E-36 to Figure E- -47). The hydraulic modelling results demonstrate that the key hazards and associated risks on the Slocan River stem from floodplain inundation.

### 6.1.4. Flood Hazard Mapping

Model results are cartographically expressed in two ways:

1. The individual hazard scenarios are captured through hazard maps that display estimated flow velocity, flow depth, and flood intensity. These maps can support assessment of development proposals and be used for emergency planning.
2. An FCL map that combines the estimated water surface elevation for the 200-year return period flood with a 0.6 m freeboard. The FCL map is useful to assist development proposals in designated hazard zones.

Both the individual scenario hazard and FCL maps serve as decision-making tools to guide subdivision and other development permit approvals.

## 6.2. Limitations and Uncertainties

While systematic scientific methods were applied in this study, a number of uncertainties remain. As with all hazard assessment and concordant maps, the hazard maps prepared Slocan River represent a snapshot in time. Future changes to the Slocan River watersheds or fans including the following may warrant re-assessment and/or re-modelling:

- Future land use (urbanization) or landcover (deforestation, forest fire) changes in the floodplain or fan
- Substantial flood events
- Major changes in the channel planform or aggradation
- Bridge re-design
- Construction of flood control structures
- Effects of future climate change.

The assumptions made on changes in runoff due to climate change reflect the current state of knowledge and will likely need to be updated occasionally as scientific understanding of such processes evolves. Despite these limitations and uncertainties, BGC believes that a credible hazard assessment has been achieved on which land use decisions can be made.

## 6.3. Considerations for Hazard Management

This section notes specific issues that could be considered in the short term given the findings of this study.

Key considerations are:

- The results of the channel change analysis show that the studied areas are highly active from a geomorphic perspective. The main fluvial processes recognized are bank erosion and avulsion, resulting in lateral instability and changes in channel planform. Despite the identified geomorphic processes being active, they are affecting the floodplain at specific locations, meaning that they are localized, and are not expected to impact overall flood hazards within the Slocan River floodplain. Further, as both areas are sparsely populated, no site-specific erosion assessment is deemed necessary at this time, although this situation could change rapidly.
- In the sections of the Slocan River where landslides have the potential to block the channel and create a temporary dam (Lemon Creek fan at the confluence with Slocan River, for instance), a hazard assessment of the downstream flooding of a potential dam breach could be considered.
- Data from high flow events were limited for model calibration. Collection of evidence for future high flow events along the Slocan River, Little Slocan River and Lemon Creek would be useful to help further calibrate and validate the model. This can be accomplished through either the installation of additional streamflow gauge(s) or the recording and survey of high-water marks after significant flood events.
- Results from the hydraulic modelling indicate that Highway 6 is impacted by the 20-year flood in places. Locations where the Highway 6 is predicted to be flooded are shown in Appendix E with the water levels for the 20- and 200-year floods (Figure E-36 to Figure E-47).
- Hydraulic modelling (1D and 2D) results indicate that the 200-year water levels are below the low chord of all the bridges. However, the Logging Bridge (Gravel Pit Road) has no freeboard (2 cm).
- The hazard mapping conducted for a range of return periods provides an improved hazard basis to apply for funding for additional risk assessment, emergency response planning, and mitigation projects. Results of the hazard mapping are provided on Drawing 06 for the 200-year water depth and digitally in Cambio Communities for the range of scenarios modelled (i.e., 20-year, 50-year, 200-year, and 500-year).
- The FCLs presented in Drawing 07 for the 200-year return period flood event plus 0.6 m freeboard provides an improved basis for community planning, bylaw development, and emergency response planning in areas subject to flood hazards, with consideration of climate change. The application of the FCL map requires discussions and regulatory decisions for both existing and proposed development. Building and floodproofing

elevations should be established from legal survey and benchmarks. Setback distances from the natural boundaries of watercourses are not shown on maps. FCLs provide a standards-based approach which are simple to apply and interpret. In some cases, the FCL may be impossible or impractical to implement for several reasons. Allowances should be permitted for stakeholders to apply for a site-specific reduction in the FCLs contingent on a report by a suitably qualified Professional Engineer, preferably using a risk-based approach.

## 6.4. Recommendations

Recommendations are provided in the Summary Report (BGC, 2020) as they pertain to all studied RDCK areas.

# 7. CLOSURE

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

Yours sincerely,

**BGC ENGINEERING INC.**
**per:**

Marc Olivier Trottier, M.A.Sc., P.Eng.
Hydrotechnical Engineer

Elisa Scordo, M.Sc., P.Geo.
Senior Hydrologist

Melissa Hairabedian, M.Sc., P.Geo.
Senior Hydrologist

Patrick Grover, M.A.Sc., P.Eng.
Senior Hydrotechnical Engineer

Reviewed by:

Rob Millar, Ph.D., P.Eng., P.Geo.
Principal Hydrotechnical Engineer

Hamish Weatherly, M.Sc., P.Geo.
Principal Hydrologist

MOT/RM/HW/mp/syt

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

# REFERENCES

Apex Geoscience Consultants Ltd. (1998). *Geological Hazards Mapping of the Slocan Valley-Phase 1.*

BC Department of Lands Forests and Water Resources. (1971). *Preliminary evaluation of flooding and erosion problems of the Slocan Valley.*

BC Ministry of Environment, Water Investigations Branch. (1979). *Slocan Valley flooding and erosion problems (Report 1319)*.

BC Ministry of Environment. (1984). *Slocan River – Lemon Creek Study*.

BGC Engineering Inc. (2019, March 31). *Flood and Steep Creek Geohazard Risk Prioritization* [Report]. Prepared for Regional District of Central Kootenay.

BGC Engineering Inc. (2019, May 24). *NDMP Stream 2 Application: Flood Mapping* [Work Plan (Revised)]. Prepared for Regional District of Central Kootenay.

BGC Engineering Inc. (2019, November 15). *NDMP Stream 2 Project Deliverables* (Revised). Prepared for Regional District of Central Kootenay.

BGC Engineering Inc. (2020). *RDCK Floodplain and Steep Creek Study, Summary Report* (Draft). Prepared for Regional District of Central Kootenay.

Boyer, D. (1996). Report on October 1996 landslide near Appledale, Slocan Valley (Report 1016).

Boyer, D. (2009, March 24). *Orphan Flood Protection Works* [Letter]. To Ramona Mattix, Manager of Development Services RDCK.

British Columbia Ministry of Forests, Lands and Natural Resource Operations, Water Management Branch. (2017). Flood protection works: Structural works [Dataset]. Retrieved from https://catalogue.data.gov.bc.ca/dataset/flood-protection-works-structural-works

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

Charlton, R. (2007). *Fundamentals of fluvial geomorphology*. Routledge.

Church, M. (2006). Bed material transport and the morphology of alluvial river channels. *Annual Reviews in Earth Planetary Science, 34*, 325-354. https://doi.org/10.1146/annurev.earth.33.092203.122721

Chow, V.T. (1959). *Open-channel hydraulics*. New York, McGraw-Hill, 680 p.

Demarchi, D.A. (2011, March). *An introduction to the ecoregions of British Columbia* (3rd ed.). Victoria, BC: British Columbia Ministry of Environment, Ecosystem Information Section. Retrieved from https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/ecosystems/broad-ecosystem/an_introduction_to_the_ecoregions_of_british_columbia.pdf.

EBA Engineering Inc. (1997). *Geotechnical assessment landslide remediation – Slocan Park* (Report 1309).

Engineers and Geoscientists BC. (2017, January). *Professional practice guidelines: Flood mapping in BC.* Retrieved from https://www.egbc.ca/getmedia/8748e1cf-3a80-458d-8f73-94d6460f310f/APEGBC-Guidelines-for-Flood-Mapping-in-BC.pdf.aspx

Engineers and Geoscientists of British Columbia (EGBC). (2018, July). *Professional practice guidelines: Legislated flood assessments in a changing climate in BC*. Retrieved from https://www.egbc.ca/getmedia/f5c2d7e9-26ad-4cb3-b528-940b3aaa9069/Legislated-Flood-Assessments-in-BC.pdf.aspx.

Farjad, B., Gupta, A., & Marceau, D.J. (2016). Annual and seasonal variations of hydrological processes under climate change scenarios in two sub-catchments of a complex watershed. *Water Resources Management, 30(8)*, 2851-2865.

Fulton, R.J., Shetsen, I., & Rutter, N.W. (1984). *Surficial Geology, Kootenay Lake, British Columbia-Alberta*. Geological Survey of Canada, Open File 1084, 2 sheets.

Harder, P., Pomeroy, J.W., and Westbrook, C.J. (2015). Hydrological resilience of a Canadian Rockies headwaters basin subject to changing climate, extreme weather, and forest management. *Hydrological Processes, 29*, 3905-3924. https://doi.org/10.1002/hyp.10596

Howes, D. E., & Kenk, E. (1997). *Terrain classification system for British Columbia (Version 2)*. BC Ministry of Environment and BC Ministry of Crown Lands, Victoria, BC.

KWL Associates Ltd. (2014). *Creek Hydrology, Floodplain Mapping and Bridge Hydraulic Assessment – Floodplain Development Permit Area, Flood Construction Level Development and Use* [Report]. Prepared for the City of North Vancouver and the District of North Vancouver.

KWL Associates Ltd. (2017). *Wildlife Enhancement Program at Burton Flats Design Feasibility* Final Report. Prepared for BC Hydro. Ref: CLBWORKS-30B.

Lawler, D.M. (2006). The measurement of river bank erosion and lateral channel change: a review. *Earth Surface Processes and Landforms, 18*(9), 777-821. https://doi.org/10.1002/esp.3290180905

Loukas, A. & Quick, M.C. (1999). The effect of climate change on floods in British Columbia. *Nordic Hydrology, 30*(3), 231-256. https://doi.org/10.2166/nh.1999.0013.

Marcus, W.A. (2012). Remote sensing of the hydraulic environment in gravel-bed rivers. In M. Church, P.M. Biron, & A.G. Roy (Eds.), *Gravel-bed rivers: Processes, Tools, Environments* (p. 259-285). John Wiley & Sons Ltd. https://doi.org/10.1002/9781119952497.ch21

Natural Resources Canada (NRCan). (2015). Land Cover of Canada – Landsat-8, 30-metre resolution. [Data]. Extracted November 28, 2019, From https://www.nrcan.gc.ca/science-and-data/science-and-research/earth-sciences/geography/topographic-information/whats-new/2015-land-cover-canada-landsat-8-30-metre-resolution-now-available/22427

Natural Resources Canada (NRCan). (2017). Federal Floodplain Mapping Framework. Version 1.0, General Information Product 112e. 20 p.

Northwest Hydraulic Consultants. (1975, January). *Slocan River-Lemon Creek, Investigation of flood and bank erosion problems* [Report]. Prepared for Water Investigations Branch, British Columbia Department of Lands Forests and Water Resources.

Northwest Hydraulic Consultants. (1989, February). *Floodplain Mapping Study Slocan River, British Columbia – Design Brief*. Prepared for Water Management Branch, Ministry of Environment, Province of British Columbia.

Northwest Hydraulic Consultants. (2008). *Flood Risk Evaluation and Flood Control Solutions, Phase 1* [Report]. Prepared for the City of Prince George.

Northwest Hydraulic Consultants. (2014). *Simulating the Effects of Sea Level Rise and Climate Change on Fraser River Flood Scenarios (GS14LMN-035)* [Report]. Prepared for BC Ministry of Forests Lands and Natural Resource Operations.

Northwest Hydraulic Consultants. (2016). North Alouette and South Alouette Rivers Additional Floodplain Analysis: Phase 2 – Technical Investigations Completion Report. Prepared for the City of Maple Ridge.

Northwest Hydraulic Consultants. (2018). *Lillooet River Floodplain Mapping, Phase 1* [Report]. Prepared for the Pemberton Valley Dyking District Office.

Schnorbus, M., Bennett, K., Werner, A., & Berland, A. (2011). *Hydrologic Impacts of Climate Change in the Peace, Campbell and Columbia Watersheds, British Columbia, Canada. Hydrologic Modelling Project Final Report (Part II).* Victoria: Pacific Climate Impacts Consortium.

Schnorbus, M., Werner, A., & Bennett, K. (2014). Impacts of climate change in three hydrologic regimes in British Columbia, Canada. *Hydrological Processes, 28*, 1170-1189. https://doi.org/10.1002/hyp.9661

Statistics Canada. (2017). Burton, UNP [Designated place], British Columbia and British Columbia [Province] (table). Census Profile. 2016 Census. Statistics Canada Catalogue no. 98-316-X2016001. Ottawa. Released November 29, 2017. https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/index.cfm?Lang=E (accessed February 25, 2020).

Timberland Consultants. (1999). *Little Slocan Landslide Rehabilitation* [Report]. Prepared for Columbia Basin Fish & Wildlife Compensation Program.

Trimble, S.W., & Cooke, R.U. (1991). Historical sources for geomorphological research in the United States. *The Professional Geographer, 43*(2), 212-228. https://doi.org/10.1111/j.0033-0124.1991.00212.x

Turner, R.J.W., Anderson, R.G., Franklin, R., & Fowler, F. (2009). Geotour guide for the West Kootenay, British Columbia. Geology, landscapes, mines ghost towns, caves and hot springs.

Geological Survey of Canada Open file 6135, British Columbia Geological Survey Geofile 2009-06.

VanDine. (1996). Overview assessment of the October 1996 landslide and terrain stability in the Slocan Valley (Report 1017).

Walsh, M. (2000) Terrain Stability and Forest Management in the Interior of British Columbia. Passmore Slide Field Visit Highway 6. Ministry of Transportation & Highways. Retrieved from: https://www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr003/FieldTripGuide_B.pdf

Wang, T., Hamann, A., Spittlehouse, D.L., & Carroll, C. (2016). Locally downscaled and spatially customizable climate data for historical and future periods for North America. *PLoS One 11: e0156720*. https://doi.org/10.1371/journal.pone.0156720.

Watt, W.E. (1989). *Hydrology of floods in Canada: a guide to planning and design*. National Research Council of Canada, Ottawa, Ont.

Water Management Consultants Inc. (2004, March 19). *Floodplain Mapping: Guidelines and Specifications* [Report]. Prepared for Fraser Basin Council.

Wheaton, J. M., Fryirs, K. A., Brierley, G., Bangen, S. G., Bouwes, N., & O'Brien, G. (2015). Geomorphic mapping and taxonomy of fluvial landforms. *Geomorphology, 248*, 273-295. https://doi.org/10.1016/j.geomorph.2015.07.010.

# APPENDIX A
# TERMINOLOGY

Table A-1 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 A-1.

**Table A-1. Geohazard terminology.**

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

| Term | Definition | Source |
|---|---|---|
| Consultation Zone | The Consultation Zone (CZ) includes all proposed and existing development in a geographic zone defined by the approving authority that contains the largest credible area affected by specified **geohazards**, and where damage or loss arising from one or more simultaneously occurring specific **geohazards** would be viewed as a single catastrophic loss. | Adapted from Porter et al. (2009) |
| Debris Flow | Very rapid to extremely rapid surging flow of saturated, non-plastic debris in a steep channel (Hungr, Leroueil & Picarelli, 2014). Debris generally consists of a mixture of poorly sorted sediments, organic material and water (see Appendix B of this report for detailed definition). | BGC |
| Debris Flood | A very rapid flow of water with a sediment concentration of 3-10% in a steep channel. It can be pictured as a flood that also transports a large volume of sediment that rapidly fills in the channel during an event (see Appendix B of this report for detailed definition). | BGC |
| Design Peak Daily Flow | The design flow (e.g. 200-year flood) based on the analysis of annual maximum daily average discharge records. | BGC |
| Design Peak Instantaneous Flow | The design flow (e.g. 200-year flood) based on the analysis of annual maximum instantaneous discharge records. | BGC |
| Elements at Risk (E) | This term is used in two ways:<br>a) To describe things of value (e.g., people, infrastructure, environment) that could potentially suffer damage or loss due to a **geohazard**.<br>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:<br>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"**<br>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) |
| 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**.<br>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.<br>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:<br>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**.<br>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.). |
| Likelihood | Conditional **probability** of an outcome given a set of data, assumptions and information. Also used as a qualitative description of **probability** and **frequency**. | Fell et al. (2005) |
| Melton Ratio | Watershed relief divided by square root of watershed area. A parameter to assist in the determination of whether a creek is susceptible to flood, debris flood, or debris flow processes. | BGC |
| Nival | Hydrologic regime driven by melting snow. | Whitfield, Cannon and Reynolds (2002) |
| Orphaned | Without a party that is legally responsible for the maintenance and integrity of the structure. | BGC |
| Paleofan | Portion of a fan that developed during a different climate, base level or sediment transport regime and which will not be affected by contemporary geomorphic processes (debris flows, debris floods, floods) affecting the active fan surface | BGC |

| Term | Definition | Source |
|---|---|---|
| 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.<br>There are two main interpretations:<br>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.<br>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:<br>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.<br>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.

Hungr, O., Leroueil, S. and Picarelli, L. (2014) The Varnes Classification of Landslide Types, an Update. Landslides, 11, 167-194. https://doi.org/10.1007/s10346-013-0436-y

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

BC 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 B
# SITE PHOTOGRAPHS

**Photo 1.**
**Slocan River at outlet of Slocan Lake looking across from the left bank.**
**Photo: BGC, July 2, 2019.**

**Photo 2.**
**From left bank of Slocan River looking at Slocan Lake from outlet.**
**Photo: BGC, July 2, 2019.**

**Photo 3.**
**From Village of Slocan Bridge looking upstream. Photo: BGC, July 2, 2019.**

**Photo 4.**
**From Village of Slocan Bridge looking downstream.**
**Photo: BGC, July 2, 2019.**

**Photo 5.**
**From left bank looking downstream at Logging Bridge.**
**Photo: BGC, July 2, 2019.**

**Photo 6.**
**Left bank material at Logging Bridge.**
**Photo: BGC, July 2, 2019.**

**Photo 7.**
**Slocan boat ramp at downstream end of the Gravel Pit Road Bridge.**
**Photo: BGC, July 2, 2019.**

**Photo 8.**
**Looking upstream at Gwillim Creek immediately before it enters Slocan River.**
**Photo: BGC, July 7, 2019.**

**Photo 9.**

**Island between Slocan Lake and Lemon Creek. Photo: BGC, July 7, 2019.**

**Photo 10.**

**Lemon Creek failed erosion protection structure 80 m west of the Highway 6 Crossing of Lemon Creek. Photo: BGC, July 2, 2019.**

**Photo 11.**
**Gravel bar upstream of Slocan Valley Rail Trail Bridge on Lemon Creek. Photo: BGC, July 2, 2019.**

**Photo 12.**
**Lemon Creek rock protection on right bank 200 m west of Highway 6. Photo: BGC, July 2, 2019.**

**Photo 13.**
**Rapids in Lemon Creek 200 m west of the Highway 6 crossing of Lemon Creek. Photo: BGC, July 2, 2019.**

**Photo 14.**
**Lemon Creek rock protection on left bank 200 m west of Highway 6. Photo: BGC, July 2, 2019.**

**Photo 15.**

**Large woody debris pile in Lemon Creek 220 m west of Highway 6.**
**Photo: BGC, July 2, 2019.**

**Photo 16.**

**From Highway 6 Bridge over Lemon Creek looking upstream. Photo: BGC, July 2, 2019.**

**Photo 17.**

**From Highway 6 Bridge over Lemon Creek looking downstream. Photo: BGC, July 2, 2019.**

**Photo 18.**

**Cliff on the right bank of the Slocan River 100 m downstream of the mouth of Lemon Creek. Photo: Midwest, July 15, 2019.**

**Photo 19.**
**Woody debris in Slocan River 650 m downstream of the mouth of Lemon Creek. Photo: Midwest, September 16, 2019.**

**Photo 20.**
**Sand bar in Slocan River 650 m downstream of the mouth of Lemon Creek. Photo: Midwest, September 16, 2019.**

**Photo 21.**

**Looking upstream from Perry Bridge. Photo: BGC, July 2, 2019.**

**Photo 22.**

**Looking downstream from Perry Bridge. Photo: BGC, July 2, 2019.**

**Photo 23.**
**Standing on Winlaw Bridge looking upstream. Photo: BGC, July 2, 2019.**

**Photo 24.**
**Standing on Winlaw Bridge looking downstream. Photo: BGC, July 2, 2019.**

**Photo 25.**
**From left looking upstream at rapids 5 km upstream of Little Slocan Bridge.**
**Photo: BGC, July 7, 2019.**

**Photo 26.**
**From left looking downstream at rapids 5 km upstream of Little Slocan Bridge.**
**Photo: BGC, July 7, 2019.**

**Photo 27.**
**Standing on Little Slocan Bridge looking upstream.**
**Photo: BGC, July 7, 2019.**

**Photo 28.**
**Standing on Little Slocan Bridge looking downstream.**
**Photo: BGC, July 7, 2019.**

**Photo 29.**
**Bed material at Little Slocan Bridge.**
**Photo: BGC, July 7, 2019.**

# APPENDIX C
# HYDROLOGICAL ANALYSIS METHODS

## C.1. INTRODUCTION

Estimating flood magnitude is of fundamental importance to reliable floodplain mapping. As most watercourses are not gauged, flood magnitude is commonly estimated for an ungauged watershed using a Regional Flood Frequency Analysis (Regional FFA). There are several methods to complete a Regional FFA. This appendix documents the methodology followed by BGC Engineering Inc. (BGC) for the regionalization of floods in British Columbia using the index-flood method (Dalrymple 1960).

This appendix begins with a description of Regional FFA and the index-flood method (Section C1.0). The study area over which the index-flood is developed is discussed in Section C2.0. The data acquisition and compilation to support the analysis is described in Section C3.0. A description of the methods and assumptions for the regionalization of floods is included in Section C4.0. Results for the different hydrologic regions that cover the Regional District of Central Kootenay (RDCK) are presented in Section C5.0, while the application of the index-flood method to ungauged watersheds in the RDCK is presented in Section C6.0. Finally, the limitations of the study are discussed in Section C7.0.

### C.1.1. Regional FFA

Extreme events are rare by definition and record lengths at hydrometric stations are often short. Regional FFA accounts for short record lengths by trading space for time where flood events at several hydrometric stations are pooled to estimate flood magnitude in a homogeneous region. Homogeneous regions can be defined as geographically contiguous regions, geographically non-contiguous regions, or as hydrological neighbourhoods. Grouping watershed areas of similar watershed characteristics into homogeneous regions is a critical part of Regional FFA because hydrologic information can be transferred accurately only within a region that is homogeneous. The more homogeneous a region is, the more reliable the flood quantile estimates. Some heterogeneity may be deemed acceptable in some cases. Studies show that even moderately heterogeneous regions can yield more accurate flood quantile estimates than a single-station FFA (Hosking & Wallis, 1997).

### C.1.2. Index-flood Method

Several methods have been developed to conduct a Regional FFA in homogeneous regions. Among the quantile estimation methods, the index-flood is considered superior to other models (Ouarda et al., 2008). The index-flood is a method of regionalization with a long history in FFA (Dalrymple, 1960). The index-flood method involves the development of a dimensionless regional growth curve assumed to be constant within a homogenous region. The index-flood method also requires the selection of an index-flood which can be the mean annual flood, the median annual flood, or another quantile of choice calculated at each hydrometric station in the region.

The probability distribution of flood events at hydrometric stations in a homogeneous region are identical apart from a site-specific scaling factor, the index-flood. The parameters of the probability distribution are estimated at each hydrometric station. These at-site estimates are combined using a weighted average to generate a regional estimate. The regional growth curve is thus a dimensionless quantile function common to every hydrometric station in the region and takes on the following form (Eq. C-1):

$$X_T = Q_T \,/\, Q_m \qquad \text{[Eq. C-1]}$$

where $X_T$ is the growth factor for return period $_T$, $Q_T$ is the flood magnitude at return period $_T$, and $Q_m$ is the index-flood magnitude. The flood magnitude at any return period is calculated using this relationship given the index-flood estimate.

### C.1.3. Application to Ungauged Watersheds

The index-flood method can be applied to an ungauged watershed by developing a regional relationship between the index-flood and watershed characteristics at hydrometric stations in the region. The relationship can be expressed in many forms including a multivariate linear regression. Flood events can be assumed to depend on the characteristics of individual watersheds such as area, elevation, percent lake, forest coverage, mean annual precipitation, mean annual temperature, etc. Once the watershed characteristics are extracted at the ungauged site, the index-flood can be estimated. The flood magnitude of any annual exceedance probability (AEP) can be estimated for an ungauged watershed using the index-flood estimate and the regional growth curve by re-organizing equation Eq. C1-1.

## C.2. STUDY AREA

A Regional FFA for British Columbia represents a considerable challenge given its regional variations in precipitation caused by sharp changes in topography as well as diverse geology. The proportion of annual precipitation that falls as snow as opposed to rain increases with latitude, elevation, and distance from the Pacific Ocean. Significant regional variations in precipitation are observed in British Columbia, influenced by the various mountain ranges. Storms approaching the West Coast are lifted rapidly along the windward mountain slopes, resulting in widespread precipitation. A rain shadow is created on the lee side of the mountains. For example, Tofino receives an average of 3,160 mm of annual precipitation while Nanaimo, on the east coast of Vancouver Island, receives 1,060 mm.

This climate pattern is repeated several times from east to west. As the weather systems approach the Coast Mountains, orographic effects result in twice as much precipitation in North Vancouver compared to Vancouver proper. Moving to the east, the Okanagan Valley is located on the lee side of the Coast Mountains resulting in an arid to semi-arid climate with annual precipitation on the order of 350 mm. The cycle is repeated over the Monashees, the Columbia Trench, and the Rocky Mountains. These orographic effects impact flood events and complicate regionalization efforts due to significant areal variations in precipitation, even for small watersheds. These significant variations in precipitation suggest that a multivariate approach to regionalization is practical for British Columbia.

Similar to precipitation, surficial geology in the province demonstrates significant spatial variability. This variability is important in that while two watersheds may be located in a similar precipitation zone, the hydrologic response can be significantly different. Watersheds dominated by colluvial veneers and bedrock will tend to have larger unit peak discharges, than those mantled by coarse morainal sediment, with the latter tending to attenuate peak discharges through available soil moisture storage. To avoid introducing boundary effects at the border with the Unites States and Alberta, the study area was extended to include the northern portion of Washington, Idaho, and Montana as well as the eastern Slopes of the Rocky Mountains. A map of the study area is presented in Figure C-1.

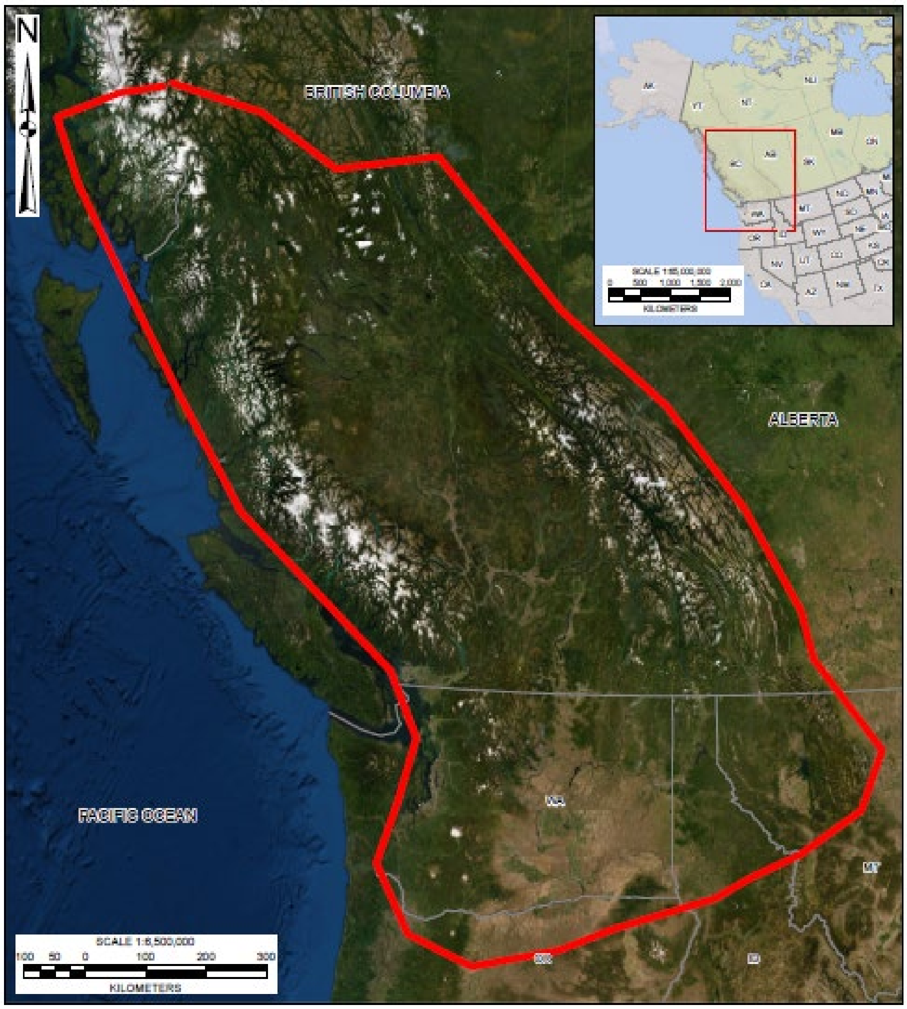



**Figure C-1. Study area where the red outline defines the boundary.**

## C.3. DATA ACQUISITION AND COMPILATION

A large component of this study consisted of acquiring the data and compiling it in a format that was usable for analysis. Suitable hydrometric stations in the study area were identified and the flood records were acquired from the appropriate monitoring agency. The watershed polygons upstream from the hydrometric stations were then delineated and the area calculated using methods specific to the scale of the watershed. Lastly, a suite of watershed characteristics was selected based on potential to influence flood events. These watershed characteristics were extracted for each polygon. The acquisition and the compilation of this rich dataset was the most time-consuming portion of the procedure. The following sections include a detailed description of how the data were acquired and how the dataset was compiled for analysis.

### C.3.1. Hydrometric Stations

A total of 3,309 hydrometric stations are located within the study area. Of these, 2115 are managed by the Water Survey of Canada (WSC) and the remaining 1194 are managed by the United States Geological Survey (USGS).

### C.3.2. Flood Records

As an initial step, all flood events recorded at the hydrometric stations were extracted. This extraction was challenging as records are stored differently by the WSC and USGS. In Canada, flood events are stored in the HYDAT database, which includes the annual maximum peak instantaneous discharge, the maximum average daily discharge, as well as the date and time of each event. The watershed area and the number of years on record are also available in the HYDAT database. The flood records were acquired directly from the HYDAT database for hydrometric stations in Canada. In the US, flood events are stored online on websites specific to each hydrometric station. The annual maximum peak instantaneous discharge, the watershed area, and the number of years on record are also stored in this way. This information was extracted from the online storage space using a programming script for each USGS hydrometric station.

### C.3.3. Maximum Peak Instantaneous Discharge

The preferred metric for analysis is the annual maximum peak instantaneous discharge. However, it is not uncommon for flood records to have more annual maximum average daily discharge records than peak instantaneous values, which are greater in magnitude. The ratio (I/D) between maximum peak instantaneous and maximum average daily discharge is typically greater for small watersheds than for very large watersheds. Therefore, where only a maximum daily discharge is reported for some years, maximum peak instantaneous discharge values can be estimated from available maximum average daily discharge records using regression analysis.

The reliability of the regression analysis was judged based on the coefficient of determination ($R^2$) in combination with the Cook distance (D). The $R^2$ is the proportion of the variance in the peak instantaneous discharge that is predictable from the average daily discharge. The D value is computed for every record within a sample and is used to assess the influence of each record on the regression (e.g., outliers). The regression analysis was deemed acceptable by BGC if the $R^2$ is above 0.95 and the maximum D value was less than 25. In this case, the maximum peak instantaneous discharge record was extended using the regression analysis for a longer record length. Alternatively, maximum peak instantaneous discharge record remained as-is where the regression analysis was deemed unacceptable.

### C.3.4. Watershed Polygons

The watershed polygons at hydrometric stations within the study area were estimated using two different approaches.

1. River Networks Tools™[1] (RNT)
2. Using an Environmental Systems Research Institute (ESRI) process (i.e., GIS-based).

The RNT-based approach is dependent on the delineation of a stream network, while the ESRI-based process is dependent on topographic data. Watershed polygons were defined for all hydrometric stations located within the study area. Watershed delineation based on a stream network was observed to be more reliable for small watersheds, especially where topographic relief is low. The watershed polygons defined by the ESRI process were selected for larger watersheds (>1,000 km$^2$), while the RNT-based approaches were selected for smaller watershed areas (<1,000 km$^2$). The selection of the best watershed polygon for analysis could not be checked directly as the monitoring agencies (WSC and USGS) do not publish polygon shape information.

### C.3.5. Watershed Areas

The watershed area was estimated for each watershed polygon (RNT, modification based on RNT, and ESRI) at each hydrometric station. The watershed area for each polygon was then compared with the value published by the respective monitoring agency. The watershed area published by monitoring agencies is generally considered most reliable (although recognizing many of the watershed areas for the WSC stations were calculated with 1:50,000 scale mapping and may not reflect more recent topographic mapping) and was used to quality check the calculated areas.

The estimated value of the watershed area was deemed acceptable if it was within ±15% of the published value. If more than 1 watershed area estimate (of the 3) was within ±15% of the published value, the watershed area with the smallest difference relative to the published value was selected as the best estimate for analysis. Approximately 90% of watershed polygons were within ±15% of the published value.

Published values are not available for all hydrometric stations. In those cases, the watershed area was deemed acceptable if the 3 estimates were within ±15% of each other. Watershed areas that did not meet the ± 15% criteria were not included in the analysis. A total of 2269 hydrometric stations were removed from the analysis because either the watershed area was deemed unreliable or water level data only was recorded at the station. Manual quality checks were not completed for these watersheds due to the time-consuming nature of this effort. The number of hydrometric stations lost that could have been considered useful is considered negligible. The

[1] The RNT is a proprietary software developed by BGC. RNT is based on publicly available 1:24,000-scale or better topographic and hydrographic datasets throughout North America that BGC has compiled and systematically developed to support a wide range of hydrotechnical calculations (e.g., watershed area) and site-specific precipitation and flood monitoring.

number of hydrometric stations in the study area is summarized in Table C-1. The ESRI watershed polygons were used for the hydrometric stations at the border between Canada and the United States because the polygons based on the two RNT approaches are observed to be poorly delineated due to differences in data resolution available between both countries.

**Table C-1. Number of hydrometric stations in the study area.**

| Criteria | Number |
|---|---|
| Hydrometric Stations in Study Area | 3284 |
| Station with Unacceptable Watershed Area Estimates | 2269 |
| Stations with Acceptable Watershed Area Estimates | 1015 |

### C.3.6. Watershed Characteristics

Watershed characteristics were selected based on potential to influence flood events. A suite of 18 watershed characteristics was ultimately selected and estimated for each hydrometric station, as summarized in Table C-2. Several data sources were used to compile the watershed characteristics which are described in the following sections.

#### C.3.6.1. Watershed Statistics

The Shuttle Radar Topography Mission (STRM) dataset (Farr et al. 2007) was used to extract the watershed elevation statistics. The watershed elevation statistics were averaged over the watershed area. This dataset was used to calculate the watershed area (just for watersheds over 1000 km$^2$), relief, length, and slope. The centroid statistics were also extracted from this dataset.

#### C.3.6.2. Climate Variables

The Climate North America (ClimateNA) dataset was used to estimate the climate variables for each watershed polygon (Wang et al., 2016). The climate variables were averaged over the watershed area and were based on the average for the period 1961 to 1990.

**Table C-2. List of selected watershed characteristics.**

| Type | No. | Acronym | Characteristic | Units | Dataset |
|---|---|---|---|---|---|
| Watershed | 1 | Centroid_Lat | Latitude at the centroid location in the watershed polygon | degrees | STRM |
| | 2 | Centroid_Long | Longitude at the centroid location in the watershed polygon | degrees | |
| | 3 | Centroid_Elev | Elevation at the centroid location in the watershed polygon | m | |
| | 4 | Area | Area of the watershed polygon | km$^2$ | |
| | 5 | Relief | Maximum minus minimum watershed elevation | m | |
| | 6 | Length | Area divided by perimeter | km | |
| | 7 | Slope | Watershed length divided by relief times 100 | % | |
| Climate | 8 | MAP | Mean annual precipitation | mm | Climate NA |
| | 9 | MAT | Mean annual temperature | ºC | |
| | 10 | PAS | Precipitation as snow | mm | |
| | 11 | PPT_wt | Winter precipitation (Dec, Jan, Feb) | mm | |
| | 12 | PPT_sp | Spring precipitation (Mar, Apr, May) | mm | |
| | 13 | PPT_sm | Summer precipitation (Jun, Jul, Aug) | mm | |
| | 14 | PPT_fl | Fall precipitation (Sep, Oct, Nov) | mm | |
| Physiographic | 15 | Forest | Forest cover in the watershed | % | NALCMS |
| | 16 | Water_Wetland | Wetland and open water cover in the watershed | % | |
| | 17 | Urban | Urban cover in the watershed | % | |
| | 18 | CN | Inferred based on integrating land cover and soils cover | unitless | NALCMS and HYSOGs250m |

#### C.3.6.3. Land cover

The North American Land Change Monitoring System (NALCMS) land cover products include the 2005 land cover map of North America. This dataset includes 19 land cover classes derived from 250 m Moderate Resolution Spectroradiometer (MODIS) image composites (Latifovic et al., 2012). This dataset was used to calculate the percent forest, percent wetland and lake, and the urban portion of the watershed.

#### C.3.6.4. Curve Number

The curve number (CN) is an empirical parameter used for predicting runoff from rainfall. BGC integrated the land cover (NALCMS) and the hydrologic soils group (HYSOGs250m) datasets to infer the average CN over each watershed. The NALCMS dataset is described in Section C.3.6.3. The HYSOGs250m dataset represents typical soil runoff potential at a 250 m spatial resolution (Ross et al., 2018). Hydrologic soils groups are defined based on soil texture, depth to bedrock or depth to groundwater. There are four basic groups: A, B, C, D. Four additional groups are included where the depth to bedrock is considered to be less than 60 cm: AD, BD, CD, and DD. The area covered by each hydrologic soils group is summed for a total area over the watershed for each hydrologic soils group.

The CN was assigned following guidance from the USGS (1986). The CN values for soils where the depth to bedrock or depth to groundwater.is expected to be less than 0.6 m from the surface (i.e., D soils) were assumed to be the same as the case where it is not expected to be close to the ground surface. The CN value assignment for the combinations of land cover and hydrologic soils groups identified in the watersheds is presented in Table C-3. The CN values were averaged over the watershed area using a weighted mean. The weight reflects the percentage of the area covered by a given CN value.

**Table C-3. CN values based on the integration between the land cover and soils datasets.**

| Land Cover (NALCMS 2005) | Cover Type (USGS 1986) | Soils | | | |
|---|---|---|---|---|---|
| | | HSG-A | HSG-B | HSG-C | HSG-D |
| Temperate or sub-polar needleleaf forest | Woods - Good | 30 | 55 | 70 | 77 |
| Temperate or sub-polar broadleaf deciduous forest | Woods - Good | 30 | 55 | 70 | 77 |
| Mixed forest | Woods - Good | 30 | 55 | 70 | 77 |
| Temperate or sub-polar shrubland | Brush - brush-weed-grass mixture with brush the major element - Fair | 35 | 56 | 70 | 77 |
| Temperate or sub-polar grassland | Pasture, grassland, or range—continuous for grazing - Good | 39 | 61 | 74 | 80 |
| Sub-polar or polar grassland-lichen-moss | Pasture, grassland, or range—continuous for grazing - Good | 39 | 61 | 74 | 80 |
| Sub-polar or polar barren-lichen-moss | Desert shrub - major plants include saltbrush. Greasewood, creosotebush, blackbrish, bursage, palo verde, mesquite, and cactus - good | 49 | 68 | 79 | 84 |
| Sub-polar taiga needleleaf forest | Woods - Good | 30 | 55 | 70 | 77 |
| Cropland | Row crops - straight row (SR) | 63 | 74 | 81 | 85 |
| Barren land | Desert shrub - major plants include saltbrush. Greasewood, creosotebush, blackbrish, bursage, palo verde, mesquite, and cactus - good | 49 | 68 | 79 | 84 |
| Urban and built-up | Urban districts - commercial and business | 89 | 92 | 94 | 95 |
| Snow and ice | NA | 0 | 0 | 0 | 0 |
| Wetland | NA | 0 | 0 | 0 | 0 |
| Water | NA | 0 | 0 | 0 | 0 |

## C.4. METHODS AND ASSUMPTIONS

Once the dataset is compiled for analysis, the regionalization of floods procedure can begin. A description of the methods and assumptions for the index-flood method is included in this section.

### C.4.1. Flood Statistics Calculations

Flood statistics were calculated using the flood record at each of the selected hydrometric stations (2101) in the study area. Flood statistics include L-moments and flood quantile estimates.

#### C.4.1.1. L-moments

The L-moment approach in the index-flood procedure was used by BGC for the regionalization of floods in British Columbia. The shape of a probability distribution has traditionally been described by the moments of the distribution including the mean, standard deviation, skewness, and kurtosis. However, moment estimators have some undesirable properties where the skewness and kurtosis can be severely biased. Both have algebraic bounds that depend on the sample size (Hosking & Wallis 1997).

L-moments are an alternative system for describing the shape of probability distributions. Studies have shown that L-moments are unbiased, less sensitive to outliers, and are better estimators of distribution parameters especially for short to moderate record length (Hosking, 1990). Furthermore, L-moments allow for the efficient computation of parameter estimates and flood quantile estimates.

L-moments evolved as modifications to the probability weighted moments (Greenwood et al., 1979). In terms of probability weighted moments, L-moments are defined as $\lambda_1$, $\lambda_2$, $\lambda_3$, and $\lambda_4$ with their mathematical expressions published for a range of probability distributions in Hosking and Wallis (1997, Appendix).

Dimensionless versions of L-moments are defined as L-moment ratios by dividing the higher order L-moments by $\lambda_2$. L-moment ratios are defined by Eq. C-2:

$$\tau_r = \lambda_r / \lambda_2 \qquad \text{[Eq. C-2]}$$

L-moment ratios depict the shape of a distribution independently of its scale measurement. Refer to Table C-4 for L-moment terminology.

**Table C-4. L-moment terminology.**

| Symbol (population) | Symbol (sample) | Definition |
|---|---|---|
| $\lambda_1$ | $\iota_1$ | L-location or the mean of the distribution |
| $\lambda_2$ | $\iota_2$ | L-scale |
| $\tau$ | $t$ | L-CV |
| $\tau_3$ | $t_3$ | L-skewness |
| $\tau_4$ | $t_4$ | L-kurtosis |

### C.4.1.2. At-site Peak Discharge Estimates

The flood quantile estimates at hydrometric stations are referred to as 'at-site' estimates and are used to compare with the modeled quantile estimates to assess the validity of the model. Flood quantile estimates were calculated using the flood data by means of a single-station FFA. A popular approach in FFA is the Annual Maximum Series (AMS) where the maximum peak instantaneous discharge for each year on record is used for analysis. The basic assumption is that the flood events are independent and identically distributed from a single population of flood events.

A probability distribution is selected to describe the flood events in the record. The true form of the underlying probability distribution is not known and there is no standard distribution appropriate in all cases. The goal is to select a probability distribution that fits the observed data well but also generates robust quantile estimates that are not sensitive to physical deviations of the true probability distribution (Hosking & Wallis, 1997). In extreme value statistics, data follow one of three extremal types of distributions: Gumbel, Fréchet, or Weibull (Coles, 2001). These three distributions can be expressed as a single formula and are considered a family of distributions known as the Generalized Extreme Value (GEV) distribution. The GEV distribution is shown to arise as an asymptotic model for maximum values in a sample and hence can be viewed as a natural model for observed flood events. In addition, the GEV distribution has been identified as a preferred probability distribution for at-site flood quantile estimates in Canada (Zhang et al., 2019). For these reasons, the GEV distribution was used to describe the recorded flood events. No statistical tests were used to assess this choice because the GEV distribution is considered flexible to account for the variability captured at a single hydrometric station.

The parameters of the GEV distribution were estimated using the L-moments. The flood quantiles were calculated for a range of return periods (Table C-5). The reliability of the quantile estimates depends on a range of factors including the record length and the range of flood event magnitudes captured in the record. The longer the record length, the more reliable the quantile estimates.

**Table C-5. Return period and associated AEP.**

| Return Period (Years) | AEP |
|---|---|
| 2 | 0.5 |
| 5 | 0.2 |
| 10 | 0.1 |
| 20 | 0.05 |
| 50 | 0.02 |
| 100 | 0.001 |
| 200 | 0.005 |
| 500 | 0.002 |

## C.4.2. Formation of Hydrological Regions

The watershed characteristics extracted over the watershed polygons were used to group the hydrometric stations into hydrological regions using a cluster analysis. Cluster analysis is an objective method for creating regions (Tasker, 1982) which historically were based subjectively using geographical, political, administrative or physiographic boundaries. 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. Hosking and Wallis (1997) suggest that cluster analysis is the most practical method of forming regions for large datasets and provides several opportunities for subjective adjustments to the regions. The algorithm used by BGC to group hydrometric stations is Agglomerative Hierarchal Clustering.

### C.4.2.1. Data Preparation

The watershed characteristics at each hydrometric station were normalized so that the average is zero and the standard deviation is approximately 1. The distance metric used is the Euclidian distance between the watershed characteristics. The suite of watershed characteristics at all hydrometric stations were compared to one another and organised using Ward's Distance measure (d) (Ward, 1963).

### C.4.2.2. Number of Hydrological Regions

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 (e.g., is there a physical meaning behind the number and distribution of the clusters?).

The Elbow Method accounts for the percentage of variance explained as a function of the number of clusters. The percentage of the variance explained decreases with increasing number of clusters. The minimum number of clusters that provides the most gain in the variance explained was selected for analysis.

The Silhouette Score is a measure of how similar the watershed of a hydrometric station is to its own cluster compared to other clusters. The Silhouette Score was calculated for each hydrometric gauge station and averaged over each cluster. The Silhouette Score ranges from -1 to +1 where a high value indicates that the hydrometric stations are well matched to their own clusters and poorly matched to neighboring clusters.

The dendrogram represents how the clustering algorithm (i.e., agglomerative hierarchal clustering) groups the watersheds and depicts a road map of the merging procedure showing which watersheds were merged and when in order of increasing cluster distance.

The spatial distribution of the clusters was then reviewed to verify that they are physically plausible. This review was done by superimposing the clusters on a map of British Columbia to see whether there is a physical meaning supporting the cluster distributions.

#### C.4.2.3. Manual Adjustments of Hydrologic Regions

The clusters identified using the clustering algorithm were adjusted manually to increase homogeneity. The manual adjustments were completed by considering the topography, spatial patterns in hydrological processes, and ecozones in Canada. The clusters were further separated based on the scale of watershed area to respect the statistical requirement for constancy in the coefficient of variation (CV) for homogeneous regions.

#### C.4.2.4. Refinement of the Hydrometric Station Selection

The hydrometric station selection was refined to increase the homogeneity of the clusters by reducing the variability introduced by many hydrometric stations. The refinement process was guided by the following 5 criteria.

1. Watersheds upstream of hydrometric stations with a regulation level greater than 25% were not included for analysis. The level of regulation is inferred by proportion of the watershed area upstream of the dams to the total watershed area upstream of the hydrometric station.
2. The watershed area range considered in the regionalization extends up to 5,000 km$^2$. Watersheds with a greater watershed area size are most likely well gauged and studied that a regionalization of flood is not required.
3. Nested hydrometric stations along the same watercourse were also removed from the region to reduce cross-correlation.
4. A minimum of 6 years of maximum peak instantaneous discharge data was set as a minimum for analysis. While this threshold is low, it is considered adequate since the influence of each hydrometric stations on the model reflects the record length.
5. Hydrometric stations recording water level only were excluded from the analysis at the onset. Hydrometric stations recording water level and discharge measurements but located within or immediately at the outlet of lakes were also removed from the analysis.

The flow regime at these locations is considered heavily regulated precluding the use of frequency analysis to estimate peak discharge.

In addition to these criteria, discordancy (*Di*) was considered to refine the selection. The discordancy is measured in term of the L-moments of the data at the hydrometric stations within a cluster. The formal definition for *Di* is found in Hosking and Wallis (1997, equation 3.3, page 46). A hydrometric station is considered discordant if *Di* is "large". The definition of "large" depends on the number of hydrometric stations in the cluster. If the cluster includes more than 15 hydrometric stations, the critical value for the discordancy statistic is 3. Discordancy was calculated for each hydrometric station within each hydrologic region. Hydrometric stations with *Di* values greater than 3 were removed from the cluster. This process was re-iterated until no more hydrometric stations showed *Di* values greater than 3.

#### C.4.2.5. Testing for Homogeneity

The hypothesis for homogeneity is that the probability distribution of the flood events at the hydrometric stations within a cluster is the same except for a site-specific scale factor. The goal is to have clusters that are sufficiently homogenous that the regionalization of floods is advantageous to a single station FFA. Testing for homogeneity is done using the H-Test. The H-Test result helps assess whether the hydrometric stations in a cluster may reasonably be considered homogeneous. The formal definition for the H-Test is found in Hosking and Wallis (1997, equation 4.5, page 63). Of note, some level of heterogeneity is expected in these clusters due to the natural variability of hydrological processes that control flood events. The H-Test is not intended to be used as a significance test but rather as a guideline to inform whether the re-definition of a region could lead to a meaningful increase in the accuracy of the flood quantile estimates (Hosking and Wallis 1993).

### C.4.3. Regionalization

Once the clusters were considered sufficiently homogeneous, they were considered "hydrologic regions". The regionalization of floods was then completed for each region. The L-moment approach in the index-flood procedure was used by BGC for the regionalization exercise. The procedure for each hydrologic region included: averaging the L-moments, selecting a distribution, estimating the parameters, developing the growth curve, and estimating the index-flood. The mean annual flood (MAF) was selected as the index-flood for this study. The following sections describe the methods and assumptions for the regionalization of floods for a given hydrologic region.

#### C.4.3.1. Regional L-moments

The L-moment ratios were averaged over each hydrologic region. A weighted average was used where the weight reflected the number of observations at each hydrometric station. The weighted average was used to put more weight on hydrometric stations with a longer record length. The weighted average helps take advantage of all available data as it is often limited in many areas of the province. The regional average L-moment ratios are defined in Table C-6. The L-moment ratios are used rather than the L-moments because they yield slightly more accurate quantile estimates.

**Table C-6. Definition for regional average L-moment ratios.**

| Symbol (sample) | Definition |
|---|---|
| $\iota_1^R$ | L-location or the mean of the distribution |
| $\iota_2^R$ | L-scale |
| $t^R$ | L-CV |
| $t_3^R$ | L-skewness |
| $t_4^R$ | L-kurtosis |

### C.4.3.2. Distribution Selection for Growth Curves

The selection of an appropriate probability distribution for the growth curves was done using a goodness-of-fit test and review of L-moment ratio diagrams. These tests were completed to assess the variability imposed compiling the results of many hydrometric stations into a single growth curve. The goodness-of-fit test was based on 1,000 simulations and looked at a suite of candidate distributions. The candidate probability distributions included Generalised Logistic (GLO), Generalised Extreme Value (GEV), Generalised Pareto (GPA), Generalised Normal (GNO), and Pearson Type III (PE3). Probability distributions with Z statistics $\leq$1.64 were deemed acceptable (Hosking & Wallis, 1997). The regional L-moments were also plotted with the L-skewness and L-kurtosis relationships for two (Exponential (E), Gumbel (G), Logistic (L), Normal (N), and Uniform (U)) and three-parameter (GLO, GEV, GPA, GNP, PE3) candidate distributions in L-moment ratio diagrams. The plotting position of the regional L-moments was reviewed for the distribution selection that provided an acceptably close visual fit.

### C.4.3.3. Parameter Estimation

The regional L-moments were used to estimate the parameters of the selected probability distribution. The equations used to estimate the parameters for the GEV distribution are found in Hosking and Wallis (1997, A.52, A.55, and A.56, page 196) in addition to other select probability distributions.

### C.4.3.4. Growth Curves and Error Bounds

The index-flood was selected to be the MAF. As a result, the regional mean was set to 1 ($\iota_1^R = 1$). The probability distribution was fit by equating the L-moment ratios of the population ($\lambda_1$, $\tau$, $\tau_3$, $\tau_4$) to the regional average L-moment ratios ($\iota_1^R$, $t^R$, $t_3^R$, $t_4^R$).

One of the strengths of the Regional FFA completed using the regional L-moments is that the procedure is useful even when the assumptions are not all satisfied (e.g., possibility of heterogeneity, misspecification of the probability distribution, and statistical dependence between observations at different sites). An approach to estimate the accuracy of the estimated flood quantiles is by Monte Carlo simulation. A Monte Carlo simulation was therefore 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.

#### C.4.3.5. Index-flood Estimation

The index-flood was estimated using a multiple linear regression. Regression is a classic statistical method to describe the relationship between a dependent variable (index-flood) and independent variables (watershed characteristics). The multiple linear regression model is expressed as follows:

$$Q_T = aA^bB^c \ldots N^n \qquad \text{[Eq. C-3]}$$

where $Q_T$ is the flood magnitude at return period $_T$, A, B, …, N are the watershed characteristics, a is the regression constant, and b, c, …, n are the regression coefficients. Base 10 logarithms are used to convert this equation to a linear form by transforming the variables to the following:

$$\log Q_T = \log a + b(\log A) + c(\log B) + \cdots + n(\log N) \qquad \text{[Eq. C-4]}$$

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.

The top 5 models were selected using consideration for the adjusted $R^2$ and the Bayesian information criterion (BIC). The 5 models with the lowest BIC were selected and the index-flood estimate was averaged. Select diagnostic plots were reviewed to control the quality of the regressions. The diagnostic plots are listed in Table C-7. The index-flood model was developed over two scales: regional and provincial. These two scales were compared to assess the influence of the distribution of hydrometric stations on the reliability of the MAF estimate.

**Table C-7. Diagnostic plots.**

| Plot | Diagnostic |
|---|---|
| At-site vs. Modeled | Inspect for a one to one relationship as close to as possible |
| At-site Quantile vs. Modeled Quantile | Inspect whether the distribution of the fitted values match the distribution of the observed values |
| At-site Quantiles vs. Modeled Residuals | Inspect for constancy in residuals. Residuals are the differences between the at-site and the modeled estimates |

#### C.4.3.6. Regional Model

The first scale considered is the regional scale where the MAF was modeled over an area consistent with the hydrologic regions defined across the province. This scale is consistent with the scale used to do develop the regional growth curves.

#### C.4.3.7. Provincial Model

The second scale considered is the provincial scale where all hydrometric stations across the province, that meet the selection criteria, were used to model the MAF. The provincial model was developed to capture the range of hydrological processes that control flood events in British Columbia.

#### C.4.3.8. Flood Quantile Estimates

Flood quantile were than estimated using the regional growth curve and index-flood estimates (both scales) for all hydrometric stations in a given region. Quantile plots were generated to compare the at-site and modeled results over the range of AEPs.

#### C.4.3.9. Watershed Characteristic Transformations

The relationship between flood events and watershed characteristics need not be linear. Experience and judgement were used to guide the selection of independent variables and inform the relationship between flood events and watershed characteristics. An exhaustive comparison of correlations between flood magnitude and watershed characteristics showed that watershed area and watershed length are proportional to flood magnitude. For this analysis, the remaining watershed characteristics needed to be log transformed.

### C.4.4. Error Statistics

The quality of the flood quantile estimates was assessed using select error statistics including the Root Mean Square Error (SRMSE), the Percent Error (SPE), and the Bias (SBIAS) for the following AEPs: 0.5, 0.1, 0.02, 0.005. The standardized version of the error statistics is used to account for the different scales (Table C-8).

**Table C-8. Error statistics, definitions, and diagnostic.**

| Error Statistic (acronym) | Definition | Diagnostic |
|---|---|---|
| SRMSE | Standard deviation of the residuals. | Inspect how concentrated the modeled estimates are around the line of best fit. |
| SPE | The difference between the modeled and at-site estimate, divided by the at-site estimate, multiplied by 100%. | Inspect how close the modeled estimate is to the at-site estimate/ |
| SBIAS | The tendency to overestimate or underestimate the modeled variable. | Inspect for a consistent over or underestimate of the modeled variable |

The mathematical expressions for the SRMSE, SPE, and SBIAS are included below in Eq. C-5, Eq. C-6, and Eq. C-7.

$$SRMSE = \sqrt{\frac{\sum_{i=1}^{Np}\left(\frac{Qm_{mod}^{i}-Qm_{at-site}^{i}}{Qm_{at-site}^{i}}\right)}{Np}} \quad \text{[Eq. C-5]}$$

$$SPE = \frac{\sum_{i=1}^{Np} abs\left(\frac{Qm_{mod}^{i}-Qm_{at-site}^{i}}{Qm_{at-site}^{i}}\right)}{Np} * 100 \quad \text{[Eq. C-6]}$$

$$SBIAS = \frac{\sum_{i=1}^{Np} \left(\frac{Qm_{mod}^{i}-Qm_{at-site}^{i}}{Qm_{at-site}^{i}}\right)}{Np} \quad \text{[Eq. C-7]}$$

### C.4.5. Decision Tree

A decision tree model was used to assign hydrologic regions to ungauged watersheds. A decision tree was built using the Random Forest classification algorithm. The decision tree model was based on the watershed characteristics at the hydrometric stations in the study area. A total of 500 random samples were pulled from the dataset (with replacement). From each random sample, a decision tree was generated by using 3 variables at each decision point. The hydrologic region assignment was based on majority votes. The out-of-bag (OBB) error rate was 7.2%. The OBB is a method of measuring the prediction error specific to random forest algorithms.

### C.4.6. Statistical Software

The statistical software used by BGC for the analysis was R (R Core Team, 2019). R is a free software environment for statistical computing. The analysis is completed with support from several packages. These packages are listed in Table C-9 for reference.

**Table C-9. Analysis and associated R package.**

| Analysis | R Packages | Authors |
|---|---|---|
| Flood Statistics | Lmom | J. R. M. Hosking |
| Clustering | stats | R Core Team |
| Discordancy, H-Test, Distribution Selection, Parameter Estimation, and Growth Curve Development | lmomRFA | J. R. M. Hosking |
| Index-flood Estimation | stats and leaps | R Core Team and Alan Miller |
| Random Forest decision tree | Rpart, randomForest | Andy Liaw and Matthew Wiener |

## C.5. RESULTS

### C.5.1. Hydrometric Station Selection

A total of 1015 hydrometric stations were included in the analysis. The hydrometric stations were distributed across the study area with a greater concentration in the south compared to the north, largely reflecting population density. There is also a greater concentration of hydrometric stations in the United States than Canada (Figure C-2).

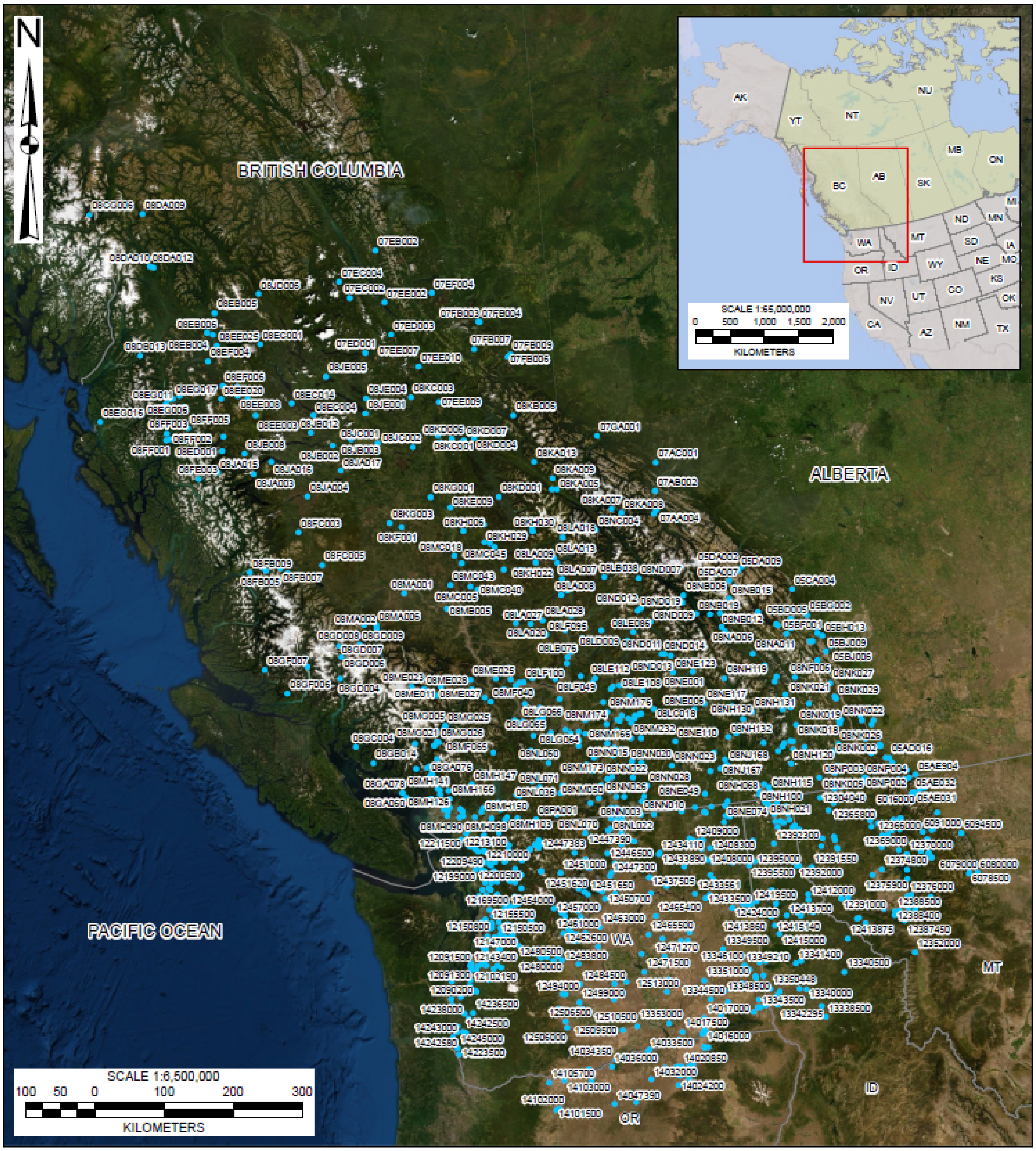



**Figure C-2. Distribution of hydrometric stations within the study area.**

The 18 watershed characteristics and their range in magnitude are summarized over the 1015 hydrometric stations in Table C-10. The climate watershed characteristics show a wide range in magnitude which is not surprising considering the sharp regional contrast imposed by the topography. The urban watersheds are concentrated in coastal Washington.

**Table C-10. Summary of watershed characteristics, including the mean, maximum, and minimum values over all hydrometric stations considered for analysis (1,015).**

| Type | No. | Acronym | Mean | Min | Max | Standard Deviation |
|---|---|---|---|---|---|---|
| Watershed | 1 | Centroid_Lat | 49.3092758 | 43.75066 | 57.094597 | 2.3 |
| | 2 | Centroid_Long | -119.5562752 | -130.965466 | -112.917172 | 3.5 |
| | 3 | Centroid_Elev | 1,133 | 18 | 3,046 | 534 |
| | 4 | Area | 7,572 | 1.3 | 601,746 | 38,417 |
| | 5 | Relief | 1,639 | 19 | 4,355 | 791 |
| | 6 | Length | 5 | 0.2 | 71 | 7 |
| | 7 | Slope | 62 | 4 | 350 | 49 |
| Climate | 8 | MAP | 1,299 | 218 | 4,173 | 787 |
| | 9 | MAT | 4.1 | -3.0 | 10.9 | 3.0 |
| | 10 | PAS | 499 | 25 | 2191 | 323 |
| | 11 | PPT_wt | 476 | 71 | 1,683 | 328 |
| | 12 | PPT_sp | 283 | 56 | 955 | 173 |
| | 13 | PPT_sm | 185 | 31 | 522 | 77 |
| | 14 | PPT_fl | 355 | 58 | 1,329 | 249 |
| Physiographic | 15 | Forest | 61 | 0 | 100 | 25 |
| | 16 | Water_Wetland | 1 | 0 | 18 | 2 |
| | 17 | Urban | 2 | 0 | 100 | 12 |
| | 18 | CN | 68 | 55 | 94 | 6 |

### C.5.2. Formation of Hydrological Regions

Based on an interative selection process, the 1,015 hydrometric stations were ultimately organized into 10 clusters. The results of the Elbow Method showed that a selection of approximately 10 hydrological regions explained the most variance in the watershed characteristics (Figure C-3).

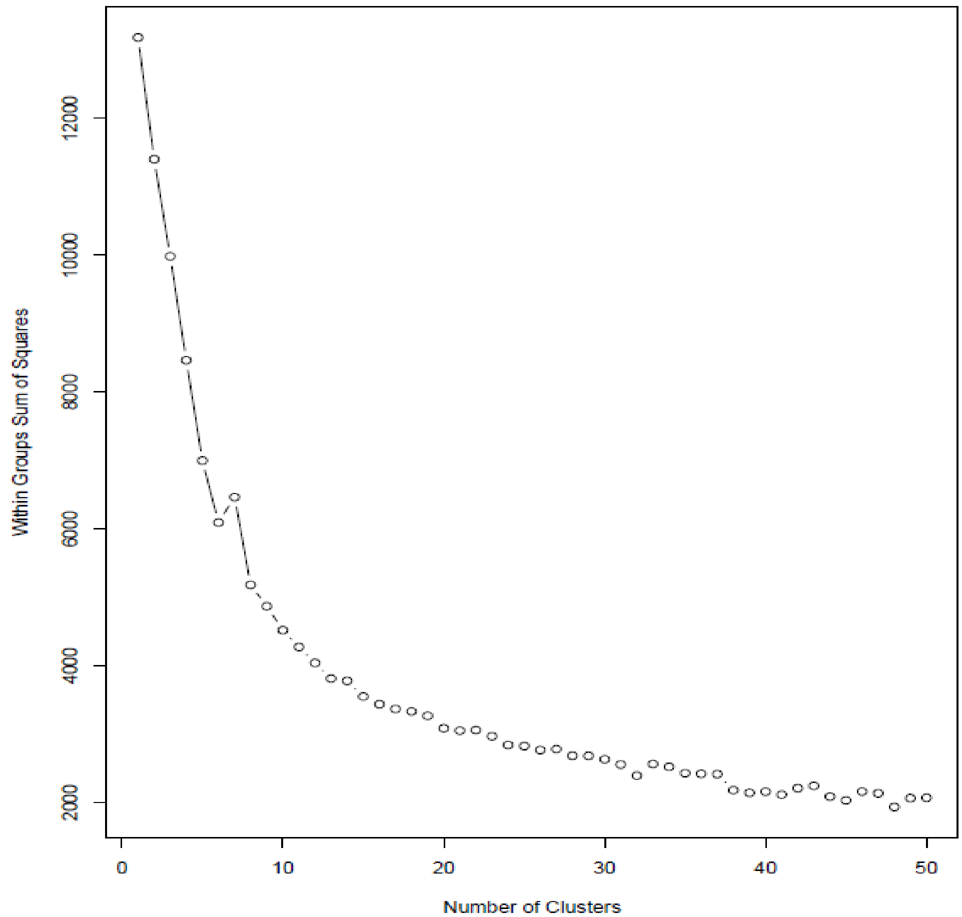



**Figure C-3. The Elbow Plot.**

The Silhouette Scores for the 10 clusters suggested some difficulty in organising the hydrometric stations based on watershed characteristics (Figure C-4). The average Silhouette Score is 0.2, suggesting that the hydrometric stations are poorly assigned to their hydrological regions. A low Silhouette Score is expected however, as it reflects the physical variability across the study area.

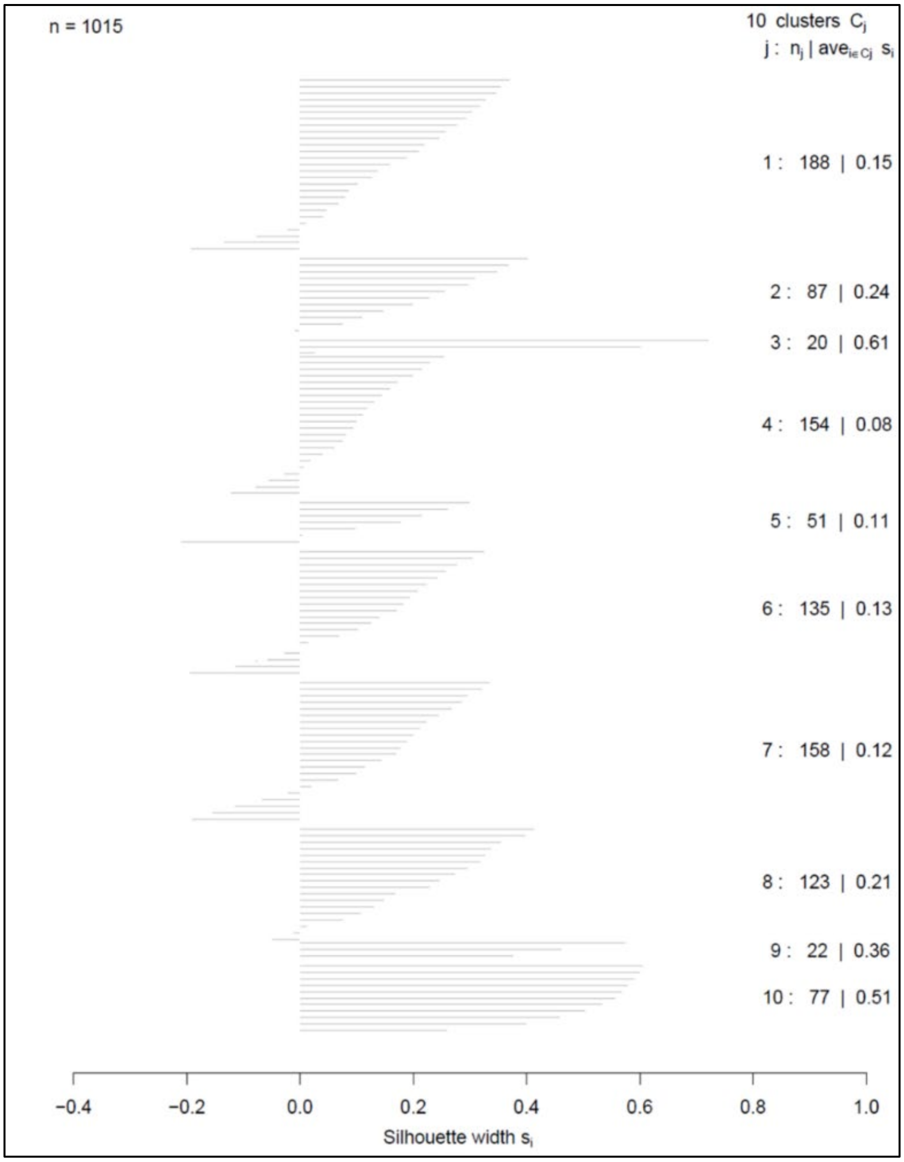



**Figure C-4. Silhouette score.**

The organization of the hydrometric stations into clusters is compiled in a dendrogram (Figure C-5). The y-axis is the dissimilarity index based on the distance metric. The horizontal axis represents the Ward's Distance (d). The green boxes separate the clusters. The 10 clusters are shown along the bottom of the dendrogram. Because we do not know how many clusters there should be in the landscape, the merging process was stopped once the clusters were more dissimilar than a threshold of approximately 90. The threshold was selected to generate a number of clusters consistent with the Elbow Plot.

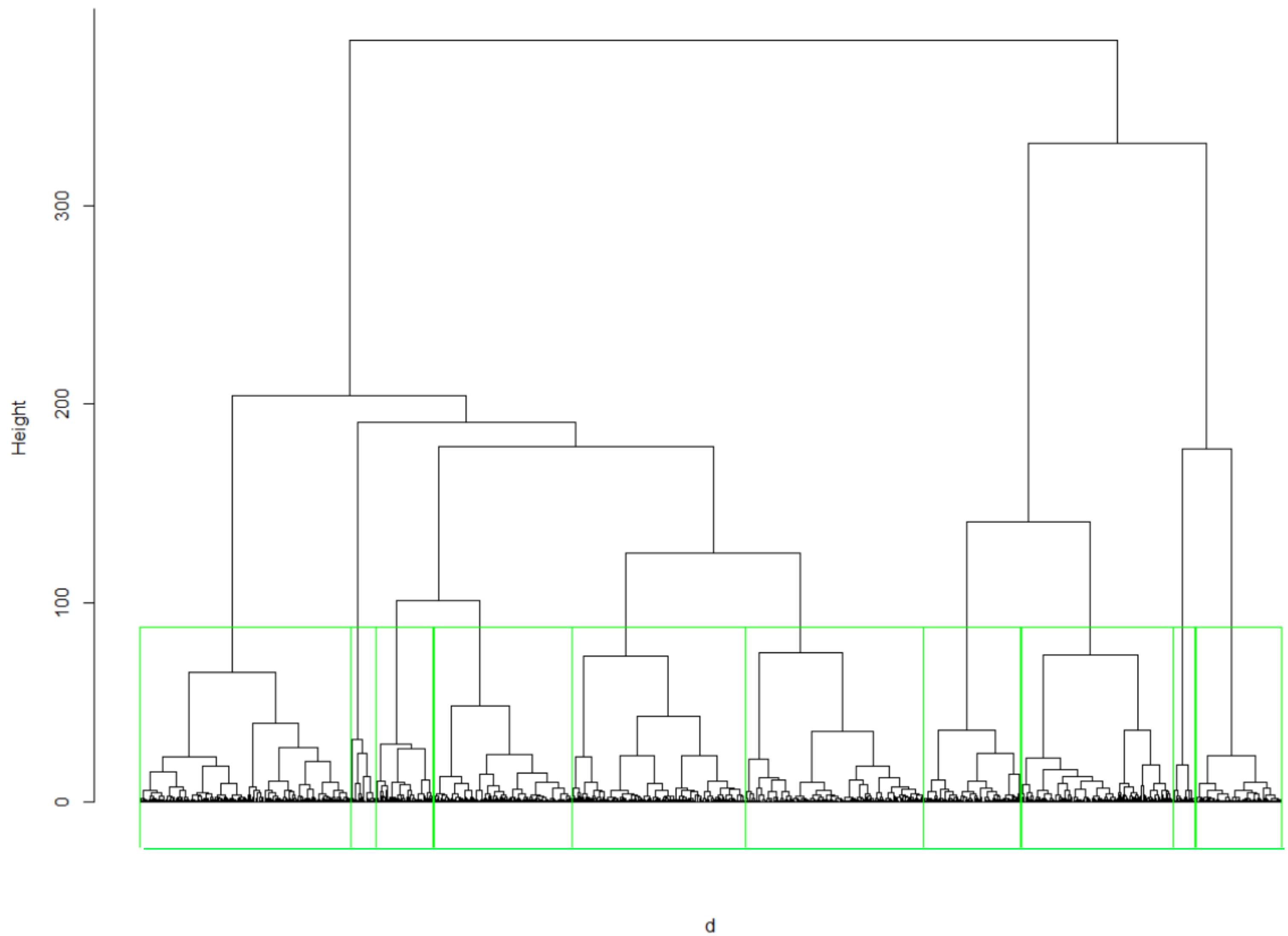



**Figure C-5. Dendrogram.**

### C.5.2.1. Physical Basis of Regions and Flood Characteristics

The spatial distribution of the clusters is considered physically plausible, considering the range in the climate watershed characteristics. Significant regional variations are expected due to the influence of the mountain ranges across the study area (e.g., Coast Mountains, Monashees, the Columbia Trench, and the Rocky Mountains). These orographic effects are expected to control, at least in part, the distribution clusters (Figure C-6).

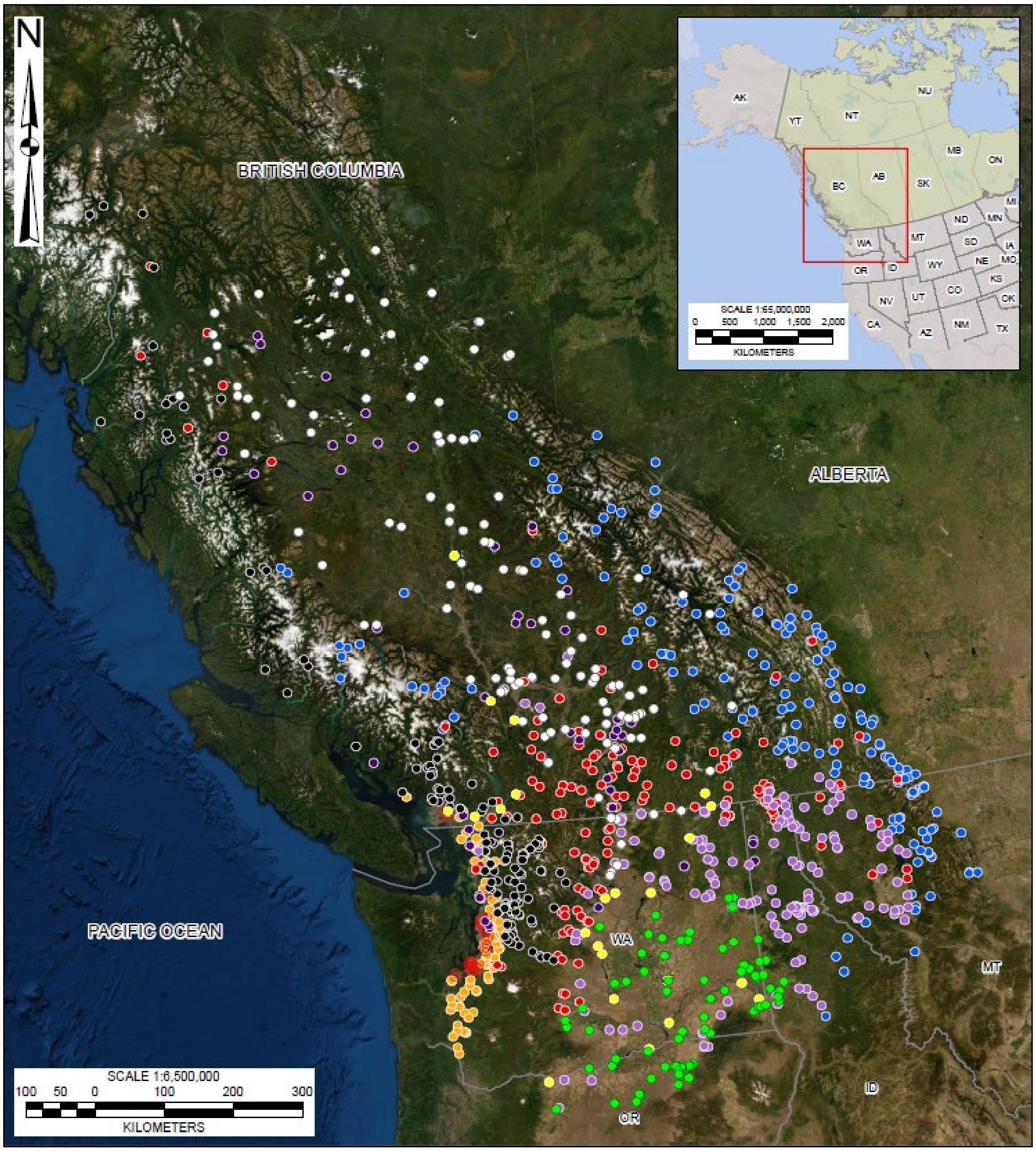



**Figure C-6. Spatial distribution of 10 clusters.**

The clusters that cover the RDCK region include 1 (blue), 4 (red), and 7 (lilac) with 188, 154, and 158 hydrometric stations, respectively. Cluster 1 is defined by the influence of the Rocky Mountains to the east forming the physiographic boundary with Alberta. Most flood events in this cluster are caused by snowmelt or rain-on-snow events in the spring. The eastern range of the Coastal mountains to the west also includes a small group of hydrometric station assigned to Cluster 1. Cluster 4 is defined generally by a climate characteristic of the semi-arid plateau between major mountain ranges. Most flood events are snowmelt dominated in the spring. In this drier climate, evaporation from water surfaces and from the land as well as transpiration from vegetation make up a large component of the regional water balance. Additional hydrometric stations assigned to Cluster 4 are in the montane cordillera to the east where flood events are often associated with rain-on-snow events during the spring freshet. Cluster 7 is defined by the southern edge of the Rocky Mountains in northwestern Montana. Significant floods in this region are caused by runoff from rain associated with moist air masses from the Gulf of Mexico, although most annual peak discharge events are from snowmelt or rain-on-snow events in the spring.

#### C.5.2.2. Manual Adjustments

The clusters were further separated manually due to the large number of hydrometric stations in each cluster. Cluster 1 was separated into the eastern and western ranges of the Rocky Mountains. The small group of hydrometric stations located along the eastern range of the Coastal Mountains were also separated from Cluster 1. Cluster 4 was separated into the eastern portion in the montane cordillera and the western portion in the semi-arid plateau. Cluster 7 was not separated due to the limited geographic spread of the hydrometric stations. Based on these manual adjustments, Cluster 1 West, 4 East, and 7 cover the RDCK region (Figure C-7).

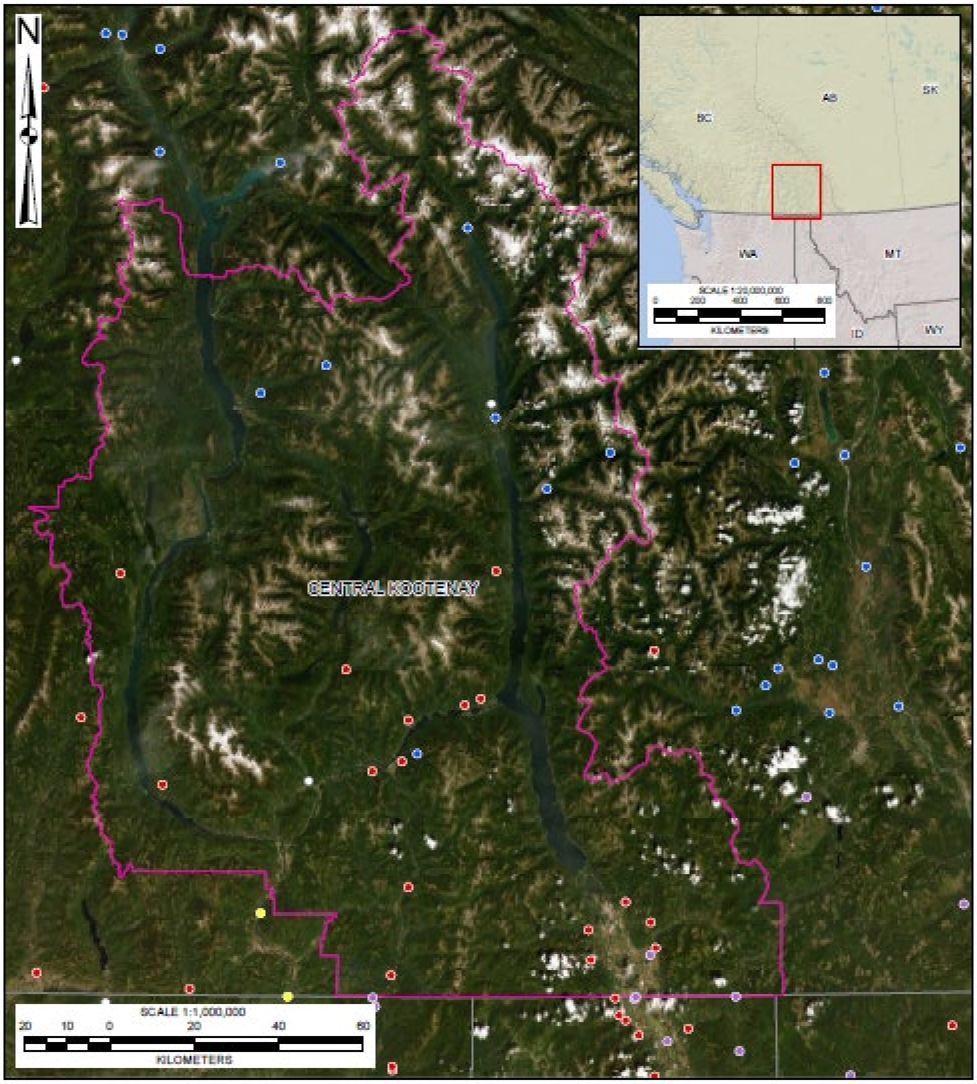



**Figure C-7. Clusters that cover the RDCK region.**

The clusters were further separated based on the scale of watershed area. The coefficient of variation (CV) is required to be constant for a given homogeneous region. A relationship between the watershed area and L-CV is observed in the clusters that cover the RDCK. However, the strength of the relationship varies considerably (Table C-11) In a flood regionalization study in British Columbia, Wang (2000) observed that in L-moment space, the L-CV varied with watershed area for the defined clusters making them heterogeneous. Wang (2000) demonstrated that the small watersheds show an increase and the large watersheds show a decrease in the L-CV

**Table C-11. $R^2$ for regression between watershed area and L-CV**

| Cluster | Number of Hydrometric Stations | R2 for regression between watershed area and L-CV |
|---|---|---|
| 1 West | 88 | 0.01 |
| 4 East | 45 | 0.12 |
| 7 | 158 | 0.15 |

To account for the lack of constancy in the L-CV reported by Wang (2000) and observed in the clusters, the range in the watershed area considered in the study was modified to include two groups: 1) less than 500 km² and 2) more than 500 km² up to 5,000 km². The clusters that cover the RDCK region thus include the following which will be the focus of the results herein.

- Cluster 1 West < 500 km²
- Cluster 1 West > 500 km²
- Cluster 4 West < 500 km²
- Cluster 4 West > 500 km²
- Cluster 7 < 500 km²
- Cluster 7 > 500 km².

### C.5.2.3. Refinement of the Hydrometric Station Selection

The final number of hydrometric stations, including the range of discordancy (*Di*) values, for each hydrologic region is presented in Table C-12. The number of hydrometric stations removed is based on the criteria presented in Section C.4.2.4.

**Table C-12. Final number of hydrometric stations and range in discordancy measure for each hydrologic region.**

| Cluster | Watershed Area Range | Initial Number of Hydrometric Stations | Number of Hydrometric Stations Removed | Final Number of Hydrometric Stations | Di (Min) | Di (Max) | Di (Mean) |
|---|---|---|---|---|---|---|---|
| 1 West | < 500 km² | 36 | 10 | 26 | 0.13 | 3.0 | 1 |
| | > 500 km² | 52 | 28 | 24 | 0.09 | 3.0 | 1 |
| 4 East | < 500 km² | 43 | 9 | 34 | 0.04 | 2.8 | 1 |
| | > 500 km² | 2 | Not enough data for regionalisation | | | | |
| 7 | < 500 km² | 75 | 35 | 40 | 0.09 | 2.6 | 1 |
| | > 500 km² | 83 | 65 | 18 | 0.11 | 2.9 | 1 |

### C.5.2.4. Homogeneity

The H-Test results are summarized in Table C-13. A cluster is declared heterogeneous if H is sufficiently "large". Hosking and Wallis (1997) recommend a cluster be considered "definitely heterogeneous” if H $\geq$ 2. Increasing the threshold implies that more heterogeneous regions are included in the analysis. Guse, Thieken, Castellarin, & Merz (2010) assessed the effect of the H-Test threshold on the performance of probabilistic regional envelope curves in Germany. Increasing the H-Test threshold from 2 to 4 resulted in a larger number of regions considered for analysis. This increase is important as it can include hydrometric stations that would have been excluded otherwise.

The reality is that while removing hydrometric stations may improve the homogeneity of a region, there may be some important reasons why the H-Test score is high. For example, the site may include a hydrometric station where a very large flood occurred. A representative heterogeneous region is better than a region that has been forced to be homogeneous (Robson and Reed 1999).

The physical variability of British Columbia was recognized by Wang (2000) where the average value for the H-Test was 6.85 based on 19 clusters. The physiographic regions in BC may be less distinct than other regions. As a result, the threshold for the H-Test was relaxed to what is practical for British Columbia.

**Table C-13. Number of hydrometric stations, Discordancy values, and H-Test results.**

| Hydrologic Region | Watershed Area Rrange | Number of Hydrometric Stations | H-Test |
|---|---|---|---|
| 1 West | < 500 km$^2$ | 26 | 6.8 |
| | > 500 km$^2$ | 24 | 9.0 |
| 4 East | < 500 km$^2$ | 34 | 13.1 |
| | > 500 km$^2$ | 2 | Not enough data |
| 7 | < 500 km$^2$ | 40 | 4.5 |
| | > 500 km$^2$ | 18 | 7.7 |

## C.5.3. Regionalization

### C.5.3.1. Regional Probability Distributions

The regionally averaged L-moments are presented in Table C-14 for hydrologic region 1 West, 4 East, and 7. For the index-flood procedure, $\iota_1$ is set to 1.

**Table C-14. Regionally averaged L-moments.**

| Hydrologic Region | Watershed Area Range | Number of Hydrometric Stations | $\iota_1$ | $\iota_2$ | $t_3$ | $t_4$ |
|---|---|---|---|---|---|---|
| 1 West | < 500 km$^2$ | 26 | 1 | 0.1796 | 0.2519 | 0.1879 |
| | > 500 km$^2$ | 24 | 1 | 0.1756 | 0.2411 | 0.2012 |
| 4 East | < 500 km$^2$ | 34 | 1 | 0.2364 | 0.2245 | 0.1624 |
| 7 | < 500 km$^2$ | 40 | 1 | 0.3014 | 0.2539 | 0.1904 |
| | > 500 km$^2$ | 18 | 1 | 0.2601 | 0.2138 | 0.1924 |

The Z-statistics for a range of candidate probability distributions is presented in Table C-15. The candidate probability distributions include GLO, GEV, GPA, GNO, and PE3. Probability distributions with Z statistics $\leq$1.64 are deemed acceptable (Hosking & Wallis 1997). All candidate distributions are deemed acceptable for the hydrologic regions that cover the RDCK based on the Z-statistic.

**Table C-15. Goodness of fit Z statistic for probability distribution selection.**

| Hydrological Region | Watershed Area Range | GLO | GEV | GNO | PE3 | GPA |
|---|---|---|---|---|---|---|
| 1 West | < 500 km$^2$ | 1.30 | -0.34 | -1.14 | -2.57 | -4.47 |
| | > 500 km$^2$ | 0.53 | -1.59 | -2.50 | -4.16 | -6.85 |
| 4 East | < 500 km$^2$ | 3.30 | 0.69 | -0.21 | -1.92 | -5.60 |
| 7 | < 500 km$^2$ | 1.41 | -0.59 | -1.59 | -3.38 | -5.66 |
| | > 500 km$^2$ | 0.62 | -1.79 | -2.55 | -4.01 | -7.54 |

To help make the decision on the most representative probability distribution, L-moment diagrams were plotted for each hydrologic region. The $t_3$ and $t_4$ position of the regional average relative to the relationships for five three-parameter (GLO, GEV, GPA, GNP, PE3) and five two-parameter (E, G, L, N, and U) candidate probability distributions are depicted in Figure C-8. The three-parameter probability distributions are depicted by the coloured lines while the two-parameter distributions are depicted by the black squares. The L-skewness and L-kurtosis ratio for each hydrologic region is depicted by the cross symbol on Figure C-8. The GEV probability distribution gives an acceptably close fit to the regional L-moments for the different hydrologic regions. As a result, the GEV probability distribution was deemed representative for all hydrologic regions.

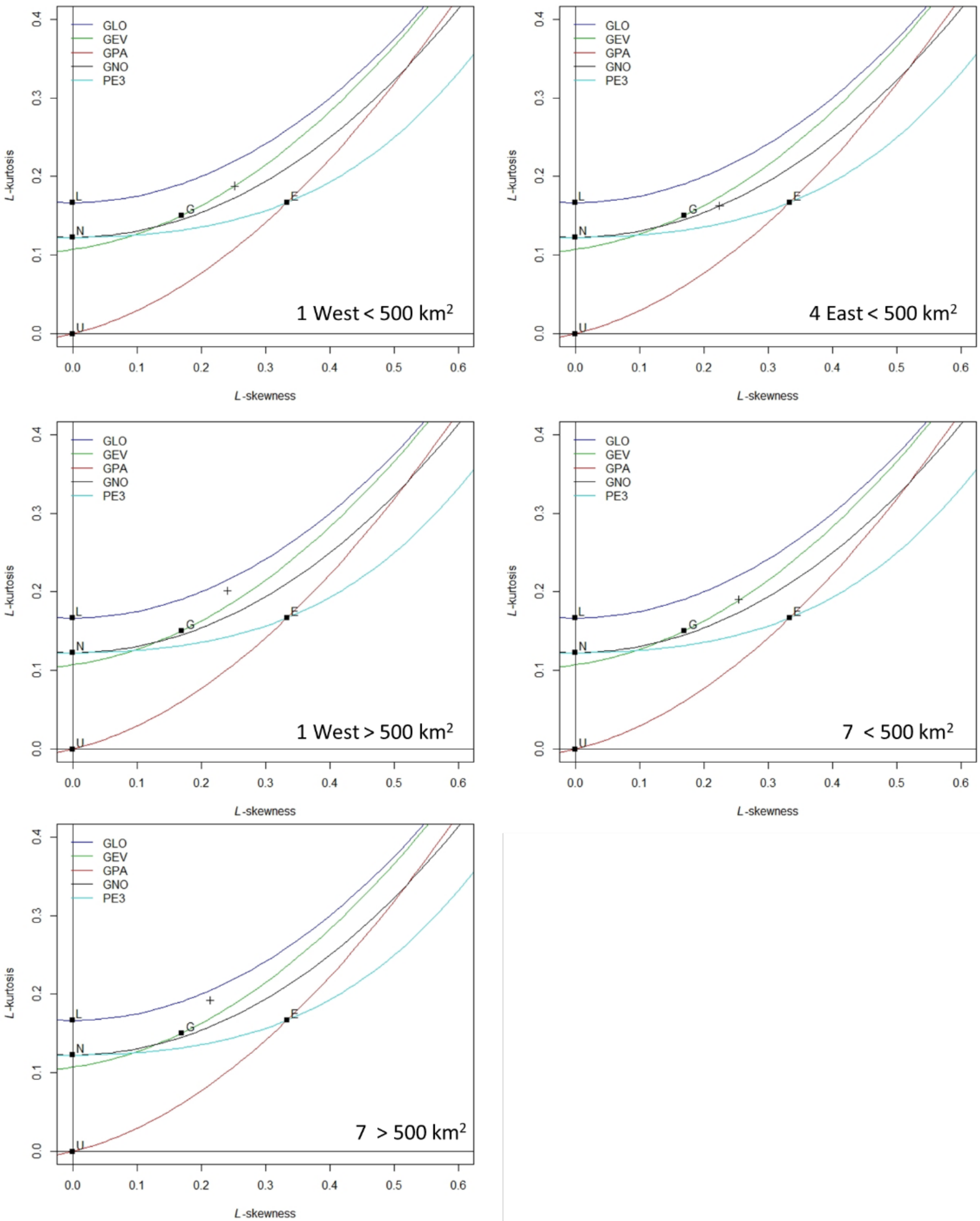



**Figure C-8. L-moment ratio diagram for each hydrologic region.**

### C.5.3.2. Parameter Estimation

The regionally weighted L-moments are used to estimate the parameters of the GEV probability distribution. The parameters for each hydrologic region are presented in Table C-16.

**Table C-16. Parameter estimates for the GEV distribution.**

| Hydrological Region | Watershed Area limit | $\xi$ | $\alpha$ | $\kappa$ |
|---|---|---|---|---|
| 1 West | < 500 km$^2$ | 0.8369 | 0.2280 | -0.1236 |
| | > 500 km$^2$ | 0.8421 | 0.2269 | -0.1078 |
| 4 East | < 500 km$^2$ | 0.7908 | 0.3139 | -0.0832 |
| 7 | < 500 km$^2$ | 0.7257 | 0.3814 | -0.1266 |
| | > 500 km$^2$ | 0.7724 | 0.3513 | -0.0671 |

### C.5.3.3. Growth Curves and Error Bounds

The regional growth curves and error bounds are presented for each region in Figure C-9.

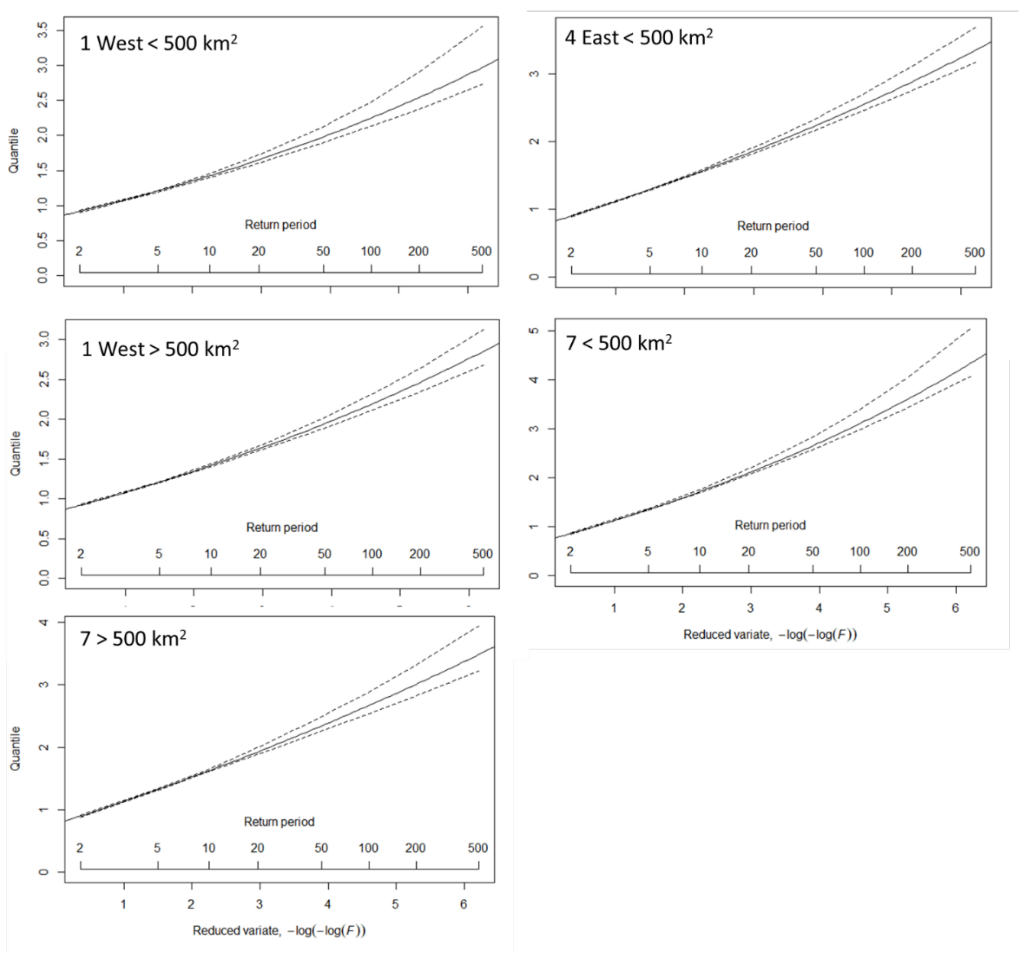



**Figure C-9. Growth curves for each hydrologic region.**

### C.5.3.4. Index Flood

The regional equations for the index-flood for each hydrologic region are presented in Table C-17. The provincial equations are also included at the end of Table C-17. The results are reported to 5 significant figures. However, a total of 5 equations are developed for each hydrologic region and across the province with the intention to average the index-flood estimates. Consequently, the results should be rounded to the nearest unit for flood magnitudes greater than 10 $m^3/s$. The adjusted $R^2$ is included for comparison of the models. Models with more watershed characteristics tend to have a lower adjusted $R^2$ as these models are penalized for increased number of independent variables.

**Table C-17. Regional and provincial equations for the index-flood including the adjusted $R^2$.**

| Hydrologic Region | Watershed Area Range | | Index-flood Equations | Adj. $R^2$ |
|---|---|---|---|---|
| 1 West < 500 km² | 42 to 454 km² | 1 | $\log Q_m = 10.169 + 1.8553(\log Area) - 0.012434(Slope) + 0.098984\,(Cen\_Long) + 0.0055555(PPT_{fl}) + 0.34911(Water\_Wetland)$ | 0.91 |
| | | 2 | $\log Q_m = 12.127 + 1.9358(\log Area) - 0.013271(Slope) + 0.11264\,(Cen\_Long) - 0.00022260(Cen\_Elev) + 0.0053230(PPT_{fl}) + 0.40695(Water\_Wetland)$ | 0.92 |
| | | 3 | $\log Q_m = 6.951 + 1.8564(\log Area) - 0.011048(Slope) + 0.071361\,(Cen\_Long) + 0.0053236(PPT_{fl})$ | 0.90 |
| | | 4 | $\log Q_m = -0.96349 + 1.7509(\log Area) - 0.0095976(Slope) + 0.0043293(PPT_{fl})$ | 0.89 |
| | | 5 | $\log Q_m = -3.2303 + 2.1932(\log Area) + 0.0015075(MAP)$ | 0.88 |
| 1 West > 500 km² | 586 to 4312 km² | 1 | $\log Q_m = -2.5781 + 2.0480(\log Area) + 0.0012740\,(MAP)$ | 0.83 |
| | | 2 | $\log Q_m = -2.3716 + 1.8939(\log Area) + 0.41806(\log Catch\_Length) + 0.0012775(MAP)$ | 0.82 |
| | | 3 | $\log Q_m = 1.3411 + 1.9306(\log Area) + 0.18827(\log Catch\_Length) + 0.0011046\,(MAP) - 0.04866(CN)$ | 0.82 |
| | | 4 | $\log Q_m = -0.70946 + 1.6015(\log Area) - 0.0081664(Slope) + 0.0013574\,(MAP) + 0.057906\,(MAT) - 0.0036032(Forest)$ | 0.83 |
| | | 5 | $\log Q_m = 0.40059 + 1.6514(\log Area) - 0.0082135(Slope) + 0.0010135\,(MAP) + 0.15045\,(MAT) - 0.016425(Forest) - 0.19361(Water\_Wetland)$ | 0.88 |

| Hydrologic Region | Watershed Area Range | Index-flood Equations | | Adj. $R^2$ |
|---|---|---|---|---|
| 4 East < 500 km² | 6 to 441 km² | 1 | $\log Q_m = -3.5763 + 2.7620(\log Area) - 0.15167(MAT) + 0.0035040(PPT_{wt}) - 0.26513(Water\_Wetland)$ | 0.96 |
| | | 2 | $\log Q_m = -4.1636 + 2.7871(\log Area) + 0.0037150(PPT_{wt}) - 0.30562(Water\_Wetland)$ | 0.96 |
| | | 3 | $\log Q_m = -1.8437 + 2.6974(\log Area) + 0.0038(PPT_{wt}) - 0.18063(MAT) + 0.0030438(PPT_{wt}) - 0.28288(Water_{Wetland}) - 0.020392(CN)$ | 0.96 |
| | | 4 | $\log Q_m = -4.0189 + 2.7063(\log Area) + 0.0047397(PPT_{fl}) - 0.3056(Water\_Wetland)$ | 0.95 |
| | | 5 | $\log Q_m = -1.3176 + 2.6880(\log Area) - 0.00069570(MAP) - 0.19022(MAT) + 0.0044279(PPT_{wt})$ | 0.96 |
| 7 < 500 km² | 8 to 471 km² | 1 | $\log Q_m = -3.8856 + 1.8844(\log Area) + 0.010435(PPT_{fl})$ | 0.74 |
| | | 2 | $\log Q_m = -3.9002 + 1.9484(\log Area) + 0.10058(PPT_{fl}) - 0.17007(Water\_Wetland)$ | 0.74 |
| | | 3 | $\log Q_m = -4.4499 + 2.0486(\log Area) + 0.0051660(PPT_{wt}) + 0.0062765(PPT_{sm}) - 0.21014(Water\_Wetland)$ | 0.74 |
| | | 4 | $\log Q_m = -20.730 + 1.7210(\log Area) + 0.36720(Cen\_Lat) - 0.00093400(Cen_{Elev}) + 0.13920(PPT_{sp}) - 0.30900(Water\_Wetland)$ | 0.75 |
| | | 5 | $\log Q_m = -1.9967 + 2.9199(\log Area) - 0.44581(\log Catch\ Length) + 0.22219(Cen\_Lat) + 0.11838(Cen\_Long) + 0.007305(PPT_{wt}) - 0.32687(Water\_Wetland)$ | 0.75 |

| Hydrologic Region | Watershed Area Range | Index-flood Equations | | Adj. $R^2$ |
|---|---|---|---|---|
| **7 >500 km²** | 529 to 4138 km² | 1 | $\log Q_m = -2.8251 + 2.0765(\log Area) - 0.65058(MAT) - 0.01087(PAS) + 0.15245(PPT_{wt}) + 0.014215(PPT_{sm}) + 0.14232(Forest)$ | 0.93 |
| | | 2 | $\log Q_m = 0.51542 + 1.4852(\log Area) - 0.024121(Slope) - 0.0078710(MAP) - 0.69867(MAT) - 0.010055(PAS)$ | 0.93 |
| | | 3 | $\log Q_m = -0.28887 + 2.1311(\log Area) - 0.00048080(Cen_{Elev}) - 0.59076(MAT) - 0.10256(PAS) + 0.14034(PPT_{wt}) + 0.14291(PPT_{sm}) + 0.018084(Forest)$ | 0.94 |
| | | 4 | $\log Q_m = -12.290 + 4.2860(\log Area) - 4.4640(\log Catch\_Length) + 0.54240(Cen\_Lat) + 0.19690(Cen\_Long) - 0.0066490(PAS) + 0.013790(PPT_{wt}) + 0.38640(Forest)$ | 0.94 |
| | | 5 | $\log Q_m = -6.0632 + 2.1265(\log Area) + 0.0053923(PPT_{wt}) + 0.030556(Forest)$ | 0.90 |
| **Provincial Model** | 1 to 4,888 km² | 1 | $\log Q_m = -10.280 + 2.0840(\log Area) - 0.052950(Cen\_Long) + 0.00078170(PAS) + 0.0045490(PPT_{sp}) - 0.077680(Water\_Wetland) + 0.015770(CN)$ | 0.88 |
| | | 2 | $\log Q_m = -10.990 + 2.0900(\log Area) - 0.054870(Cen\_Long) + 0.00079820(PAS) + 0.0045680(PPT_{sp}) + 0.0022550(Forest) - 0.079050(Water\_Wetland) + 0.020340(CN)$ | 0.88 |
| | | 3 | $\log Q_m = -9.7160 + 2.0890(\log Area) - 0.044870(Cen_{Long}) - 0.00015400(Cen\_Elev) + 0.00095000(PAS) + 0.0043910(PPT_{sp}) + 0.0027010(Forest) - 0.081050(Water\_Wetland) + 0.021030(CN)$ | 0.89 |
| | | 4 | $\log Q_m = -8.3390 + 2.0610(\log Area) - 0.047040(Cen_{Long}) + 0.00070070(PAS) + 0.0043090(PPT_{sp}) + 0.0027010(Forest)$ | 0.88 |
| | | 5 | $\log Q_m = -2.7860 + 2.0520(\log Area) - 0.0023640(PPT_{wt}) + 0.0028430(PPT_{sm}) - 0.063700(Water\_Wetland)$ | 0.88 |

### C.5.4. Error Statistics

The weighted standardized error statistics for the regional and provincial model over a range of flood quantiles for the different hydrologic regions are presented in Table C-18. The error statistics are not consistent across all hydrologic regions. The regional model may be selected for the 4 East < 500 km$^2$ hydrologic region. In the case of the 1 West region, either the regional or provincial model would be considered adequate. Lastly, the regional model is probably the model of choice for the 7 hydrologic region. As expected, the error statistics for the lower flood quantiles are lower than those for higher flood quantiles reflecting the increased uncertainty in higher quantile estimates.

**Table C-18. Weighted standardized error statistics for the regional and provincial models over a range of flood quantiles. Green highlighted cells depict a positive bias while the red highlighted cells depict a negative bias.**

| Error Stats | AEP | 1 West < 500 km$^2$ | | 1 West > 500 km$^2$ | | 4 East < 500 km$^2$ | | 7 < 500 km$^2$ | | 7 > 500 km$^2$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Regional Qm | Provincial Qm | Regional Qm | Provincial Qm | Regional Qm | Provincial Qm | Regional Qm | Provincial Qm | Regional Qm | Provincial Qm |
| SRMSE | 0.5 | 0.24 | 0.31 | 0.27 | 0.26 | 0.39 | 0.92 | 2.71 | 3.80 | 0.19 | 0.99 |
| | 0.1 | 0.28 | 0.31 | 0.26 | 0.28 | 0.33 | 0.69 | 3.08 | 4.10 | 0.21 | 0.96 |
| | 0.02 | 0.40 | 0.41 | 0.31 | 0.33 | 0.38 | 0.64 | 3.70 | 4.80 | 0.27 | 1.01 |
| | 0.005 | 0.54 | 0.53 | 0.38 | 0.39 | 0.45 | 0.66 | 4.37 | 5.59 | 0.36 | 1.09 |
| SPercent Error | 0.5 | 18 | 21 | 20 | 21 | 27 | 59 | 70 | 122 | 15 | 65 |
| | 0.1 | 22 | 24 | 20 | 24 | 22 | 45 | 74 | 128 | 14 | 65 |
| | 0.02 | 31 | 32 | 25 | 29 | 27 | 39 | 84 | 144 | 20 | 68 |
| | 0.005 | 42 | 40 | 30 | 33 | 34 | 38 | 97 | 165 | 29 | 74 |
| SBIAS | 0.5 | 0.03 | -0.08 | 0.04 | -0.09 | 0.07 | 0.30 | 0.39 | 1.03 | 0.03 | 0.39 |
| | 0.1 | 0.06 | -0.06 | 0.04 | -0.07 | 0.07 | 0.23 | 0.44 | 1.08 | 0.03 | 0.39 |
| | 0.02 | 0.09 | -0.03 | 0.06 | -0.06 | 0.08 | 0.20 | 0.52 | 1.21 | 0.04 | 0.42 |
| | 0.005 | 0.13 | 0.02 | 0.08 | -0.03 | 0.10 | 0.20 | 0.62 | 1.37 | 0.06 | 0.45 |

## C.6. APPLICATION TO UNGAUGED WATERSHEDS

The goal of the regionalization of floods is to estimate quantiles for ungauged watersheds in the RDCK. A total of 12 watersheds are modeled for clearwater floods. To begin, a watershed polygon was defined for each ungauged watershed, as shown in Figure C-10. The suite of 18 watershed characteristics were then extracted and averaged over the area for each ungauged watershed. The resulting watershed characteristics are presented in Table C-19.

The ungauged watersheds were subsequently assigned to one of the hydrologic regions identified across the study area. The hydrologic region assignment was completed using the Random Forest classification algorithm. Once a hydrologic region was assigned to the ungauged watershed; the index-flood was estimated based on the appropriate model (regional and / or provincial). The flood quantiles were then estimated for a range of AEPs using the index-flood estimate and the appropriate regional growth curve. The hydrologic region assignment, index-flood estimate, and flood quantiles for each ungauged watershed are presented in Table C-20.

The magnitude of the flood quantiles is influenced by the watershed characteristics. This is because the index-flood is calculated using a multiple linear regression that depends on the watershed characteristics that define the best 5 models for a given region. Two watersheds of similar area may have significantly different flood quantile estimates because of major differences in watershed characteristics. For example, Lost Creek and Porcupine Creek share comparable watershed areas of 62 km$^2$ and 68 km$^2$, respectively. However, flood quantiles for Porcupine Creek are 35% greater than Lost Creek, with the difference in magnitude attributed to difference in climate characteristics.

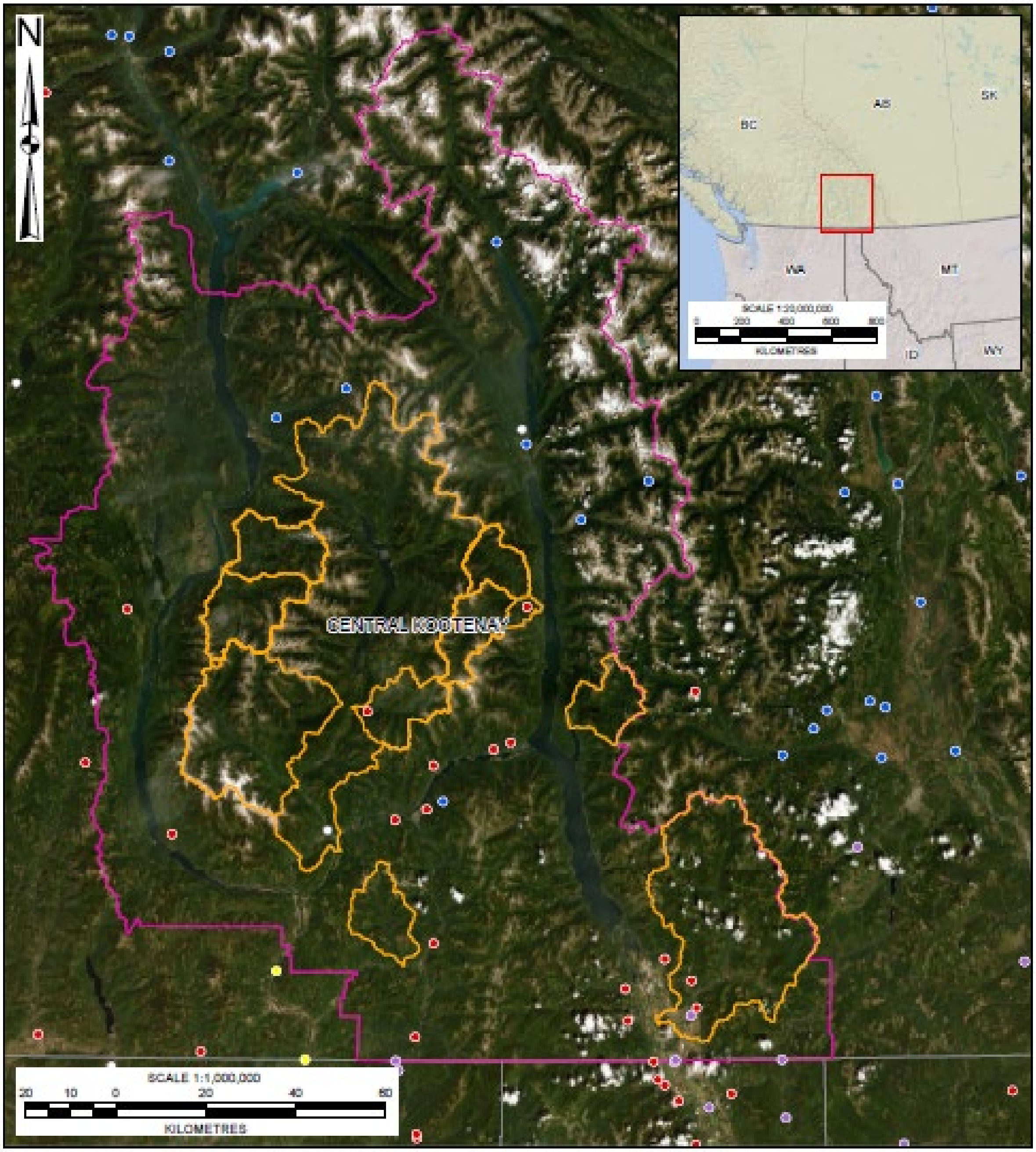



**Figure C-10. Watershed polygons for the ungauged watersheds.**

**Table C-19. Watershed characteristics for the clearwater sites located in the RDCK region.**

| Watershed Name | Area ($km^2$) | Relief (m) | Watershed Length (km) | Slope (%) | Centroid Latitude (degrees) | Centroid Longitude (degrees) | Centroid Elevation (m) | MAP (mm) | MAT (ºC) | PAS (mm) | PPT_wt (mm) | PPT_sp (mm) | PPT_sm (mm) | PPT_fl (mm) | Forest (%) | Water and Wetland (%) | Urban (%) | CN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Crawford Creek | 186 | 2092 | 2.53 | 83 | 49.693818 | -116.700089 | 1181 | 1116 | 3.0 | 590 | 383 | 233 | 198 | 302 | 88 | 0.0 | 0.2 | 70 |
| Keen Creek | 202 | 2066 | 2.37 | 87 | 49.861962 | -117.119617 | 1584 | 1390 | 1.3 | 857 | 460 | 307 | 240 | 384 | 66 | 0.2 | 7.7 | 67 |
| Upper Kaslo Creek | 150 | 1927 | 2.35 | 82 | 49.990505 | -117.046683 | 1182 | 1244 | 2.7 | 668 | 416 | 265 | 223 | 340 | 90 | 0.0 | 0.8 | 70 |
| Kalso Creek at Kootenay Lake | 386 | 2228 | 3.09 | 72 | 49.914818 | -117.077853 | 1280 | 1312 | 2.1 | 756 | 438 | 284 | 230 | 360 | 78 | 0.2 | 4.3 | 68 |
| Lemon Creek | 206 | 2046 | 2.58 | 79 | 49.717145 | -117.338618 | 1956 | 1322 | 2.7 | 754 | 461 | 284 | 206 | 370 | 90 | 0.1 | 0.7 | 65 |
| Burton at Arrow Lake | 530 | 2323 | 4.13 | 56 | 49.952644 | -117.773748 | 1300 | 1242 | 2.4 | 704 | 4280 | 258 | 220 | 336 | 85 | 0.3 | 1.2 | 64 |
| Caribou Creek | 238 | 2235 | 2.97 | 75 | 50.019565 | -117.726695 | 1213 | 1260 | 2.4 | 709 | 432 | 261 | 226 | 341 | 92 | 0.1 | 0.3 | 67 |
| Snow Creek | 291 | 2314 | 3.05 | 76 | 49.897831 | -117.811685 | 1742 | 1227 | 2.3 | 700 | 425 | 255 | 216 | 331 | 80 | 0.3 | 1.8 | 63 |
| Little Slocan River | 818 | 2281 | 5.40 | 42 | 49.664986 | -117.79715 | 1612 | 1161 | 2.8 | 643 | 416 | 245 | 188 | 313 | 82 | 0.5 | 1.7 | 63 |
| Slocan River | 3475 | 2544 | 8.13 | 31 | 49.85497 | -117.525816 | 1196 | 1224 | 3.0 | 666 | 431 | 256 | 206 | 332 | 81 | 2.9 | 2.1 | 66 |
| Goat River | 1259 | 2111 | 6.01 | 35 | 49.28428 | -116.347233 | 1050 | 857 | 3.2 | 433 | 284 | 194 | 163 | 217 | 88 | 0.1 | 0.2 | 69 |
| Erie Creek Upstream End | 201 | 1575 | 2.71 | 58 | 49.288665 | -117.392234 | 1010 | 1265 | 3.8 | 617 | 435 | 286 | 210 | 333 | 95 | 0.0 | 0.0 | 62 |

**Table C-20. Hydrologic region assignment for the ungauged watersheds.**

| Watershed Name | Hydrometric Station | Watershed Area (km²) | Hydrologic Region[1] | Qm (m³/s) | Flood Quantiles | | |
|---|---|---|---|---|---|---|---|
| | | | | | 0.05 AEP (m³/s) | 0.02 AEP (m³/s) | 0.005 AEP (m³/s) |
| Crawford Creek | - | 186 | 7 | 27 | 50 | 61 | 80 |
| Keen Creek | 08NH132 | 202 | pro-rated | - | 78 | 94 | 125 |
| Upper Kaslo Creek | 08NH005 | 150 | pro-rated | - | 99 | 120 | 160 |
| Kaslo Creek at Kootenay Lake | 08NH005 | 386 | pro-rated | - | 160 | 200 | 260 |
| Lemon Creek | 08NJ160 | 206 | pro-rated | - | 72 | 84 | 105 |
| Burton at Arrow Lake | - | 530 | 4 | 80 | 150 | 180 | 230 |
| Caribou Creek | - | 238 | 4 | 42 | 78 | 94 | 120 |
| Snow Creek | - | 291 | 4 | 45 | 83 | 100 | 130 |
| Little Slocan River | | 818 | 4 | 103 | 190 | 230 | 290 |
| Slocan River | 08NJ013 | 3475 | pro-rated | - | 685 | 770 | 880 |
| Goat River | 8NH004 | 1259 | 7 | - | 387 | 430 | 500 |
| Erie Upstream End | - | 201 | 4 | 35 | 65 | 79 | 102 |

Note:

1. A pro-rated calculation is completed when a representative hydrometric station is located upstream or downstream from the ungauged site and has a record length considered long enough for reliable frequency analysis. Flood quantile estimates calculated at the hydrometric station are transferred to the ungauged site by relating the annual maximum peak instantaneous discharge at the hydrometric station to the ungauged site using watershed area size.

## C.7. UNCERTAINTY

The process of flood regionalization is inherently uncertain because of the several limitations. The probability distribution of flood events is unknown. While there are statistical tools to help reach a ‘best estimate’, it is not possible to know what the probability distribution is in practice. As a result, the flood quantile estimates are supported by a mathematical model that is considered reliable based on the available flood data.

The regionalisation of floods tends to underestimate peak discharges for small watersheds and overestimate peak discharges for larger watersheds. This is in part due to differences in hydrological processes that control peak discharges. For example, maximum annual peak instantaneous discharges in small watersheds within the study area are more likely controlled by rainfall compared to larger watershed that tend to be more snowmelt-dominated in the spring. The rainfall control in small watersheds reflects the greater likelihood that a rainfall event, like a convective storm, covers the entire watershed area. In the case for larger watersheds, it is more likely for snowmelt to occur across the entire area in the spring.

While hydrometric stations with watershed areas starting from approximately 6 $km^2$ up to 5,000 $km^2$ are included in the analysis, it is not likely that the equations apply to watersheds if they are either too small or too large. The regional models are only reliable if applied within the range of watershed areas used to build the models in the first place. Extrapolation beyond the limit of the model may yield poor or unreliable results.

The regional models are as reliable as the data that is used to support them. There is inherent measurement error in flood events, especially for larger flood events. Furthermore, the data record may simply be incorrect due to a transcription error. In addition, the measuring device may have been moved to a new location or trends over time may come about from changes in the monitoring device. It is not possible to inspect every record at every hydrometric station to control for these sources of error because so much data are pooled across such a large area.

The same applies to the watershed polygon delineation. Much of the watershed delineation was automated using tools that were developed to speed up this process (RNT and ESRI tools). Manual spot checks were completed in conjunction with quality control of the area by means of comparison with published values. Nevertheless, it was not possible to inspect every watershed polygon to control for delineation errors due to the high number of polygons that were generated for this study. It is expected that these sources of error are negligible next to the quantity of data that is processed across the study area.

Trends in the flood record imposed by climate change, land use change, wildfires, insect infestations, or urban development generally precludes the use of frequency analysis. Trend analyses were completed on the flood record to account for some level of trend. However, the flood record often captures a small window of the flood history at a given location. The limited record makes it difficult to identify a real trend from an artifact of the data record. Therefore, no hydrometric stations were discarded from the analysis due to the presence of a trend in the flood record.

# REFERENCES

Coles, S. (2001). *An Introduction to Statistical Modeling of Extreme Values*. Springer Verlag London Limited. 208 p.

Dalrymple, T. (1960). *Flood Frequency Analysis*. US Geological Survey. Water Supply Paper, 1543 A.

Farr, T.G., et al. (2007), The Shuttle Radar Topography Mission. *Reviews of Geophysics, 45*, RG2004, https://doi.org/10.1029/2005RG000183.

Greenwood, J.A., Lanswehr, J.M., Matalas, N.C., & Wallis, J.R. (1979). Probability weighted moments: Definition and relation to parameters of several distributions expressible in reserve form. *Water Resources Research, 15*, 1049-54.

Guse, B., Thieken, A.H., Castellarin, A., & Merz, B. (2010). Deriving probabilistic regional envelope curves with two pooling methods. *Journal of Hydrology, 380(1-2)*, 14-26. https://doi.org/10.1016/j.jhydrol.2009.10.010

Hosking, J.R.M. (1990). L-moments: Analysis and estimation of distributions using linear combinations of order statistics. *Journal of the Royal Statistical Society, Series B, 52*, 105-24.

Hosking, J.R.M. & Wallis, J.R. (1993). Some statistics useful in regional frequency analysis. *Water Resources Research*, 29, 271-81.

Hosking, J.R.M. & Wallis, J.R. (1997) *Regional Frequency Analysis: An Approach Based on L-moments*. Cambridge University Press, UK. http://dx.doi.org/10.1017/cbo9780511529443

Ouarda, T.B.M.J., St-Hilaire, A., & Bobée, B. (2008). Synthèse des développements récents en analyse régionale des extrêmes hydrologiques. *Journal of Water Sciences, 21*, 219–232. https://doi.org/10.7202/018467ar.

R Core Team. (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Robson, A.J. & Reed, D.J. (1999). Statistical Procedures for Flood Frequency Estimation. Flood Estimation Handbook, vol. 3. Institute of Hydrology, Wallingford, UK.

Ross, C.W., Prihodko, L., Anchang, J., Kumar, S., Ji, W., & Hanan, N.P. (2018). HYSOGs250m, global gridded hydrologic soil groups for curve-number-based runoff modeling. ORNL Distributed Active Archive Center. https://doi.org/10.3334/ORNLDAAC/1566.

Latifovic, R., Homer, C., Ressl, R., Pouliot, D. Hossain, S.N., Colditz, R.R., Olthof, I., Giri, C., & Victoria, A. (2012). North American Land Change Monitoring System. In C. Giri (Ed) *Remote Sensing of Land and Land Cover: Principles and Applications* (p. 303-324). CRC Press.

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

Tasker, G.D. (1982). Comparing methods of hydrologic regionalization. *Water Resources Bulletin, 18*(6), 965-970.

United States Geological Survey (USGS). (1986). *Urban hydrology for small watersheds*. Technical report 55.

Wang, Y. (2000). Development of methods for regional flood estimates in the province of British Columbia (Doctoral dissertation). Retrieved from University of British Columbia. 200 pp.

Wang, T., Hamann, A., Spittlehouse, D., & Carroll, C. (2016). Locally Downscaled and Spatially Customizable Climate Data for Historical and Future Periods for North America. *PLoS ONE 11(6)*: e0156720. https://doi.org/10.1371/journal.pone.0156720

Ward, J.H., Jr. (1963). Hierarchical Grouping to Optimize an Objective Function. *Journal of the American Statistical Association, 58*, 236–244.

Zhang, Z., Stadnyk, T.A., & Burn, D.H. (2019). Identification of a preferred statistical distribution for at-site flood frequency analysis in Canada. *Canadian Water Resources Journal*. https://doi.org/10.1080/07011784.2019.1691942

# APPENDIX D
# CLIMATE CHANGE CONSIDERATIONS

## D.1. INTRODUCTION

The hydroclimate of British Columbia (BC) is complex because of proximity to the Pacific Ocean, mountainous terrain, and extent in latitude. The hydrologic regime is either freshet-dominated (nival regime) or snow-influenced (hybrid nival-pluvial or nival-glacial regimes) throughout most of BC (Eaton & Moore, 2010). Hydrologic trends over recent decades generally include a warming and decreasing snowpack (Kang, Shi, Gao, & Déry, 2014) and earlier onset of spring melt (Déry et al., 2009). The hydrologic response to climate change in BC is expected to be influenced by the regional variability in projected temperature and precipitation changes and by regional variations in physical geography. For example, snow dynamics are strongly influenced by elevation-based temperature gradients resulting in large spatial variations in regions of diverse topography (Schnorbus, Werner, & Bennett, 2014). Also, warmer hybrid nival-pluvial regimes may be more sensitive to changes in regional temperature, precipitation, and rainfall trends (Whitfield, Cannon, & Reynolds, 2002).

Climate change impacts were assessed by BGC for the clearwater watersheds using statistically- and process-based methods. This appendix presents a description of these methodologies and their results. This appendix begins with a description of the anticipated climate change impacts on the hydroclimate within the RDCK (Section D.2). The climate change sensitivity of clearwater watersheds within the region is examined in Section D.3. Finally, an evaluation of the climate change impacts using statistically- and process-based methods for the clearwater watersheds is presented in Section D.4. This appendix ends with a summary of the method that was used to account for the climate change impacts on the hydrology of clearwater watersheds in the RDCK region.

## D.2. CLIMATE CHANGE IMPACTS

### D.2.1. Hydroclimate

Historical changes to climate have been documented in BC (Barnett et al., 2008). While there is a natural variability component to the changes in climate, such as El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), historical trends in western North America have been attributed to climate change in the form of increased regional warming (Barnett et al., 2008).

Climate change is projected to impact the overall mean as well as the extremes for a range of climate variables including temperature, precipitation, snow, and rainfall intensities. Projected change in mean annual precipitation (MAP), temperature (MAT), and precipitation as snow (PAS) from historical conditions (1961 to 1990) for clearwater watersheds across the RDCK region for 2050 (average of years 2041 to 2070) are presented in Table D-1.

The climate-adjusted variables are calculated using projections based on the Representative Carbon Pathway (RCP) 8.5 which are averaged across 15 fifth phase Coupled Model Intercomparison project (CMIP5) models (CanESM2, ACCESS1.0, IPSL-CM5A-MR,MIROC5, MPI-ESM-LR, CCSM4, HadGEM2-ES, CNRM-CM5, CSIRO Mk 3.6, GFDL-CM3, INM-CM4, MRI-CGCM3, MIROC-ESM, CESM1-CAM5, GISS-E2R) that were chosen to represent all major clusters of similar atmosphere-ocean general circulation models (AOGCMs) (Knutti, Massin, & Gettleman, 2013), and that had high validation statistics in their CMIP3 equivalents.

**Table D-1. Projected change (RCP 8.5, 2050) from 1961 to 1990 historical conditions (Wang et al., 2016).**

| Watershed | Change in MAP (mm) | Change in MAT (ºC) | Change in PAS (Snow Water Equivalent, mm) |
|---|---|---|---|
| Crawford Creek | 59 | 3.5 | -206 |
| Keen Creek | 82 | 3.6 | -239 |
| Upper Kaslo Creek | 72 | 3.6 | -231 |
| Kalso Creek at Kootenay Lake | 76 | 3.6 | -233 |
| Lemon Creek | 82 | 3.5 | -252 |
| Burton at Arrow Lake | 73 | 3.5 | -221 |
| Caribou Creek | 75 | 3.5 | -225 |
| Snow Creek | 72 | 3.6 | -217 |
| Little Slocan River | 69 | 3.5 | -215 |
| Slocan River | 74 | 3.5 | -220 |
| Goat River | 40 | 3.5 | -151 |
| Erie Creek Upstream End | 69 | 3.6 | -247 |

Projected changes in average climate variables across the RDCK by 2050 show that there is likely to be:

- A net increase in MAP ranging from 40 mm to 82 mm
- A net increase in MAT ranging from 3.5 ºC to 3.6 ºC
- A net decrease in PAS ranging from 151 mm to 252 mm.

In addition, short-term precipitation extremes (sub-daily) are expected to increase in most of North America with a warming atmosphere. The frequency of extremes increases 5-fold in large parts of Canada in December, January, and February (Figure D-1a). The frequency of extremes decreases to approximately a 2-fold increase in southeast BC in June, July, and August (Figure D-1b). This shift in frequency covers the period January 2001 to September 2013. The increase is due to a shift towards moister and warmer climatic conditions (Prein et al., 2017). Extremes in short-term precipitation contributes to the frequency and magnitude of flood events, especially for small watersheds where soil storage is either low or full (i.e., < 250 km$^2$).

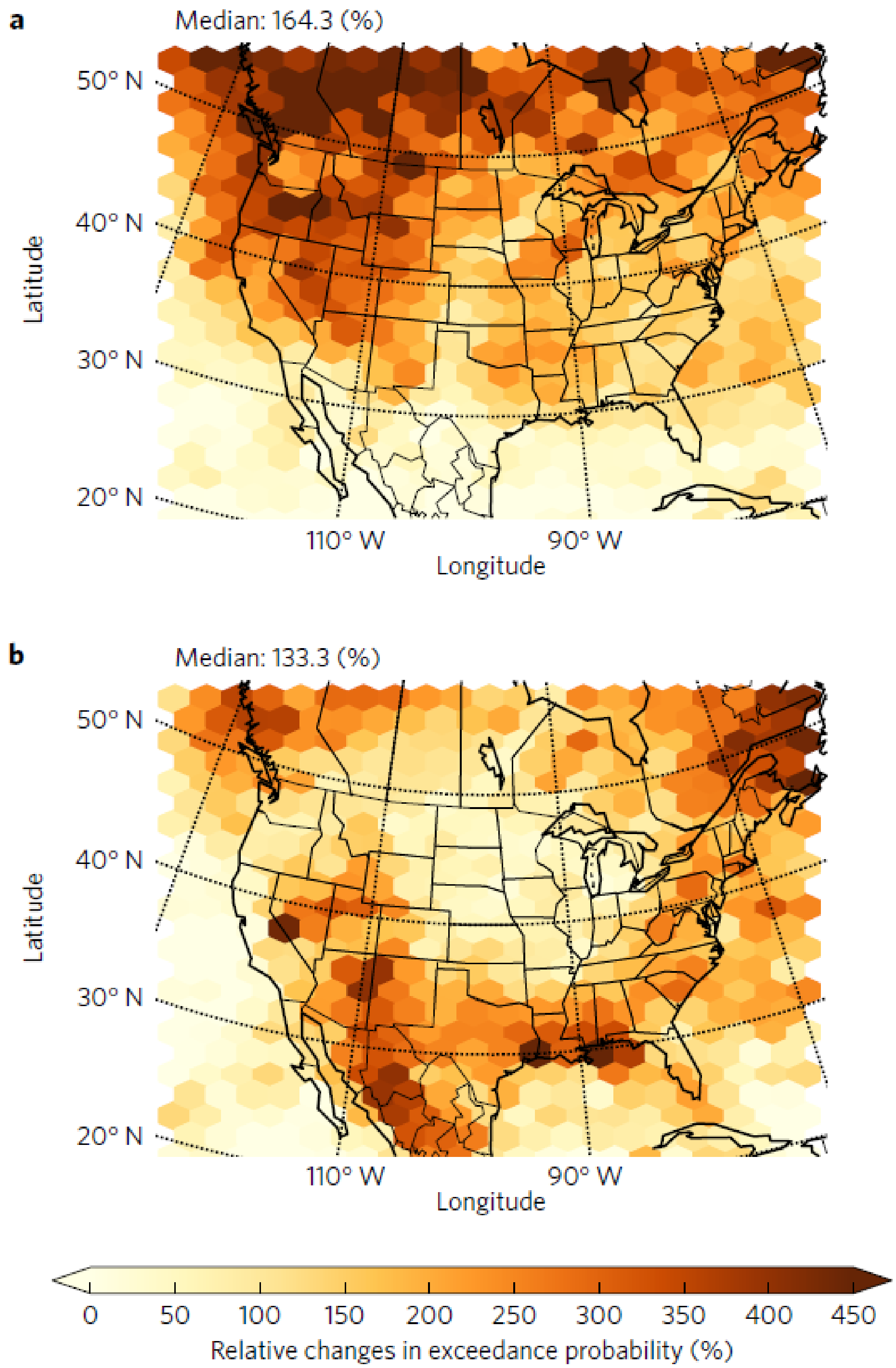



**Figure D-1. Change in the exceedance probability of hourly precipitation intensities for (a) December, January, and February, and (b) June, July, and August (Prein et al., 2017).**

### D.2.2. Peak Discharges

The RDCK is situated within the Montane Cordillera ecozone which covers most of southern BC. Extreme flood events in this area are often associated with rain-on-snow events in the spring (Harder et al., 2015). A hydrograph example where the regime is freshet-dominated is shown in Figure D-2. Although the effects of climate change on precipitation are not clear, projected increases in temperature are expected to have the largest impact on annual minimum temperatures occurring in the winter months (Harder et al., 2015).

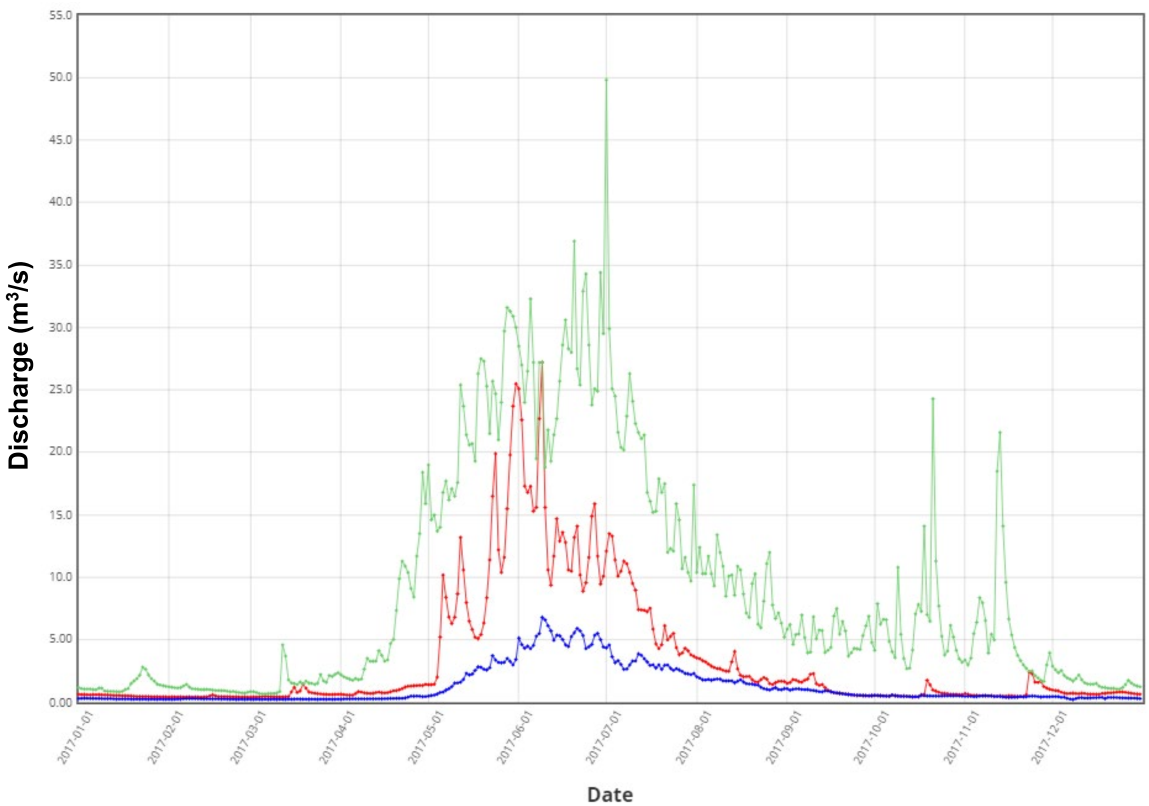



**Figure D-2. Example freshet-driven hydrologic regime for Keen Creek below Kyawats Creek (08NH132). Green line is the maximum discharge, the blue line is the minimum discharge, and the red line is the 2017 discharge.**

The effects of temperature change differ throughout the region. High elevation regions throughout parts of the Montane Cordillera (e.g., Upper Columbia watershed) are projected to experience increases in snowpack, limiting the response in high elevation watersheds while lower elevations are projected to experience a decrease in snow water equivalent (Loukas & Quick, 1999; Schnorbus et al., 2014).

Projected changes in discharge vary spatially and seasonally based on snow and precipitation changes and topography-based temperature gradients. Researchers anticipate that discharge will increase in the winter and spring in the RDCK due to earlier snowmelt and more frequent rain-on-snow events, while earlier peak discharge timing is expected in many rivers (Schnorbus et al., 2014; Farjad, Gupta, & Marceau, 2016).

## D.3. WATERSHED SENSITIVITY

The RDCK includes 6 detailed clearwater study areas (Crawford Creek, Kaslo Creek, Slocan River, Burton Creek, Goat River, and Salmo River). Each study area includes one or more clearwater watersheds that were assessed to inform the floodplain delineation. All clearwater watersheds in the RDCK are characterized by a freshet-dominated regime. Freshet-dominant regimes are characterized by a maximum annual discharge in the spring

In a warmer climate, hydrologic regime shifts are likely to intensify although regional responses are expected due to each watershed's unique characteristics like elevation range and proximity to the 0$^{o}$C air temperature threshold during the cold season. The largest changes in the timing of peak floods would be expected for those areas with a hydrologic regime that shifts from a freshet-dominated to rainfall dominated regime. Therefore, those watersheds with the thinnest snowpacks would be the most sensitive.

The RDCK can be sub-divided into five regions, each with a relatively different, typical snowpack depth (Figure D-3). Two of those five regions cover the clearwater watersheds. The typical snow depths for the clearwater watersheds ranges from moderate snowpack at high elevations for Goat River and Crawford Creek to moderate to deep snowpack for the remaining sites (Table D-2). The elevation range for each clearwater watershed is included in Table D-2 for reference. The clearwater watershed with largest projected change in precipitation as snow by 2050 is Lemon Creek (decrease of 252 mm) followed by Erie Creek Upstream End (decrease of 247 mm) and Keen Creek (decrease of 239 mm) as listed in Table D-1. Hydrographs based on representative hydrometric stations for each study area are presented at the end of the appendix for reference (Figure D-8 to Figure D-11).

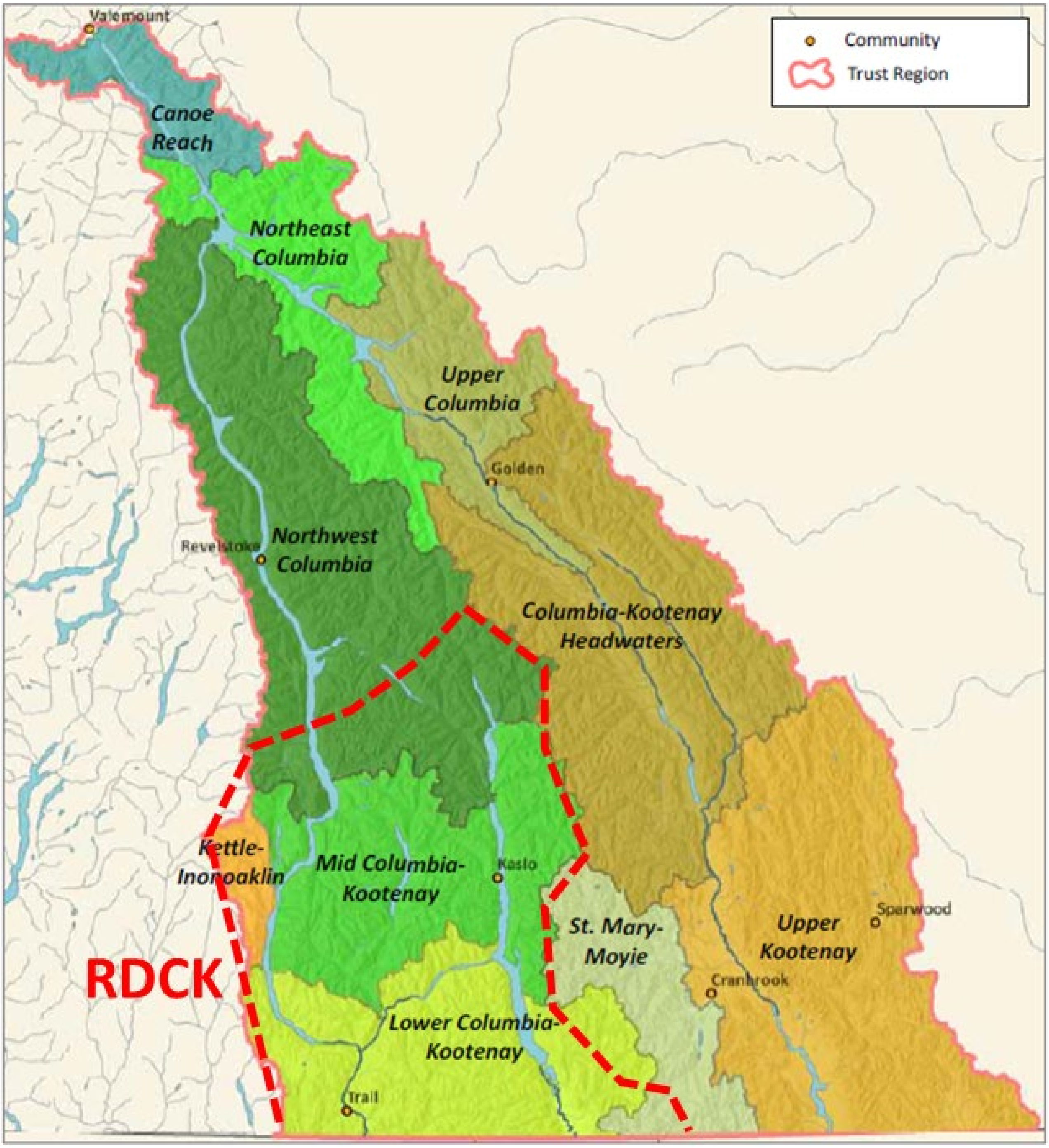



**Figure D-3. Regions of the Columbia Basin as defined by patterns of climate and surface runoff. The RDCK contains 5 of these regions, 2 of which cover the clearwater watersheds (CBT, 2017)**

**Table D-2. Regions of the Columbia Basin covering the RDCK and their current relative snowpack depth (CBT, 2017).**

| Region | Existing Relative Snowpack Depth | Study Area | Representative Hydrometric Station | Clearwater Watersheds | Elevation Range (m) |
|---|---|---|---|---|---|
| Lower Columbia-Kootenay | Moderate snowpack at higher elevations | Goat River | 08NH004 | Goat River | 532 to 2622 |
| | | Salmo River | 08NE074 | Erie Creek Upstream End | 712 to 2287 |
| Mid Columbia-Kootenay | Moderate to deep snowpack | Crawford Creek | ungauged watershed | Crawford Creek | 530 to 2627 |
| | | Kaslo Creek | 08NH005 | Keen Creek | 704 to 2797 |
| | | | | Upper Kaslo Creek | 699 to 2670 |
| | | | | Kalso Creek at Kootenay Lake | 549 to 2785 |
| | | Burton Creek | Ungauged watershed | Snow Creek | 465 to 2731 |
| | | | | Burton at Arrow Lake | 439 to 2785 |
| | | | | Caribou Creek | 1117 to 2630 |
| | | Slocan River | 08NJ013 | Lemon Creek | 538 to 2604 |
| | | | | Little Slocan River | 498 to 2803 |
| | | | | Slocan River | 450 to 2973 |

## D.4. CLIMATE CHANGE IMPACT ASSESSMENT

Assessments of climate change impacts for all clearwater watersheds were performed to quantify the anticipated changes in the annual maximum discharge by 2050 (average between 2041 to 2070) under the RCP 8.5 emission scenario. The Engineers and Geoscientists British Columbia (EGBC) offer guidelines that include procedures to account for climate change when flood magnitudes for protective works or mitigation procedures are required (EGBC, 2018). BGC used four different approaches which can be classified into two statistically-based assessments and two process-based assessments to account for climate change in peak discharge, in consideration of the EGBC guidelines. The legislated guidelines as well as the two statistically-based and the two process-based assessment results are presented in the following sections.

### D.4.1. Legislated Guidelines

The EBGC guidelines recommend that at-site time-series data (precipitation and/or discharge) be analyzed for statistically significant trends in magnitude or frequency. If no at-site data is available, nearby recorded precipitation or discharge records from watersheds of similar characteristics are to be used for assessment.

If a statistically significant trend is not detectable, the guidelines recommend that when regional discharge magnitude frequency relations are used, a 10% upward adjustment in design discharge is to be applied to account for likely future change in water input from precipitation.

If a statistically significant trend is detectable the guidelines recommend three different procedures.

1. For large basins in which the flows are seasonably driven, the flood magnitude and frequency are to be adjusted based on the best available regionally downscaled projections of annual precipitation and snowpack magnitude, assuming that the precipitation increment will all be added to peak runoff. For snowpack, compare projections with historical records of runoff from snowpacks of similar magnitude. Consider potential effects of plausible land use change and combine the effects if considered necessary.
2. For small basins adjust IDF curves for expected future precipitation and apply the results of stormwater runoff modelling appropriate for expected future land surface conditions.
3. Adjust expected flood magnitude and frequency according to the projected change in runoff during the life of the project, or by 20% in small drainage basins for which information of future local conditions is inadequate to provide reliable guidance. Consider potential effects of land use change in the drainage basin.

### D.4.2. Statistically-based Assessment

Two statistically-based methods were developed to assess the effect of climate change on flood quantiles. The first method was based on an examination of the historical annual maximum flood series data to identify statistically significant trends (positive or negative). The second method was based on the index-flood model developed as part of the Regional Flood Frequency Analysis (Regional FFA) (see Appendix C) to estimate the climate-adjusted index flood using climate-adjusted variables derived from downscaled global circulation model (GCM) predictions (Wang et al., 2016). The two methods are described in more detail and results are presented in the following sections.

#### D.4.2.1. Discharge Trend Analysis

Statistical discharge trend analysis on the annual maximum series (AMS)[1] was performed on suitable hydrometric stations (e.g., sufficient period of record, not regulated) located within the watersheds of clearwater study areas and within the hydrological regions formed as part of the Regional FFA.

The presence of a trend (positive or negative) in the AMS was inferred to be caused, at least in part, by climate change. The Mann-Kendall (M-K) statistical test was used to conduct the trend analyses. The M-K test was preferred over alternative statistical tests because it is non-parametric, and therefore does not assume a functional relationship between time and discharge

[1] The Annual Maximum Series (AMS) is a time series of the largest peak discharge for each year.

magnitude. The M-K test detects consistently increasing or decreasing trends in time series. The M-K test examines for an absence of trend in the time series (the null hypothesis) and returns the probability that the null hypothesis (that there is no monotonic trend in the series) is true. Failing the null hypothesis would in turn suggest that there is a statistically significant temporal trend in the time series. The M-K test was applied only to hydrometric stations with periods of records which spanned the year 2000 to ensure the time series included the most current climate.

Although it was assumed that statistically significant trends were at least in part caused by climate change, changes to the watershed's land cover (e.g., wildfire, insect infestations, changes in land use) were considered as possible causes to trends in peak discharges. Furthermore, the peak discharge records often capture a small window of the flood history at a given location. The limited record lengths make it difficult to differentiate between a long-term trend cause by climate change and the intrinsic climate variability captured in the time series. Consequently, the presence of a statistically significant trend in the peak flow time series could not be solely attributed to climate change.

#### D.4.2.2. Assessment of Discharge at Hydrometric Stations within Study Areas

One or more suitable hydrometric stations were identified on the Slocan, Kaslo and Salmo Rivers for trend analysis. A hydrometric station with historical discharge data is available on the Goat River (*Goat River Near Erickson* (08NH004)); however, the data at the hydrometric station cannot be used for assessment of trends as the hydrologic regime of the Goat River is regulated by a dam. Of the six hydrometric stations assessed for the three rivers, none were found to show strong or even weak evidence of a trend in the AMS.

**Table D-3. Trend results for hydrometric stations within the clearwater study areas (where suitable hydrometric station exist).**

| Hydrometric Station | Name | Start Year | End Year | p-value | Trend Direction | Sen's Slope[1] |
|---|---|---|---|---|---|---|
| | **Slocan River** | | | | | |
| 08NJ013 | Slocan River Near Crescent Valley | 1914 | 2018 | 0.18 | - | 0.48 |
| 08NJ160 | Lemon Creek Above South Lemon Creek | 1973 | 2017 | 0.23 | - | 0.17 |
| **Kaslo River** | | | | | | |
| 08NH005 | Kaslo River Below Kemp Creek | 1972 | 2017 | 0.32 | - | -0.21 |
| 08NH132 | Keen Creek Below Kyawats Creek | 1974 | 2016 | 0.79 | - | 0.04 |
| **Salmo River** | | | | | | |
| 08NE074 | Salmo River Near Salmo | 1949 | 2018 | 0.47 | - | -0.29 |
| 08NE114 | Hidden Creek Near the Mouth | 1973 | 2016 | 0.73 | - | 0.02 |

### D.4.2.2.1 Assessment of Discharge Trends within Homogenous Regions

Each clearwater watershed was assigned to a homogeneous region as part of the Regional FFA formed using cluster analysis. (see Section 4.5 in Appendix C). A trend analysis was performed on the annual peak discharge time series recorded at the hydrometric stations located within the homogeneous region assigned to the clearwater watersheds

#### *D.4.2.2.1.1 1 West – for Watersheds < 500 km$^2$*

Within the "1 West – for watersheds less than 500 km$^2$" hydrological region, one hydrometric station out of 15 reported a statistically significant trend ($p < 0.05$ - less than a 5% chance of rejecting the null hypothesis) in the flood series: *Kuskanax near Nakusp* (08NE006). The trend in the magnitude of the flood series for that station was in the decreasing direction (Table D-4).

**Table D-4. Trend results for the hydrometric stations in the 1 West – for watersheds < 500 km$^2$ hydrologic region.**

| Hydrometric Station Code | Start Year | End Year | p-value | Trend Direction | Sen's Slope[1] |
|---|---|---|---|---|---|
| 08LB038 | 1985 | 2016 | 0.246 | - | 0.33 |
| 08NP004 | 1995 | 2017 | 0.239 | - | 0.13 |
| 08NH131 | 1973 | 2004 | 0.444 | - | 0.19 |
| 08KA001 | 1969 | 2013 | 0.738 | - | 0.06 |
| 08NJ168 | 1983 | 2014 | 0.475 | - | 0.04 |
| 08NB014 | 1973 | 2017 | 0.431 | - | -0.25 |
| 08NH132 | 1974 | 2016 | 0.795 | - | 0.04 |
| 08ND019 | 1973 | 2005 | 0.650 | - | 0.13 |
| 08NE006 | 1968 | 2011 | 0.006 | Decreasing* | -1.33 |
| 08NK022 | 1977 | 2015 | 0.143 | - | -0.19 |
| 08NG076 | 1973 | 2017 | 0.314 | - | 0.07 |
| 08KA009 | 1967 | 2018 | 0.881 | - | -0.04 |
| 08KB006 | 1978 | 2015 | 0.386 | - | 0.20 |
| 08LE086 | 1997 | 2016 | 1.000 | - | 0.00 |
| 08KA010 | 1908 | 2015 | 0.118 | - | -0.25 |

Notes:

1. The Sen's slope is a robust estimate of the magnitude of a trend and commonly used to identify the slope of a trend line in hydrological time series (Yue et al. 2002). It is considered robust because it is sensitive to outliers.

* Strong evidence of trend ($p < 5\%$) – less than 5% chance that the null hypothesis – that there is no trend – is true.

** Weak evidence of trend ($p < 10\%$)– less than 10% chance that the null hypothesis – that there is no trend – is true.

### *D.4.2.2.1.2 1 West – for Watersheds > 500 km$^2$*

Within the "1 West – for watersheds greater than 500 km$^2$" hydrological region, one out of 15 hydrometric stations reporting a statistically significant trend in the flood series (*Fraser River at Red Pass*, 08KA007) with a trend in the decreasing direction (Table D-5).

**Table D-5. Trend results for the hydrometric stations in the 1 West – for watersheds > 500 km² hydrologic region.**

| Hydrometric Station Code | Start Year | End Year | p-value | Trend Direction | Sen's Slope[1] |
|---|---|---|---|---|---|
| 08NB019 | 1985 | 2018 | 0.836 | - | 0.20 |
| 08NB012 | 1970 | 2017 | 0.818 | - | 0.11 |
| 08LE024 | 1973 | 2017 | 0.143 | - | -1.07 |
| 08NP001 | 1929 | 2017 | 0.845 | - | -0.06 |
| 08NK018 | 1973 | 2015 | 0.530 | - | -0.23 |
| 08KA007 | 1955 | 2016 | 0.016 | Decreasing* | -0.81 |
| 08NH130 | 1973 | 2012 | 0.990 | - | 0.00 |
| 08ND012 | 1964 | 2018 | 0.670 | - | -0.11 |
| 08ND013 | 1964 | 2017 | 0.228 | - | 0.72 |
| 08NA006 | 1912 | 2017 | 0.317 | - | -0.61 |
| 12358500 | 1940 | 2017 | 0.623 | - | -0.45 |
| 08KA013 | 1998 | 2017 | 0.576 | - | 3.25 |
| 12355500 | 1911 | 2017 | 0.857 | - | -0.11 |
| 08LE027 | 1915 | 2017 | 0.598 | - | 0.15 |
| 08NA011 | 1949 | 2018 | 0.319 | - | -0.36 |

Notes:

1. The Sen’s slope is a robust estimate of the magnitude of a trend and commonly used to identify the slope of a trend line in hydrological time series (Yue et al. 2002). It is considered robust because it is sensitive to outliers.

* Strong evidence of trend ($p < 5\%$) – less than 5% chance that the null hypothesis – that there is no trend – is true.

** Weak evidence of trend ($p < 10\%$)– less than 10% chance that the null hypothesis – that there is no trend – is true.

### *D.4.2.2.1.3 4 East – for Watersheds < 500 km²*

Within the “4 East – for watersheds less than 500 km²” hydrological region, 19 hydrometric stations were analysed for presence of a trend (Table D-6). The M-K test identified two stations as having statistically significant trends in their time series with the first showing an increasing trend (*Boundary Creek near Porthill Idaho,* 12321500) and the second showing a decreasing trend (*Arrow Creek near Erickson*, 08NH084). Two other stations, *Redfish Creek near Harrop* (08NJ061) and *Outlet Creek near Metaline Falls* (12397100), were found to have marginally statistically significant decreasing trends ($p < 0.1$ - less than a 10% chance of rejecting the null hypothesis), while *St-Mary River below Morris Creek* (08NG077) was found to have a marginally statistically significant increasing trend ($p < 0.1$).

**Table D-6. Trend results for the hydrometric stations in the 4 East – for Watersheds > 500 km² hydrologic region.**

| Hydrometric Station Code | Start Year | End Year | p-value | Trend Direction | Sen's Slope[1] |
|---|---|---|---|---|---|
| 08NK026 | 1986 | 2018 | 0.332 | - | -0.01 |
| 08NJ130 | 1945 | 2017 | 0.177 | - | 0.01 |
| 12321500 | 1929 | 2017 | 0.002 | Increasing** | 0.23 |
| 08NH084 | 1980 | 2015 | 0.009 | Decreasing** | -0.30 |
| 08NH005 | 1972 | 2017 | 0.322 | - | -0.21 |
| 08NE110 | 1971 | 2015 | 0.567 | - | 0.14 |
| 08NJ061 | 1968 | 2017 | 0.052 | Decreasing** | -0.06 |
| 08NG077 | 1973 | 2017 | 0.083 | Increasing* | 0.50 |
| 08NN023 | 1974 | 2015 | 0.555 | - | -0.12 |
| 08NE087 | 2001 | 2017 | 0.964 | - | -0.01 |
| 08NH016 | 1947 | 2017 | 0.504 | - | -0.02 |
| 08NJ160 | 1973 | 2017 | 0.229 | - | 0.17 |
| 12313000 | 1928 | 2002 | 0.386 | - | 1.58 |
| 08NJ026 | 1995 | 2017 | 0.239 | - | 0.13 |
| 12397100 | 1959 | 2015 | 0.065 | Decreasing* | -0.07 |
| 08NE114 | 1973 | 2016 | 0.727 | - | 0.02 |
| 08NE039 | 1930 | 2017 | 0.507 | - | -0.06 |
| 12304040 | 1990 | 2000 | 0.533 | - | 0.43 |
| 08NH115 | 1964 | 2017 | 0.303 | - | 0.00 |

Notes:

1 The Sen's slope is a robust estimate of the magnitude of a trend and commonly used to identify the slope of a trend line in hydrological time series (Yue et al. 2002). It is considered robust because it is sensitive to outliers.

* Strong evidence of trend ($p < 5\%$) – less than 5% chance that the null hypothesis – that there is no trend – is true.

** Weak evidence of trend ($p < 10\%$)– less than 10% chance that the null hypothesis – that there is no trend – is true.

### *D.4.2.2.1.4 7 – for Watersheds > 500 km²*

Within the "7 – for watersheds greater than 500 km²" hydrological region, 17 hydrometric stations were analysed for presence of a trend (Table D-7). The M-K test identified three USGS stations as having statistically significant decreasing trends in their time series: *Thompson River near Thompson Falls MT* (12389500), *Yaak River near Troy MT* (12304500), and *Yakima River at Umtanum, WA* (12484500). One other station, *Colville River at Kettle Falls, WA* (12409000), was found to have a marginally statistically significant increasing trend ($p < 0.1$).

**Table D-7. Trend results for the hydrometric stations in the 7 – for Watersheds > 500 $km^2$ hydrologic region.**

| Hydrometric Station Code | Start Year | End Year | p-value | Trend Direction | Sen's Slope[1] |
|---|---|---|---|---|---|
| 13339500 | 1980 | 2017 | 0.237 | - | 0.61 |
| 12414900 | 1966 | 2017 | 0.185 | - | 0.67 |
| 12433890 | 1972 | 2012 | 0.553 | - | 0.43 |
| 12354000 | 1911 | 2017 | 0.129 | - | -0.98 |
| 12388200 | 1990 | 2010 | 0.124 | - | 0.77 |
| 12301300 | 1948 | 2016 | 0.189 | - | -0.15 |
| 12365000 | 1931 | 2006 | 0.528 | - | -0.08 |
| 12306500 | 1930 | 2017 | 0.983 | - | 0.00 |
| 12389500 | 1948 | 2017 | 0.044 | Decreasing* | -0.55 |
| 12370000 | 1922 | 2017 | 0.290 | - | -0.15 |
| 12304500 | 1948 | 2017 | 0.006 | Decreasing* | -1.37 |
| 12302055 | 1948 | 2017 | 0.408 | - | -0.35 |
| 12413000 | 1912 | 2017 | 0.542 | - | 0.75 |
| 12409000 | 1923 | 2017 | 0.076 | Increasing** | 0.13 |
| 12414500 | 1911 | 2017 | 0.935 | - | 0.00 |
| 12413500 | 1911 | 2017 | 0.125 | - | 1.67 |
| 12484500 | 1906 | 2017 | 0.021 | Decreasing* | -0.70 |

Notes:

1 The Sen's slope is a robust estimate of the magnitude of a trend and commonly used to identify the slope of a trend line in hydrological time series (Yue et al. 2002). It is considered robust because it is sensitive to outliers.

* Strong evidence of trend ($p < 5\%$) – less than 5% chance that the null hypothesis – that there is no trend – is true.

** Weak evidence of trend ($p < 10\%$)– less than 10% chance that the null hypothesis – that there is no trend – is true.

### D.4.2.3. Statistical Flood Frequency Modelling

A statistical approach to estimating flood quantiles for the clearwater watersheds was performed using the Regional FFA model. The multivariate regression model to estimate the index-flood (mean annual peak discharge) included three climatic variables as predictors: MAP, MAT, and PAS. This regression model was calibrated using historical values of climatic variables, thus representing current conditions.

To estimate the climate-adjusted index flood for 2050, projected values of the climatic variables were input to the regression model. These projected values were estimated from model ensemble results for the RCP 8.5 emissions scenario using the ClimateNA v5.10 software package, available at http://tinyurl.com/ClimateNA, and based on the methodology described by Wang et al. (2016). The historical and climate-adjusted MAP, MAT, and PAS for the clearwater watersheds in the RDCK region are presented in Table D-8.

**Table D-8. Climate variables used in the index flood quantile regression model with historical and climate-adjusted values for the clearwater watersheds in the RDCK.**

| Study Area | Watershed | MAP | | MAT | | PAS | |
|---|---|---|---|---|---|---|---|
| | | Historical Value | Climate-adjusted | Historical Value | Climate-adjusted | Historical Value | Climate-adjusted |
| Crawford Creek | Crawford Creek | 1116 | 1175 | 3.0 | 6.4 | 590 | 384 |
| Kaslo Creek | Keen Creek | 1390 | 1472 | 1.3 | 4.9 | 857 | 618 |
| | Upper Kaslo Creek | 1244 | 1316 | 2.7 | 6.3 | 668 | 437 |
| | Kalso Creek at Kootenay Lake | 1312 | 1389 | 2.1 | 5.7 | 756 | 523 |
| Burton Creek | Burton at Arrow Lake | 1242 | 1315 | 2.4 | 5.9 | 704 | 483 |
| | Caribou Creek | 1259 | 1334 | 2.4 | 6.0 | 709 | 484 |
| | Snow Creek | 1227 | 1299 | 2.3 | 5.8 | 700 | 483 |
| Slocan River | Little Slocan River | 1161 | 1230 | 2.8 | 6.3 | 643 | 428 |
| | Lemon Creek | 1322 | 1404 | 2.7 | 6.3 | 754 | 503 |
| | Slocan River | 1224 | 1297 | 3.0 | 6.6 | 666 | 446 |
| Goat River | Goat River | 857 | 897 | 3.2 | 6.7 | 433 | 282 |
| Salmo River | Erie Creek Upstream End | 1265 | 1334 | 3.8 | 7.4 | 617 | 371 |

Note:
1. The ensemble model projections are averages across 15 CMIP5 models (CanESM2, ACCESS1.0, IPSL-CM5A-MR, MIROC5, MPI-ESM-LR, CCSM4, HadGEM2-ES, CNRM-CM5, CSIRO Mk 3.6, GFDL-CM3, INM-CM4, MRI-CGCM3, MIROC-ESM, CESM1-CAM5, GISS-E2R).

Climate-adjusted flood quantiles were calculated using the climate-adjusted index flood and the regional growth curves. The regional growth curves are assumed to be stationary. The ratio between the magnitude of the index-flood and the other flood quantiles was assumed to be the same in a climate-adjusted context. The regional growth curves are presented in the Regional FFA (Appendix C). Historical and climate-adjusted flood quantiles are summarized in Table D-9. Results show a small decrease in magnitude between the historical and climate-adjusted flood quantiles. Examination of the regression model for the index flood revealed that both the MAP and PAS were dominant predictors. The increase in the MAP was found to offset the decrease in the PAS resulting in little change in the estimate of the climate-adjusted index flood.

**Table D-9. Historical and climate-adjusted flood quantiles for clearwater watersheds in the RDCK.**

| Study Area | Clearwater Watershed | Index-flood | | 2-year return period (0.5 AEP) | | 20-year return period (0.05 AEP) | | 200-year return period (0.005 AEP) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Historical ($m^3/s$) | Climate-adjusted ($m^3/s$) | Historical ($m^3/s$) | Climate-adjusted ($m^3/s$) | Historical ($m^3/s$) | Climate-adjusted ($m^3/s$) | Historical ($m^3/s$) | Climate-adjusted ($m^3/s$) |
| Crawford Creek | Crawford Creek | 27 | 27 | 25 | 24 | 50 | 49 | 78 | 76 |
| Kaslo Creek | Keen Creek | 45 | 45 | 42 | 41 | 75 | 74 | 115 | 114 |
| | Upper Kaslo Creek | 38 | 37 | 34 | 34 | 70 | 68 | 109 | 106 |
| | Kalso Creek at Kootenay Lake | 81 | 80 | 74 | 73 | 150 | 148 | 234 | 230 |
| Burton Creek | Burton at Arrow Lake | 81 | 79 | 73 | 71 | 149 | 145 | 232 | 227 |
| | Caribou Creek | 42 | 41 | 38 | 37 | 78 | 76 | 121 | 119 |
| | Snow Creek | 45 | 44 | 41 | 40 | 83 | 81 | 129 | 126 |
| Slocan River | Little Slocan River | 103 | 100 | 94 | 91 | 191 | 186 | 297 | 289 |
| | Lemon Creek | 39 | 38 | 35 | 34 | 72 | 69 | 111 | 108 |
| | Slocan River | 347 | 339 | 315 | 308 | 642 | 627 | 1000 | 977 |
| Goat River | Goat River | 110 | 109 | 100 | 98 | 172 | 170 | 317 | 312 |
| Salmo River | Erie Creek Upstream End | 35 | 34 | 32 | 31 | 65 | 63 | 102 | 97 |

Note:
Final flood quantiles for Upper Kaslo Creek, Kaslo Creek at Kootenay Lake, Lemon Creek, Little Slocan River, Slocan River, and Goat River were estimated using a pro-rated calculation because they are gauged by a hydrometric station. The flood quantiles reported in Table D-9 were not used for subsequent analysis.

### D.4.3. Process-based Assessment

To complement the statistical assessment, results from process-based modelling were examined. Process-based models involve the direct application of the downscaled GCM model forecasts into hydrological models. Process-based assessments are better suited for situations where a threshold change in process is likely e.g., a transition from nival (snowmelt dominated) runoff regime to a pluvial-hybrid (snow influenced) runoff regime.

#### D.4.3.1. Climate-adjusted Discharge

PCIC provides simulated daily discharge time series for over 120 sites located in the Peace, upper Columbia, Fraser, and Campbell River watersheds. The time series are simulated at Water Survey of Canada (WSC) hydrometric stations and BC Hydro project sites. The simulated time series represent naturalized flow conditions (i.e., with effects of upstream regulation removed) for those sites affected by storage regulation. The hydrologic projections were forced with GCM data downscaled to a 1/16-degree resolution using Bias-Correction Spatial Disaggregation (BCSD) (Wood et al., 2004) following Werner (2011). Application of the Variable Infiltration Capacity (VIC) model and the generation of hydrologic projections for the Peace, Fraser, upper Columbia, and Campbell River watersheds are described in Shrestha et al. (2012) and Schnorbus et al. (2011, 2014).

An ensemble of 8 models forecasting daily discharge time series for locations near the study area was accessed from PCIC's website. This included forecasted time series on the Slocan and Salmo Rivers, specifically:

- Slocan River Near Crescent Valley (08NJ013)
- Salmo River Near Salmo (08NE074).

The RCP 8.5 emissions scenario was not available for this dataset so the IPCC A2 Emission Scenario (business as usual) was selected as the most similar. The 200-year flood quantile was assessed for three periods between 2009-2038, 2039-2068 and 2069-2098 and compared to the 200-year flood quantile based on the historical modelling (1955-2009). Maps showing the trend in the 200-year flood for the PCIC assessed sites and the location of the clearwater watersheds in the study for the three periods are shown in Figures D--4 to D-6 for the three periods assessed.

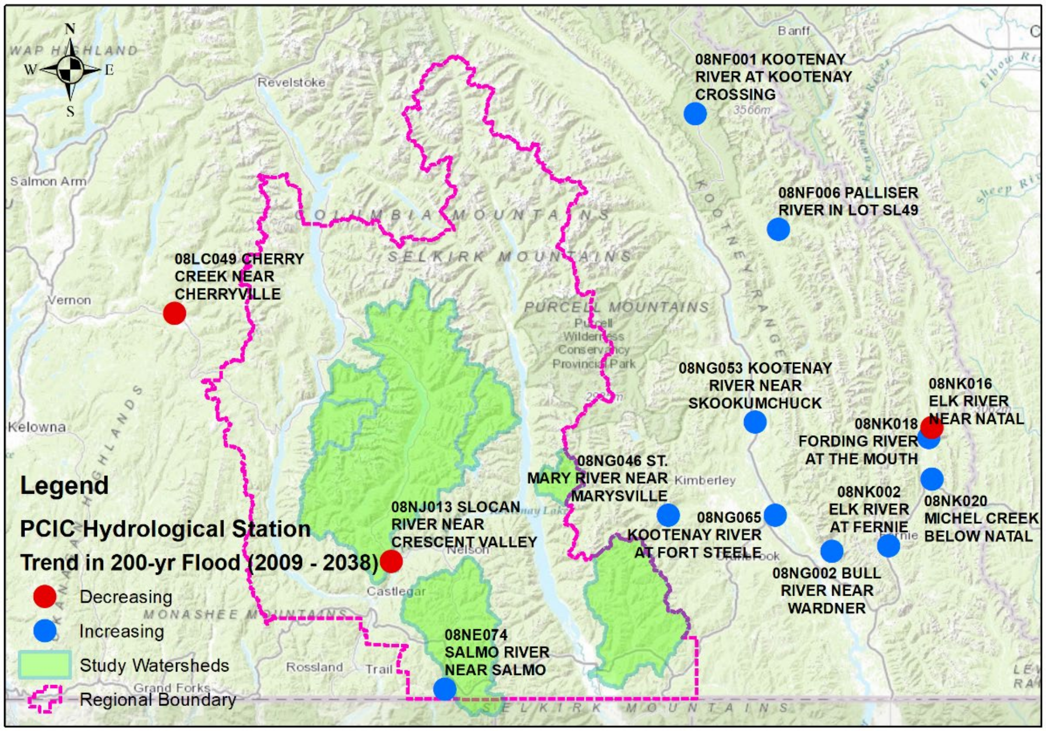



**Figure D-4.** **Map showing nearby the PCIC hydrometric stations examined and their trend in the 200-year flood (period between 2009-2038).**

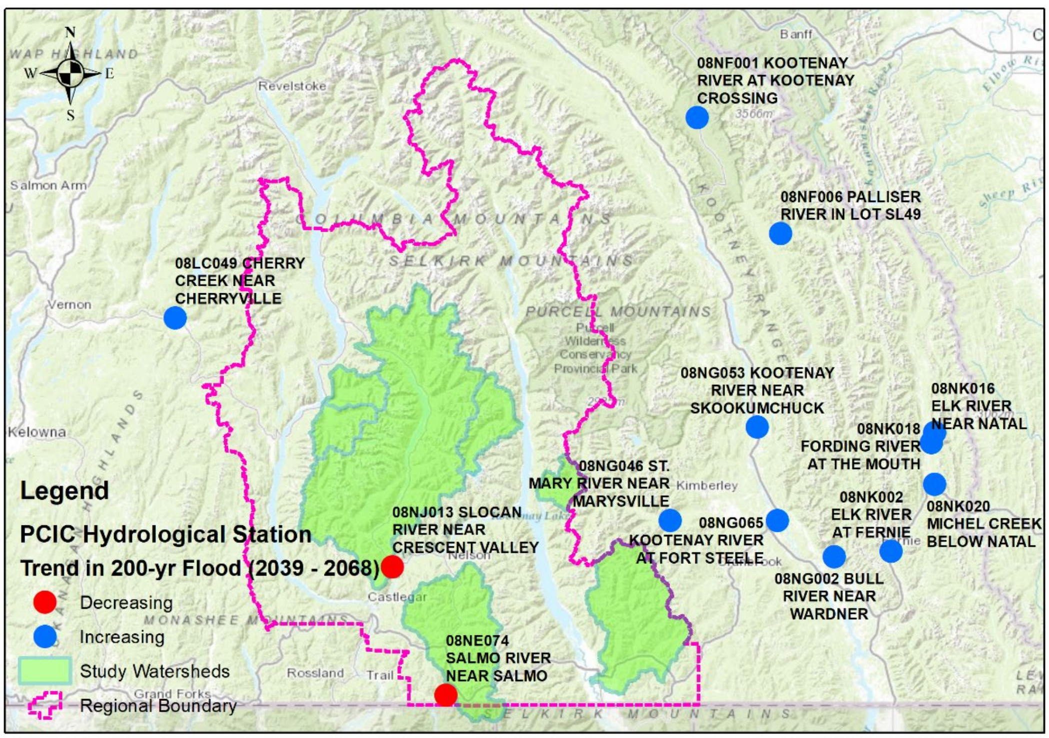



**Figure D-5.** **Map showing nearby the PCIC hydrometric stations examined and their trend in the 200-year flood (period between 2039-2068).**

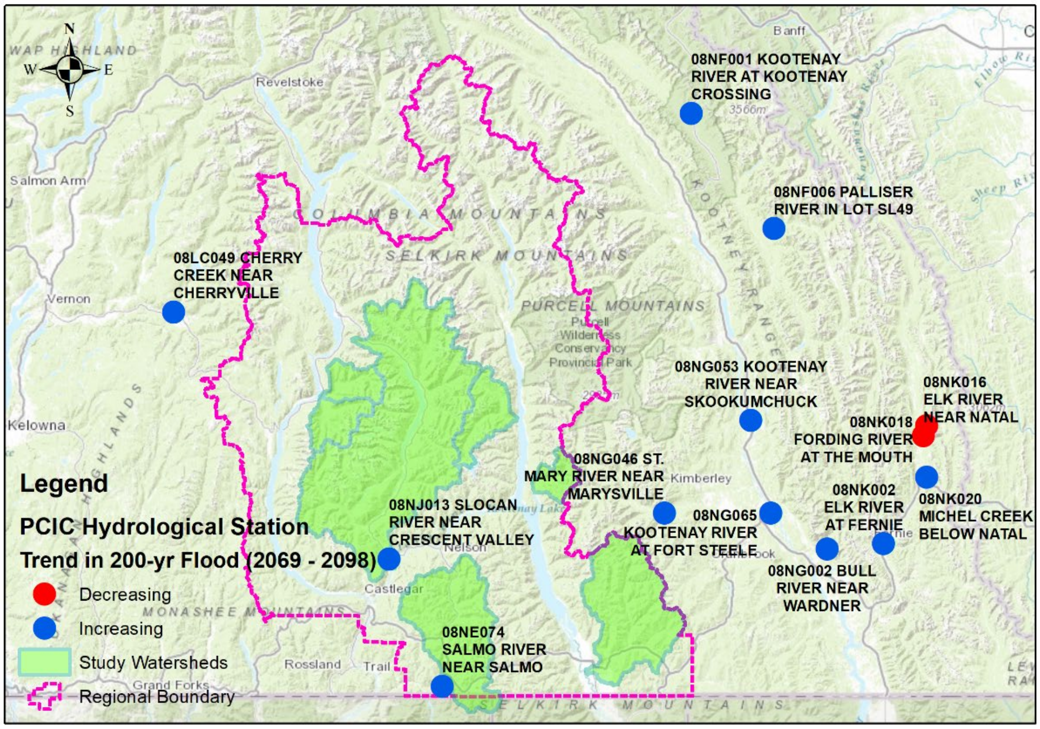



**Figure D-6. Map showing nearby the PCIC hydrometric stations examined and their trend in the 200-year flood (period between 2069-2098).**

The maps show that, in general, most of the thirteen stations examined show an increase in the magnitude of the 200-year flood over time with some exceptions based on an assessment of the mean of the eight models. A bar chart of the results for the individual hydrometric stations is shown in Figure D-7. The expected change in 200-year flood for the 2039-2068 period varies between –9% and +28% from the 1955-2009 period. For the 2069-2098 period, the range in the change of the 200-year flood magnitude increases from -7% and +60% from the 1955-2009 period. The mean of the predicted changes in the 200-year flood for Slocan River Near Crescent Valley (08NJ013) show virtually no change for the 2009-2038 period (-0.1%) followed by a small decrease and small increase for the 2039-2068 (-5%) and 2069-2098 (+16%) periods respectively. The mean of the predicted changes in the 200-year flood for Salmo River Near Salmo (08NE074) show a small increase for the 2009-2038 period (+8%) followed by small decrease for the 2039-2068 period (-97%) followed by a large increase for the 2069-2098 period (+60%).

Boxplots of the results for the three periods for the eight model runs are provided in Figure D-12a and Figure D-12b. The boxplots provide a sense of the uncertainty in the analysis by the considerable range in the estimated 200-year flood quantile. Of note, the PCIC hydrologic model output was found by BGC to poorly predict historical flood quantiles.

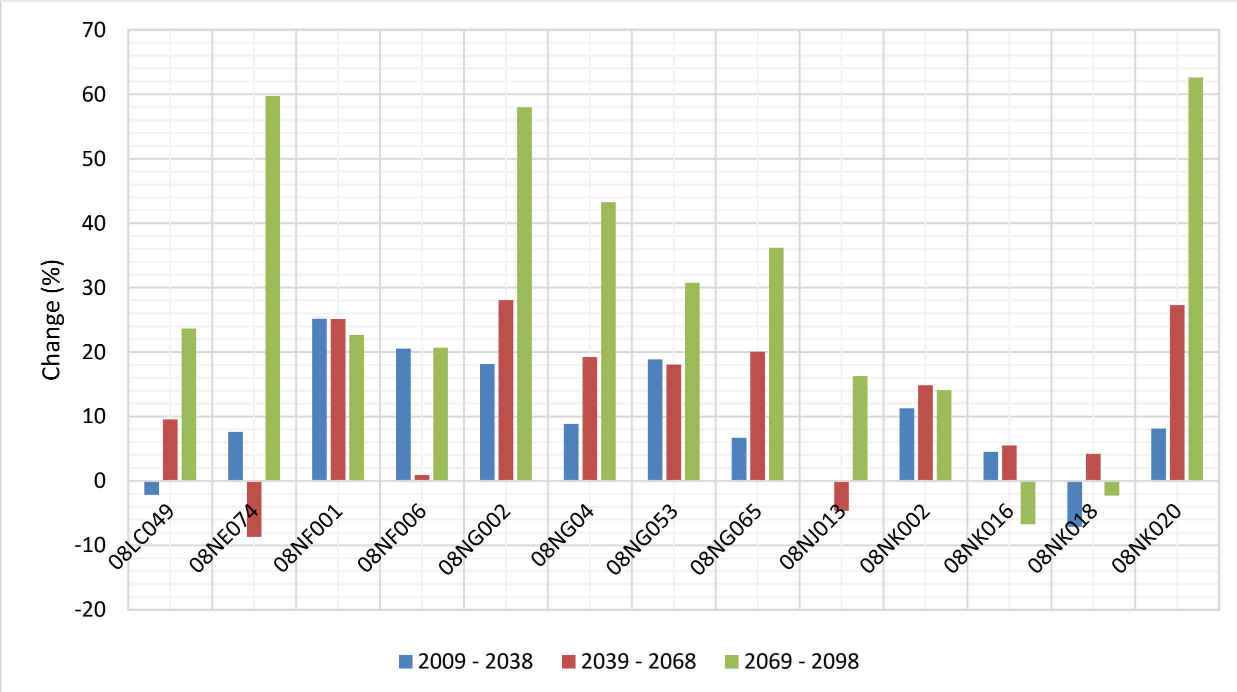



**Figure D-7. Bar-graph of the PCIC hydrometric stations and their change in the magnitude of the 200-year flood for the three periods examined compared to the 1955-2009 historical period. *Note that Station 08NJ013 and 08NE074 are stations located on the Slocan and Salmo Rivers respectively*.**

## D.5. SUMMARY

The EGBC guidelines, summarized in Section D.4.1, offer procedures to account for climate change when flood magnitudes for protective works or mitigation procedures are required (EGBC, 2018). The guidelines recommend that at-site (or nearby) time-series data be analyzed for statistically significant trends. If a statistically significant trend is not detectable, the guidelines recommend that a 10% upward adjustment in design discharge is to be applied to account for likely future change in water input from precipitation. If a statistically significant trend is detectable the guidelines recommend three different procedures including consideration of 1) regionally downscaled projections of annual precipitation and snowpack magnitude, 2) adjustment of IDF curves for expected future precipitation, and or 3) adjustment of the expected flood magnitude and frequency according to the projected change in runoff during the life of the project, or by 20% in small drainage basins for which information of future local conditions is inadequate to provide reliable guidance.

For this study, the impacts of climate change on peak discharge estimates by 2050 (2041 to 2070) were assessed by BGC using statistical and processed-based methods. The statistical methods included a trend assessment on historical flood events using the Mann-Kendall test as well as the application of climate-adjusted variables (mean annual precipitation, mean annual temperature, and precipitation as snow) to the Regional FFA model. The process-based methods included a trend analysis for climate-adjusted flood and precipitation data offered by the PCIC.

The results of the statistical and process-based methods were found to be inconsistent across the RDCK by 2050 (2041 to 2070). Most of the discharge assessed from hydrological regions did not indicate statistically significant trends. The trends that were found were also not consistent with some showing an increasing trend while others a decreasing trend. The results of the statistical flood frequency modelling generally predict a small decrease in the flood magnitude, while the results of the process-based modelling of discharge generally show an increase with a wide range in magnitude. The results of the process-based assessment of the IDF quantiles show an increase during the 1961-1990 and 1971-2000 historical period and then are projected to remain generally constant until 2050. The wide range in magnitude can be a function of many variables including catchment characteristics (e.g., proportion of catchment elevation above a given threshold) which were not explicitly addressed in this assessment.

## D.6. CONCLUSION

The climate change impact assessment results were difficult to synthesise in order to select climate-adjusted peak discharges on a site-specific basis. The assessment of the trends in the discharge records was inconclusive. The results of the statistical flood frequency modelling generally show a small decrease in the flood magnitude, while the results of the process-based discharge modelling generally show an increase with a wide range in magnitude. As a result, peak discharge estimates were adjusted upwards by 20% to account for the uncertainty in the impacts of climate change in the RDCK.

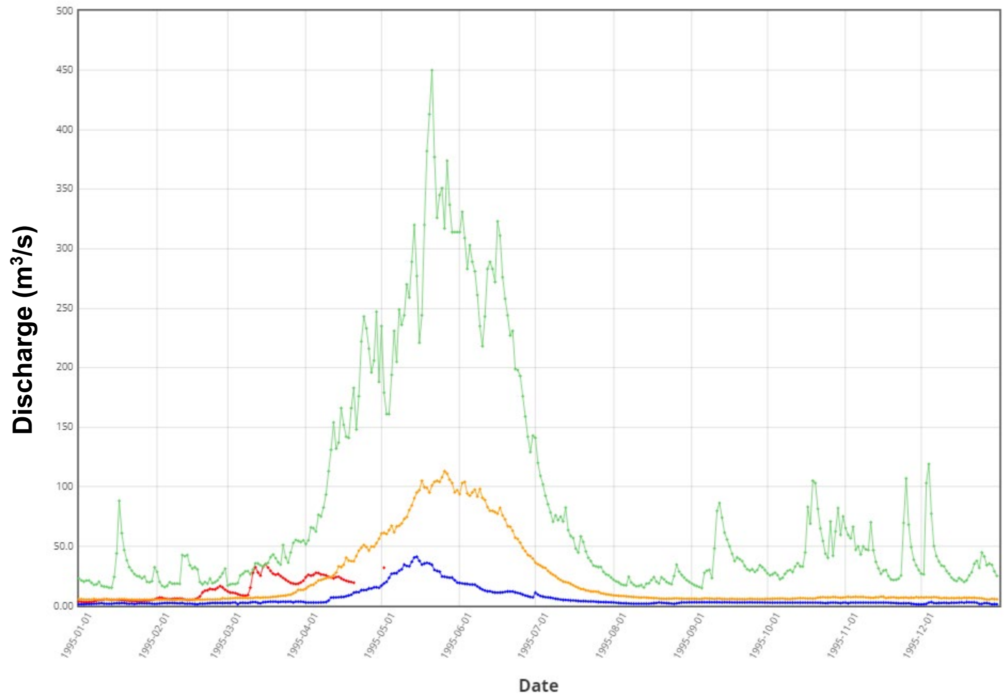



**Figure D-8.** **Example freshet-driven hydrologic regime for Goat River near Erickson (08NH004). Green line is the maximum discharge, the blue line is the minimum discharge, the orange line is the median discharge, and the red line is the 1995 discharge.**

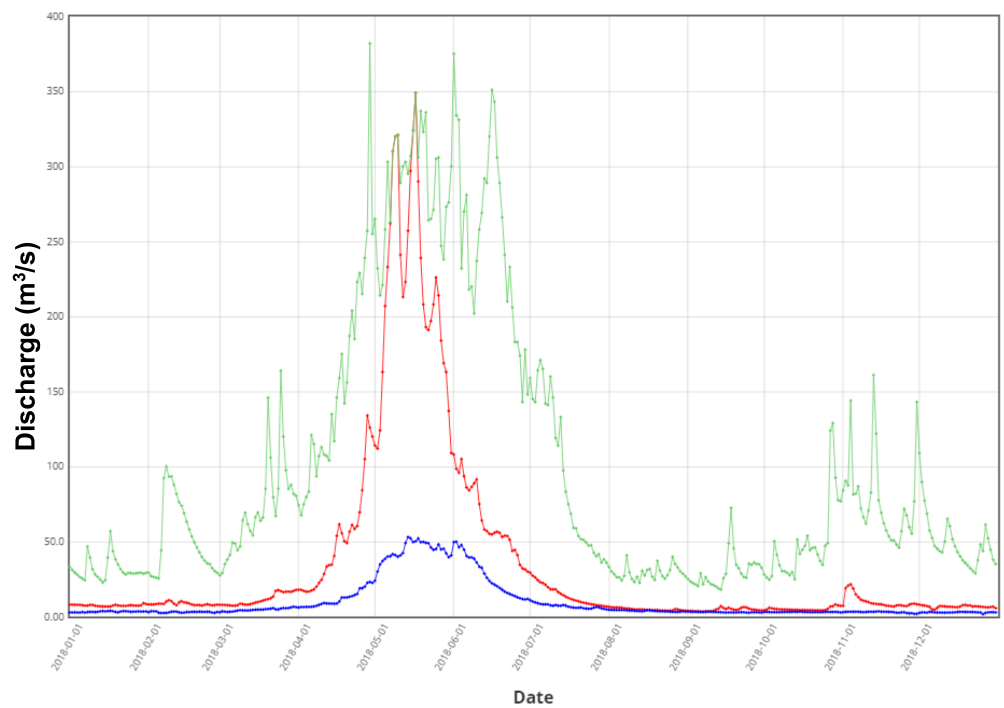



**Figure D-9.** **Example freshet-driven hydrologic regime for Salmo River near Salmo (08NE074). Green line is the maximum discharge, the blue line is the minimum discharge, and the red line is the 2018 discharge.**

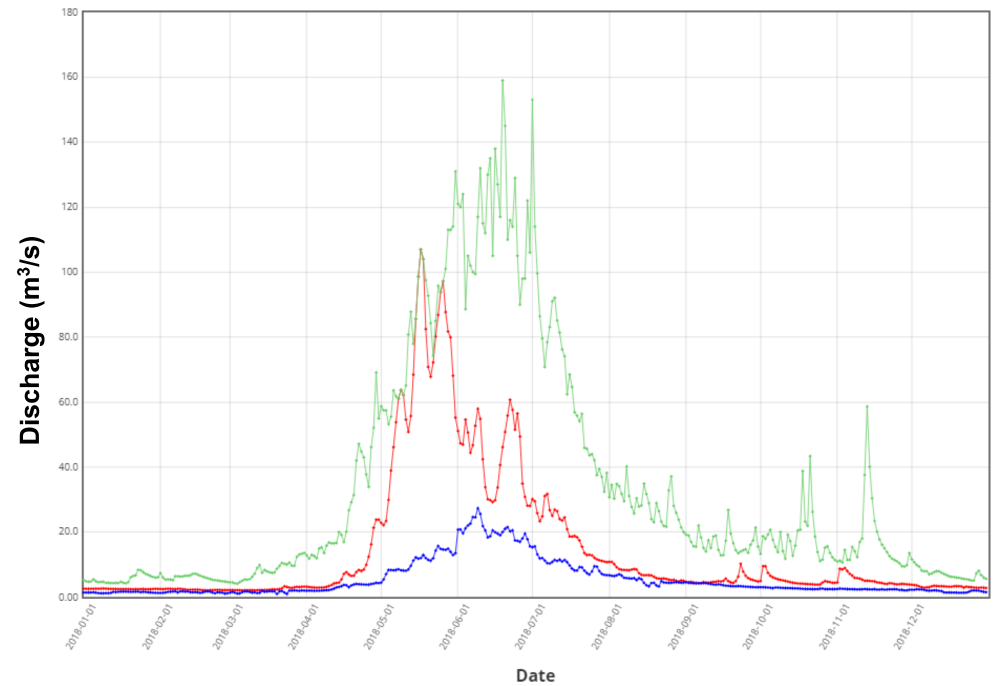



**Figure D-10. Example freshet-driven hydrologic regime for Kaslo below Kemp Creek (08NH005). Green line is the maximum discharge, the blue line is the minimum discharge, and the red line is the 2018 discharge.**

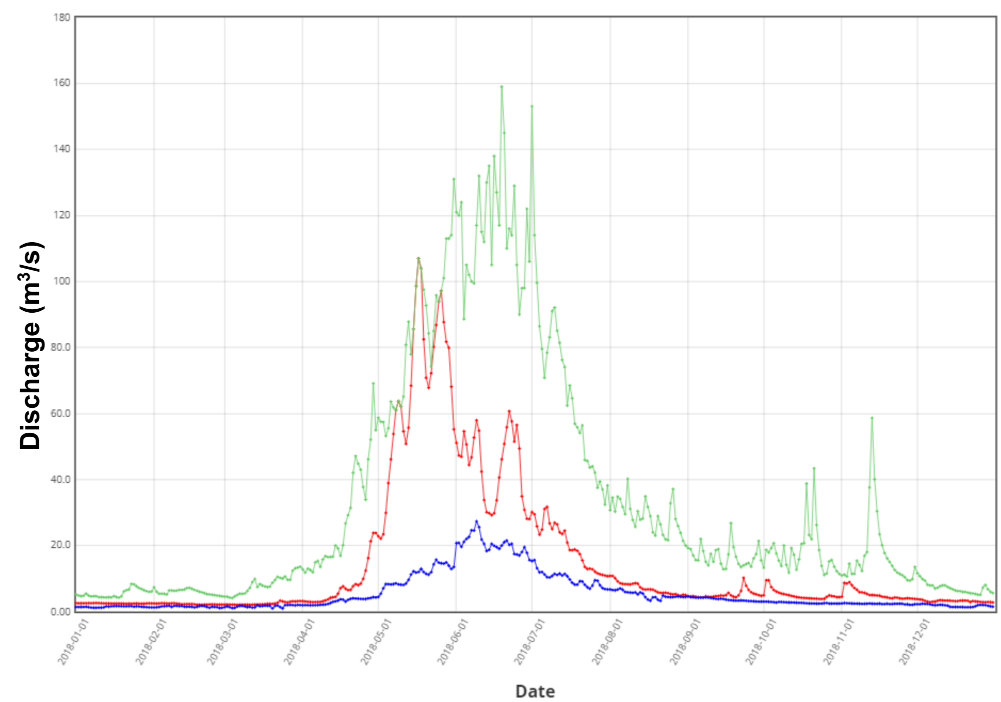



**Figure D-11. Example freshet-driven hydrologic regime for Slocan River near Crescent Valley (08NJ013). Green line is the maximum discharge, the blue line is the minimum discharge, and the red line is the 2018 discharge.**

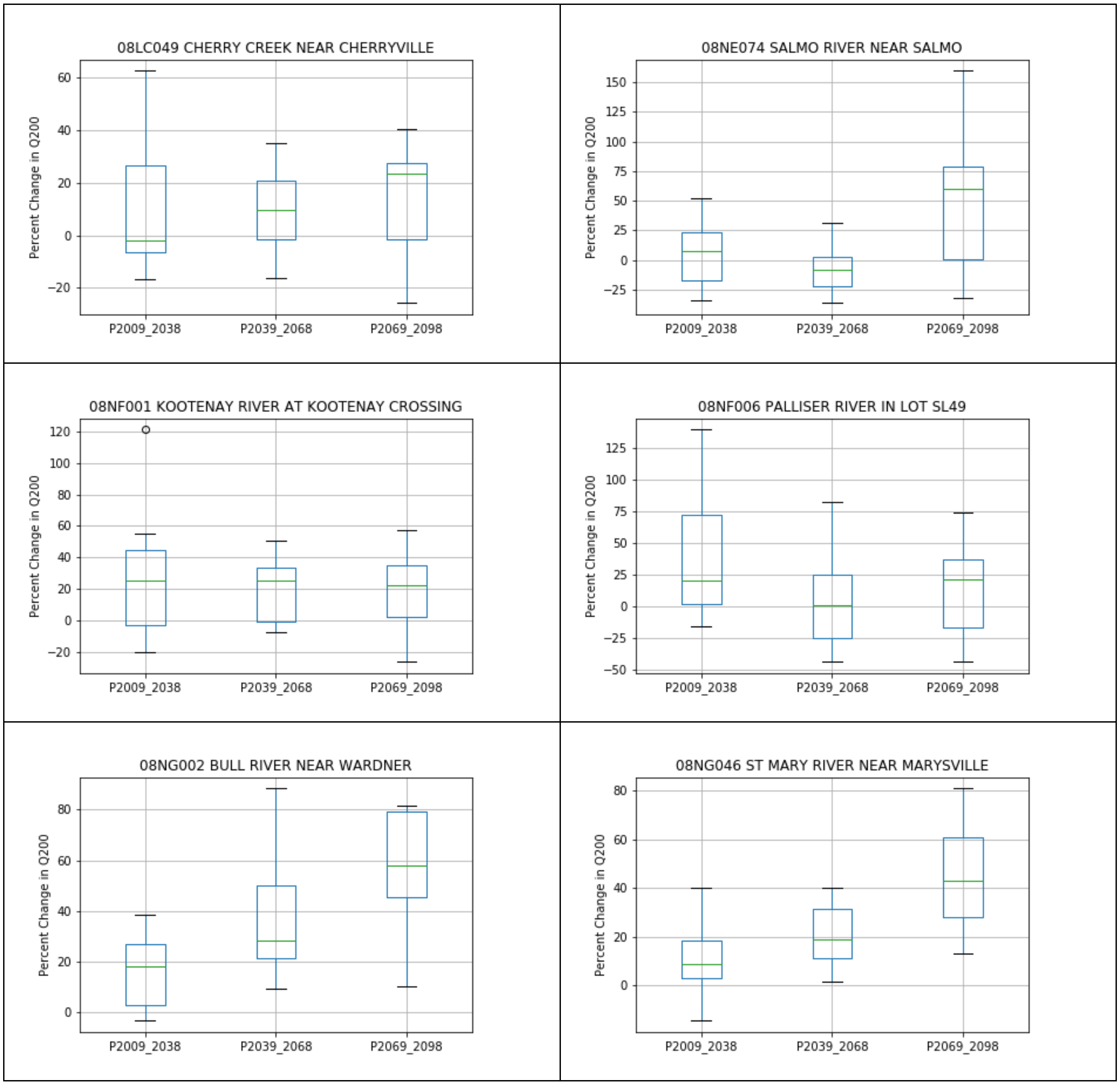



**Figure D-12a. Boxplots of the PCIC Hydrological Stations and their change in the magnitude of the 200-year flood for the three periods examined compared to the 1955-2009 historical period. Boxplots represent the interquartile range from the ensemble of 8 GCM models.**

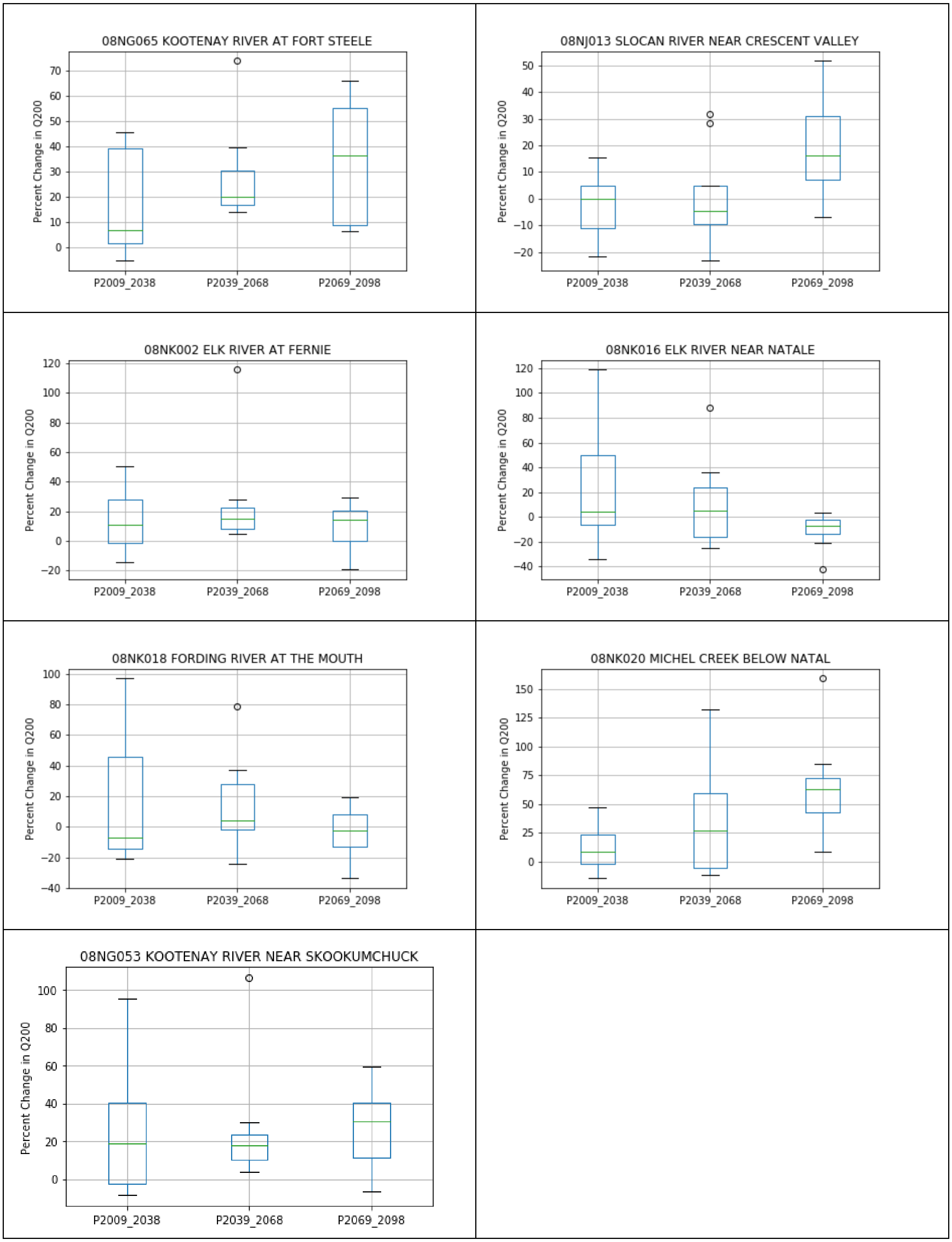



**Figure D-12b. Boxplots of the PCIC Hydrological Stations and their change in the magnitude of the 200-year flood (continued).**

# REFERENCES

Barnett, T. P., Pierce, D. W., Hidalgo, H. G., Bonfils, C., Santer, B. D., Das, T., …Mirin, A. A. (2008). Human-induced changes in the hydrology of the western United States. *Science, 319*(5866), 1080–1083.

Columbia Basin Trust (CBT). (2017). *Water Monitoring and Climate Change in the Upper Columbia Basin – Summary of Current Status and Opportunities*.

Déry, S. J., Stahl, K., Moore, R., Whitfield, P., Menounos, B., & Burford, J. E. (2009). Detection of runoff timing changes in pluvial, nival, and glacial rivers of western Canada. *Water Resources Research, 45*, W04426. https://doi.org/10.1029/2008WR006975

Eaton, B. & Moore, R. (2010) Regional hydrology. In R. Pike, T. Redding, R. Moore, R. Winkler, K. Bladon (Eds), *Compendium of Forest Hydrology and Geomorphology in British Columbia, Land Management Handbook 66, Vol 1, BC* (Chap 4). Ministry of Forests and Range, Forest Science Program and FORREX Forum for Research and Extension in Natural Resources: Victoria, BC and Kamloops, BC, URL htto://www.for.gov.bc.ca/Lmh/Lmh66.htm

Engineers and Geoscientists BC (EGBC). (2018). *Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC*. Version 2.1.

Farjad, B., Gupta, A., & Marceau, D.J. (2016). Annual and seasonal variations of hydrological processes under climate change scenarios in two sub-catchments of a complex watershed. *Water Resources Management, 30*(8), 2851-2865. https://doi.org/10.1007/s11269-016-1329-3

Harder, P., Pomeroy, J.W., & Westbrook, C.J. (2015). Hydrological resilience of a Canadian Rockies headwaters basin subject to changing climate, extreme weather, and forest management. *Hydrological Processes, 29*, 3905-3924. https://doi.org/10.1002/hyp.10596

Kang, D.H., Shi, X., Gao, H., & Déry, S. J. (2014). On the changing contribution of snow to the hydrology of the Fraser River basin, Canada. *Journal of Hydrometeorology, 15*(4), 1344–1365.

Knutti, R., Massin, D., & Gettelman, A. (2013). Climate model genealogy: Generation CMIP5 and how we got there. *Geophysical Research Letters, 40*(6), 1194-1199. https://doi.org/10.1002/grl.50256

Loukas, A. & Quick, M.C. (1999). The effect of climate change on floods in British Columbia. *Nordic Hydrology, 30*(3), 231-256. https://doi.org/10.2166/nh.1999.0013

Pacific Climate Impacts Consortium (PCIC). (2011). Hydrologic *Impacts of Climate Change in the Peace, Campbell and Columbia Watersheds, British Columbia, Canada: Hydrologic Modeling Project Final Report (Part II)*.

Pacific Climate Impacts Consortium (PCIC). (2012). Plan2Adapt. Retrieved from https://www.pacificclimate.org/analysis-tools/plan2adapt.

Pacific Climate Impacts Consortium (PCIC). (2013). Climate Summary for: Kootenay / Boundary Region. Retrieved from https://www.pacificclimate.org/sites/default/files/publications/Climate_Summary-Kootenay-Boundary.pdf

Pacific Climate Impacts Consortium (PCIC). (2014). Station Hydrologic Model Output. Downloaded from https://data.pacificclimate.org/portal/hydro_stn/map/ on November 2019.

Pacific Climate Impacts Consortium (PCIC). (2019). Statistically Downscaled Climate Scenarios. Downloaded from https://data.pacificclimate.org/portal/downscaled_gcms/map/ on November 2019. Method: BCCAQ v2.

Prein, A.F., Rasmussen, R.M., Ikeda, K., Liu, C., Clark, M.P, & Holland, G.J. (2017). The future intensification of hourly precipitation extremes. *Nature Climate Change, 7*, 48-52. http://dx.doi.org/10.1038/nclimate3168

Schnorbus, M.A., Bennett, K.E., Werner, A.T., & Berland, A.J. (2011). *Hydrologic Impacts of Climate Change in the Peace, Campbell and Columbia Watersheds, British Columbia, Canada*. Pacific Climate Impacts Consortium, University of Victoria, Victoria, BC, 157 p.

Schnorbus, M., Werner, A., & Bennett, K. (2014). Impacts of climate change in three hydrologic regimes in British Columbia, Canada. *Hydrological Processes, 28*, 1170-1189. https://doi.org/10.1002/hyp.9661

Shrestha, R.R., Schnorbus, M.A., Werner, A.T., & Berland, A.J. (2012). Modelling spatial and temporal variability of hydrologic impacts of climate change in the Fraser River basin, British Columbia, Canada. *Hydrological Processes, 26*, 1840–1860. https://doi.org/10.1002/hyp.9283.

Wang, T., Hamann, A. Spittlehouse, D.L., & Carroll, C. (2016). Locally downscaled and spatially customizable climate data for historical and future periods for North America. *PLoS One 11*, e0156720. https://doi.org/10.1371/journal.pone.0156720

Werner, A. T., 2011: BCSD downscaled transient climate projections for eight select GCMs over British Columbia, Canada. Pacific Climate Impacts Consortium, University of Victoria, Victoria, BC, 63 p.

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

Wood, A.W., Leung, L.R., Sridhar, V., & Lettenmaier, D.P. (2004). Hydrologic implications of dynamical and statistical approaches to downscaling climate model outputs. *Climate Change*, 62, 189–216. https://doi.org/10.1023/B:CLIM.0000013685.99609.9e.

# APPENDIX E
# HYDRAULIC ASSESSMENT METHODS

## E.1. INTRODUCTION

This appendix describes the approach used to develop a hydraulic model to estimate flood inundation extents for 20-, 50-, 200- and 500-year return period floods in the Slocan River study area. The following sections describe the methods used to develop the hydraulic model including model selection, model domain, scenarios and sensitivity analyses.

## E.2. MODELLING SOFTWARE

Modelling results, including water surfaces profiles, water depths and flow velocities, were estimated using HEC-RAS version 5.0.7 hydraulic model. HEC-RAS is a public domain hydraulic modelling program developed and supported by the United States Army Corps of Engineers (Brunner & CEIWR-HEC, 2016). This version of HEC-RAS supports both one-dimensional (1D) and two-dimensional (2D) hydraulic modelling.

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

A limitation of 2D models in HEC-RAS 5.0.7 is with the modelling of bridges. While the model can accommodate box culverts, the 2D module cannot model high flows at bridges (i.e., when the water surface elevation is greater than the low cord of the bridge). Incorporation of bridge piers can be accomplished within the 2D flow area using fine mesh elements, but it comes at a significant computational cost. To address this, 1D models were created and used to check the water surface elevations at bridges against the 2D model and determine whether adjustments to the final water surface elevations were necessary.

## E.3. MODEL DOMAIN AND BOUNDARY CONDITIONS

### E.3.1. Model Domain

The model domain covers the entire Slocan River (Figure E-1) from Slocan Lake to the Kootenay River (58 km along the thalweg), 4.5 km of Little Slocan River and 2.3 km of Lemon Creek. The upstream model boundary is located at the outlet of Slocan Lake extending approximately 500 m into the lake to capture the flow within the transition from the lake to the river and minimize boundary condition effects. The downstream boundary of the model domain extends approximately 500 m into the Kootenay River downstream of the confluence. The edges of the modelled domain were set sufficiently far from the regions of flow so as to not influence the results.

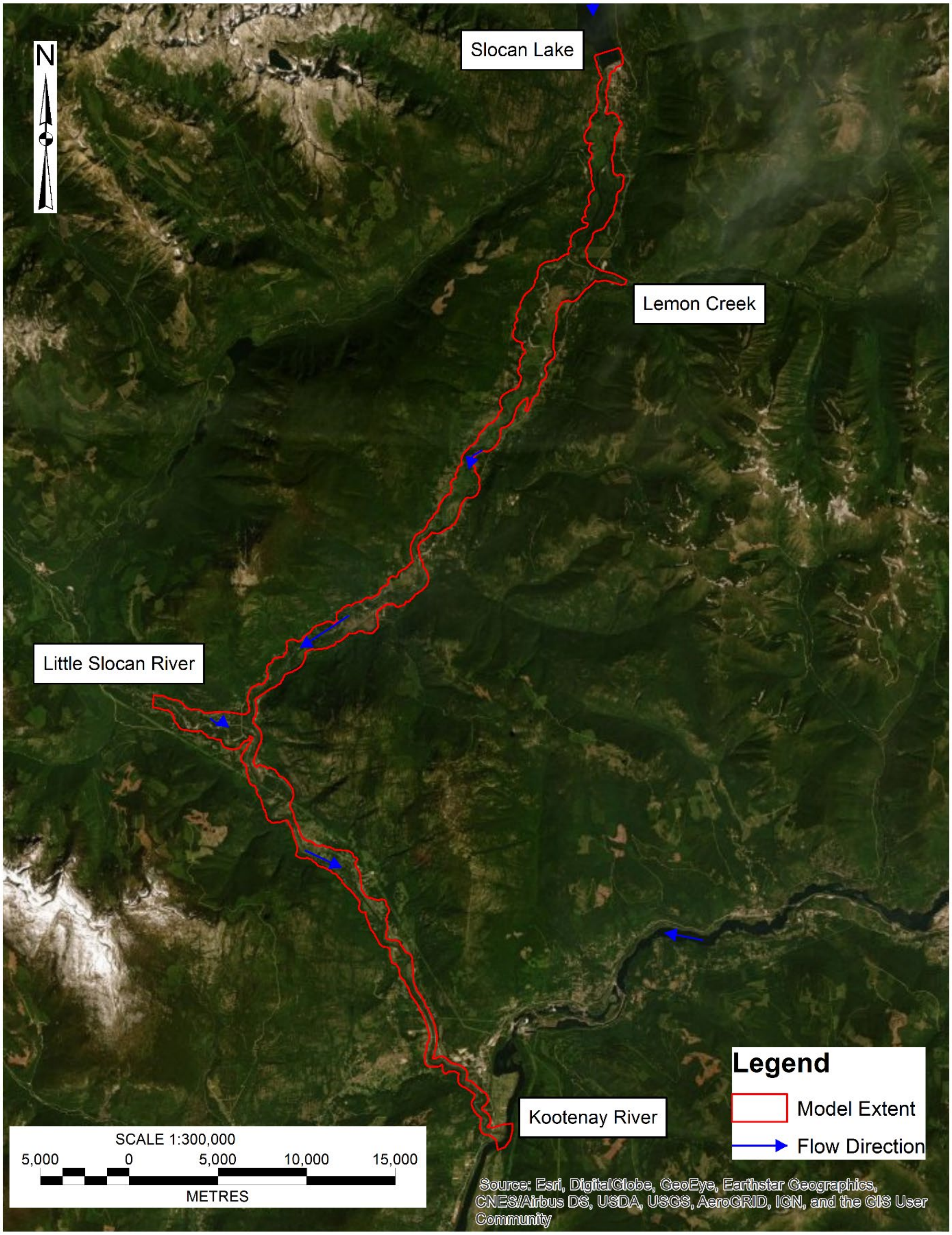



**Figure E-1. Slocan River study area modelling domain.**

### E.3.2. Boundary Conditions

The upstream boundary conditions located at Slocan Lake, Lemon Creek and Little Slocan River were defined as steady-state inflow hydrographs. The inflows were based on the return period being modelled (20-, 50-, 200- and 500-year flood events) and the flood scenario. As discussed in Section 4.4.2.3, two separate flood scenarios were modelled: 1) flooding of the Slocan River and 2) flooding on Lemon Creek and the Little Slocan River. The inflows used for the return periods and the flood scenarios are presented in Section E.6.

A stage hydrograph was used at the downstream boundary on the Kootenay River. Flood stages were provided by Fortis BC and are based on the Brilliant forebay normal operating levels. The normal upper operating limit of 450.3 m (1477.0 ft) was used for flood scenarios with a return periods up to 100-year (i.e., 20-, 50-year floods). The maximum allowable operating limit of 450.8 m (1479.0 ft) was used for the scenarios with a return period of 200 years and above (i.e., 200-, 500-year floods).

## E.4. CHANNEL AND FLOODPLAIN HYDRAULIC ROUGHNESS

In common with many hydraulic models, HEC-RAS 2D uses the Manning's roughness coefficient (Manning's n) to represent the hydraulic flow roughness. Measured flow and water level data for high-flow events were available for the Slocan River, and therefore it was possible to perform some calibration with the Manning's n values being selected based on observed water levels. Observed high-water marks (NHC, 1989) from the June 5, 1986 event of 496 $m^3/s$ at WSC gauge 08NJ013 (approximate return period of 10 to 25 years) were used to calibrate the hydraulic roughness (Table E-1). The outflow from Slocan Lake was estimated at 308 $m^3/s$. The elevations quoted in NHC (1989) are based on the CGVD 1928 vertical datum and were converted to CGVD 2013 using an online tool from Natural Resources Canada (https://webapp.geod.nrcan.gc.ca/geod/tools-outils/gpsh.php?locale =en). The differences between the two datum varies from 0.25 m to 0.29 m along the Slocan River with an average of 0.27 m.

The first step in the calibration of the channel roughness was to simulate the June 5, 1986 event with different channel roughness, from n=0.01 to n=0.04, and comparing the computed water surface elevation to the observed high-water marks (Table E-2). The final Manning's n was determined by selecting the values which most closely matched the observed data. The calibrated Manning's n values vary along the reaches of the Slocan River (0.03 to 0.04) and are presented in Figure E-2.

## Table E-1. Observed high water mark data from June 5, 1986 event (NHC, 1989).

| Location | Station[1] | UTM 11 | | Ground Elevation | WSE Observation June 5, 1986 | | |
|---|---|---|---|---|---|---|---|
| | m | X | Y | (CGVD 2013) | (CGVD 1928) | (CGVD 2013) | Δ (m) |
| Crescent Valley Bridge | 6200 | 459353 | 5477769 | 464.63 | 468.3 | 468.59 | 0.287 |
| WSC Station 08NJ013 | 7232 | 459053 | 5478738 | 465.38 | 469.5 | 469.79 | 0.287 |
| Survey XS 11 (1986) | 13731 | 458270 | 5480296 | 468.98 | 477 | 477.25 | 0.254 |
| Slocan Park Bridge | 16618 | 454382 | 5485325 | 478.08 | 480.9 | 481.16 | 0.262 |
| Passmore Bridge | 21550 | 452720 | 5487756 | 489.25 | 491 | 491.26 | 0.26 |
| Survey XS 38 (1986) | 31234 | 452675 | 5489364 | 494.18 | 506 | 506.26 | 0.26 |
| Winlaw Bridge | 35000 | 459080 | 5496062 | 515.77 | 518.8 | 519.07 | 0.273 |
| Appledale Bridge | 39800 | 460997 | 5499229 | 514.69 | 520 | 520.26 | 0.262 |
| Perry Bridge | 43600 | 463100 | 5501496 | 516.48 | 520.7 | 520.97 | 0.268 |
| Logging Bridge | 56993 | 465776 | 5511449 | 533.78 | 536.7 | 536.95 | 0.252 |
| Slocan Bridge | 58328 | 465911 | 5512734 | 534.20 | 537.1 | 537.35 | 0.254 |
| Slocan Lake | 58725 | 465877 | 5513308 | 535.93 | 537.6 | 537.86 | 0.262 |
| | | | | | | **Mean** | **0.265** |

Note:
1. Stationing from confluence with Kootenay River to Slocan Lake.

**Table E-2. Water surface elevation (CGVD 2013) from various channel roughness values compared to observed high water mark data from June 5, 1986.**

| Location | Station (m) | WSE Observation June 5, 1986 (m) | NHC 1989 | | WSE for Various Manning's n Values | | | | | | | | | | Final Roughness Values | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (m) | Δ (m) | n=0.01 | Δ (m) | n=0.025 | Δ (m) | n=0.03 | Δ (m) | n=0.035 | Δ (m) | n=0.04 | Δ (m) | n | (m) | Δ (m) |
| Crescent Valley Bridge | 6200 | 468.59 | 468.51 | -0.08 | 467.81 | -0.77 | 467.89 | -0.70 | 468.14 | -0.45 | 468.38 | -0.21 | 468.60 | 0.01 | 0.04 | 468.47 | -0.11 |
| WSC Station 08NJ013 | 7232 | 469.79 | 469.89 | 0.10 | 469.12 | -0.67 | 469.22 | -0.57 | 469.53 | -0.26 | 469.82 | 0.03 | 470.09 | 0.30 | 0.035 | 469.77 | -0.02 |
| Survey XS 11 (1986) | 13731 | 477.25 | 477.18 | -0.07 | 476.82 | -0.44 | 476.91 | -0.35 | 477.14 | -0.11 | 477.36 | 0.11 | 477.56 | 0.31 | 0.032 | 477.13 | -0.12 |
| Slocan_Park_Bridge | 16618 | 481.16 | 481.78 | 0.62 | 481.46 | 0.30 | 481.55 | 0.39 | 481.80 | 0.64 | 482.03 | 0.86 | 482.23 | 1.07 | 0.03 | 481.72 | 0.56 |
| Passmore Bridge | 21550 | 491.26 | 491.73 | 0.47 | 491.35 | 0.09 | 491.45 | 0.19 | 491.68 | 0.42 | 491.90 | 0.64 | 492.10 | 0.84 | 0.03 | 491.59 | 0.33 |
| Survey XS 38 (1986) | 31234 | 506.26 | 506.04 | -0.22 | 506.23 | -0.03 | 506.02 | -0.24 | 506.18 | -0.08 | 506.31 | 0.05 | 506.43 | 0.17 | 0.035 | 506.28 | 0.02 |
| Winlaw Bridge | 35000 | 519.07 | 518.92 | -0.15 | 518.59 | -0.48 | 518.40 | -0.67 | 518.61 | -0.46 | 518.80 | -0.27 | 518.98 | -0.10 | 0.035 | 518.76 | -0.31 |
| Appledale Bridge | 39800 | 520.26 | 520.33 | 0.07 | 519.90 | -0.36 | 519.64 | -0.63 | 519.96 | -0.30 | 520.26 | -0.01 | 520.51 | 0.24 | 0.035 | 520.20 | -0.06 |
| Perry Bridge | 43600 | 520.97 | 520.97 | 0.00 | 520.51 | -0.46 | 520.27 | -0.70 | 520.61 | -0.36 | 520.88 | -0.08 | 521.12 | 0.15 | 0.037 | 520.86 | -0.11 |
| Logging Bridge | 56993 | 536.95 | 536.88 | -0.07 | 535.78 | -1.17 | 536.36 | -0.60 | 536.56 | -0.40 | 536.72 | -0.23 | 536.87 | -0.08 | 0.037 | 536.78 | -0.17 |
| Village of Slocan Bridge | 58328 | 537.35 | 537.70 | 0.35 | 536.31 | -1.05 | 537.15 | -0.20 | 537.39 | 0.04 | 537.61 | 0.25 | 537.80 | 0.45 | 0.03 | 537.62 | 0.27 |
| Slocan Lake | 58725 | 537.86 | 537.88 | 0.02 | 536.41 | -1.45 | 537.34 | -0.52 | 537.54 | -0.32 | 537.74 | -0.12 | 537.85 | -0.01 | 0.04 | 537.75 | -0.12 |
| | | | **Sum of Squares** | **0.83** | | **6.48** | | **3.18** | | **1.57** | | **1.43** | | **2.36** | | | **0.68** |

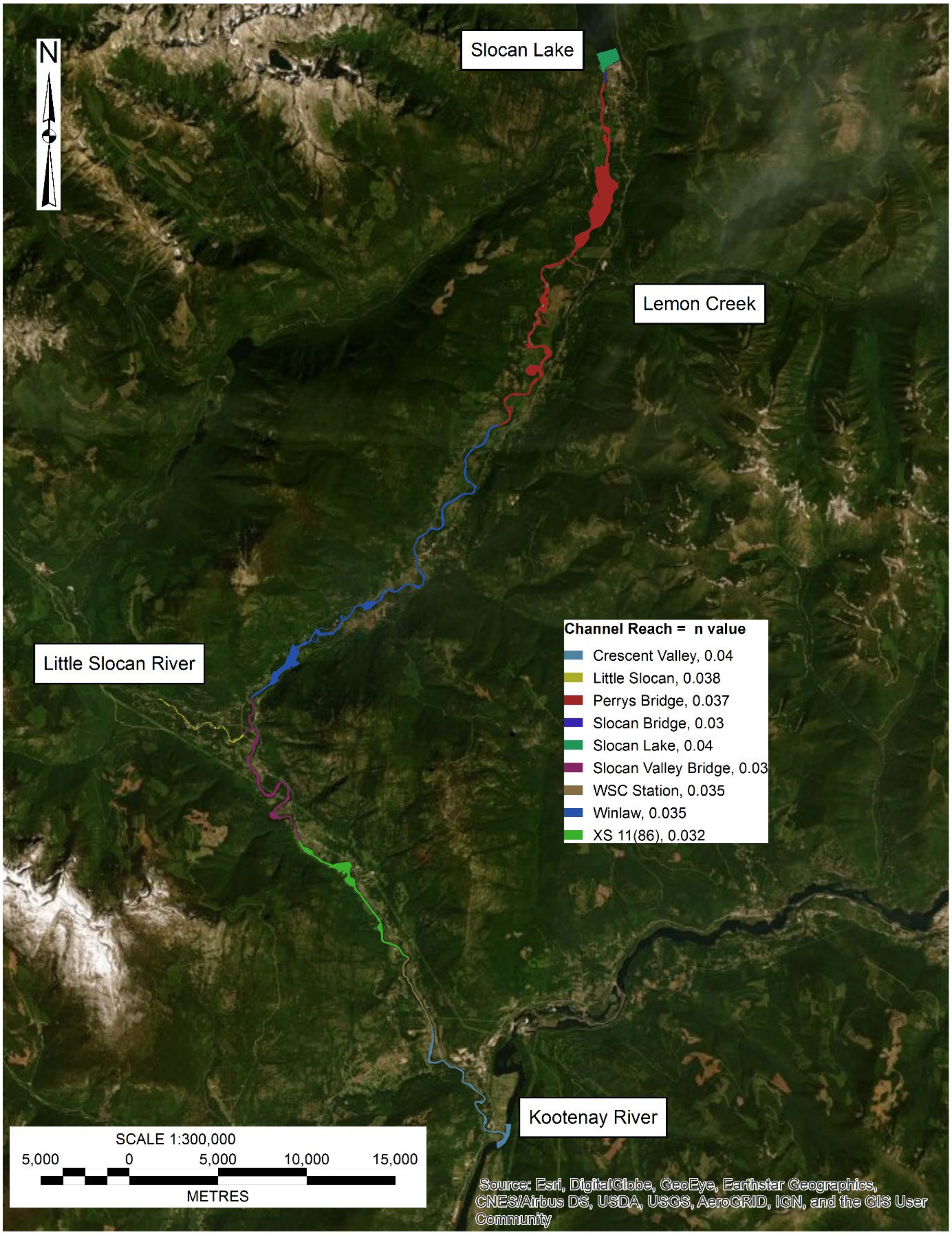



**Figure E-2. Manning's n values adopted along the Slocan River channel.**

Manning's n values for floodplain areas are based on land cover types (Figure E-3) with Manning's n values for each land cover type from Chow (1959) as shown in Table E-3. The spatial land cover distributions were imported from digital land cover maps from the North American Land Change Monitoring System (NRCan, 2019). The sensitivity of the model to variations in the Manning's n values is presented in Section E.8.2.

**Table E-3. Manning's roughness value for land cover class from NALCMS.**

| Land Class | Manning's n |
|---|---|
| 1. Temperate or sub-polar needleleaf forest | 0.1 |
| 2. Sub-polar taiga needleleaf forest | 0.1 |
| 3. Tropical or sub-tropical broadleaf evergreen forest | 0.1 |
| 4. Tropical or sub-tropical broadleaf deciduous forest | 0.1 |
| 5. Temperate or sub-polar broadleaf deciduous forest | 0.1 |
| 6. Mixed Forest | 0.1 |
| 7. Tropical or sub-tropical shrubland | 0.07 |
| 8. Temperate or sub-polar shrubland | 0.07 |
| 9. Tropical or sub-tropical grassland | 0.035 |
| 10. Temperate or sub-polar grassland | 0.035 |
| 11. Sub-polar or polar shrubland-lichen-moss | 0.035 |
| 12. Sub-polar or polar grassland-lichen-moss | 0.03 |
| 13. Sub-polar or polar barren-lichen-moss | 0.03 |
| 14. Wetland | 0.044 |
| 15. Cropland | 0.035 |
| 16. Barren Lands | 0.044 |
| 17. Urban and Built-up | 0.025 |
| 18. Water | 0.044 |
| 19. Snow and Ice | 0.044 |

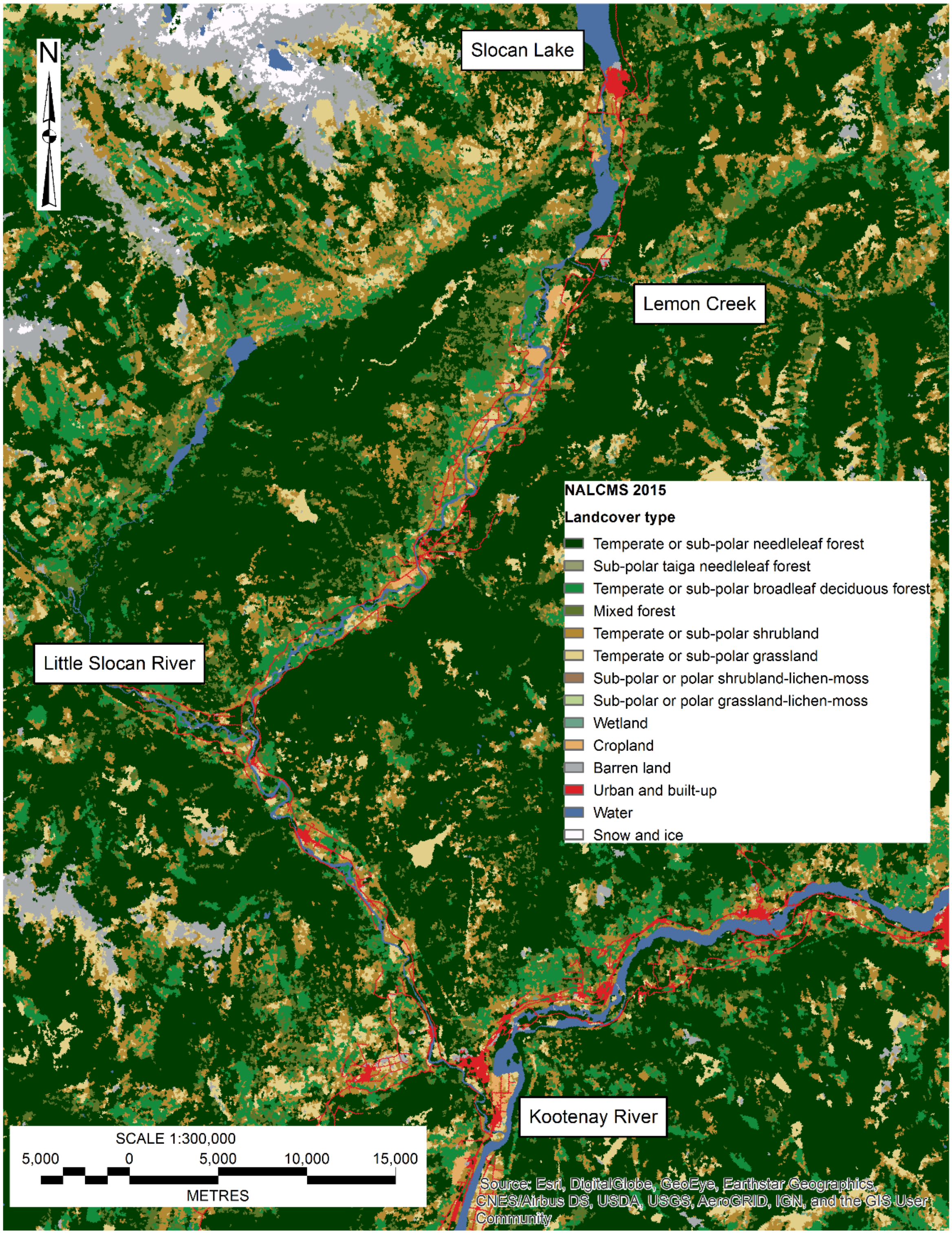



**Figure E-3. Manning's n roughness in the floodplain from landcover.**

## E.5. MODEL MESHING

With 2D models the main challenge is to define a model with sufficient accuracy while using a mesh resolution that limits model runtime. The runtime is predominantly determined by the number of cells within the model 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 as they allow refinement of the model in locations where the flow is changing rapidly and/or where additional resolution is desired and coarser in locations where a finer mesh is not necessary.

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.

### E.5.1. Initial Mesh Development

For the Slocan River Study area, an initial base model resolution of 30 m was developed to determine the required model extent. This low-resolution grid was iteratively refined to capture the topographical features in the watershed and to provide a minimum number of cells in the main channel to help the numerical stability of the model. The final mesh used a base cell size of 15 m. A breakline was placed along the centerline of the main channel of the creek with a resolution of 10 m cells with the same resolution (repeats) on each side. Terrain features such as ridges, drainage ditches and dikes were captured using breaklines to which the mesh was aligned with a resolution of 10 m.

### E.5.2. Mesh Refinement

Based on the results of preliminary simulation runs, additional breaklines were introduced in areas where 'leakage' was noted between cells. Leakage is a result of the cell faces not aligning with terrain features and/or cells that are too large and hydraulically connects areas separated by a physical barrier to flow (e.g., a local ridge in the underlying terrain). A total of 171 breaklines were used to represent terrain features and guide the mesh generation algorithm. A number of cross sections located at key locations (e.g., Slocan Lake outlet, surveyed cross section, bridge crossing) were also input as breaklines to locally orient the mesh and compute cross-sectional properties (e.g., total discharge through a cross section). The final mesh consisted of 207,784 computational cells with an average cell size of 181 $m^2$, a maximum cell size of 1,576 $m^2$ and a minimum cell size of 33 m$^2$. An example of the mesh developed around Slocan Lake is given in Figure E-4. It shows a breakline on each bank and the channel centerline. A breakline was added at the bridge crossing and at a ditch located near the shore of the lake.

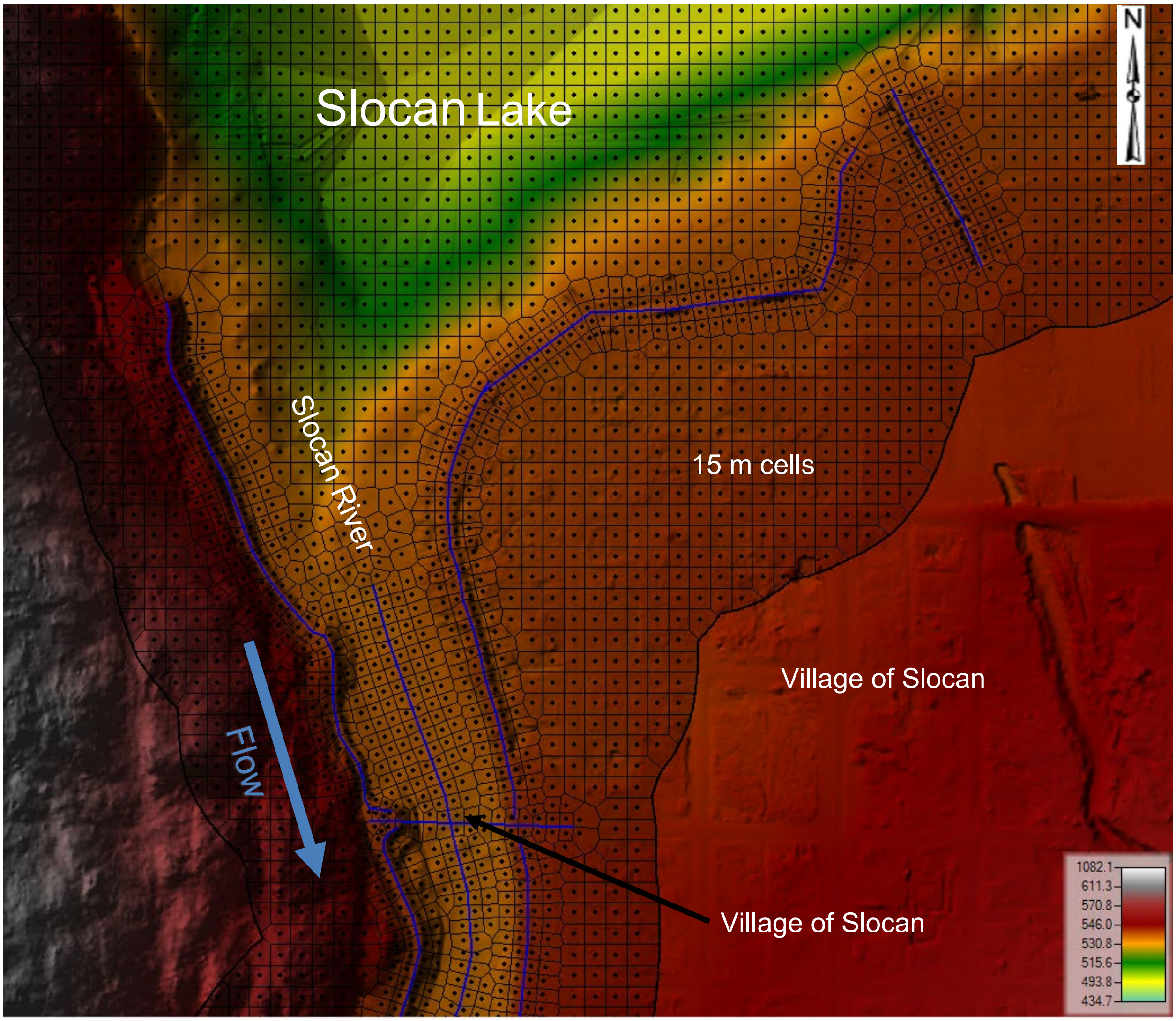



**Figure E-4. Example of the mesh used for the model at Slocan Lake outlet showing the breaklines used for refinement.**

### E.5.3. Hydraulic Structures

#### E.5.3.1. Bridge Crossings

As indicated in Section E.2, bridge crossings cannot be readily modelled with HEC-RAS 2D v5.0.7. Bridge decks were removed from the terrain model for 2D simulations and separate HEC-RAS 1D models of the bridge crossings were developed. A total of twelve bridge crossings of the Slocan River (nine), Little Slocan (one) and Lemon Creek (two) were identified within the study area (Figure E-5). Bridges were surveyed by Midwest Surveys in July – September 2019 to capture bridge and pier dimensions, as well as low chord (bottom-of-deck) and top-of-deck elevations (Figure E-6). A brief description of these bridges is provided below from upstream to downstream, followed by a table summarizing key bridge dimensions and characteristics, modelling approach, and results of the 1D models (Table E-4).

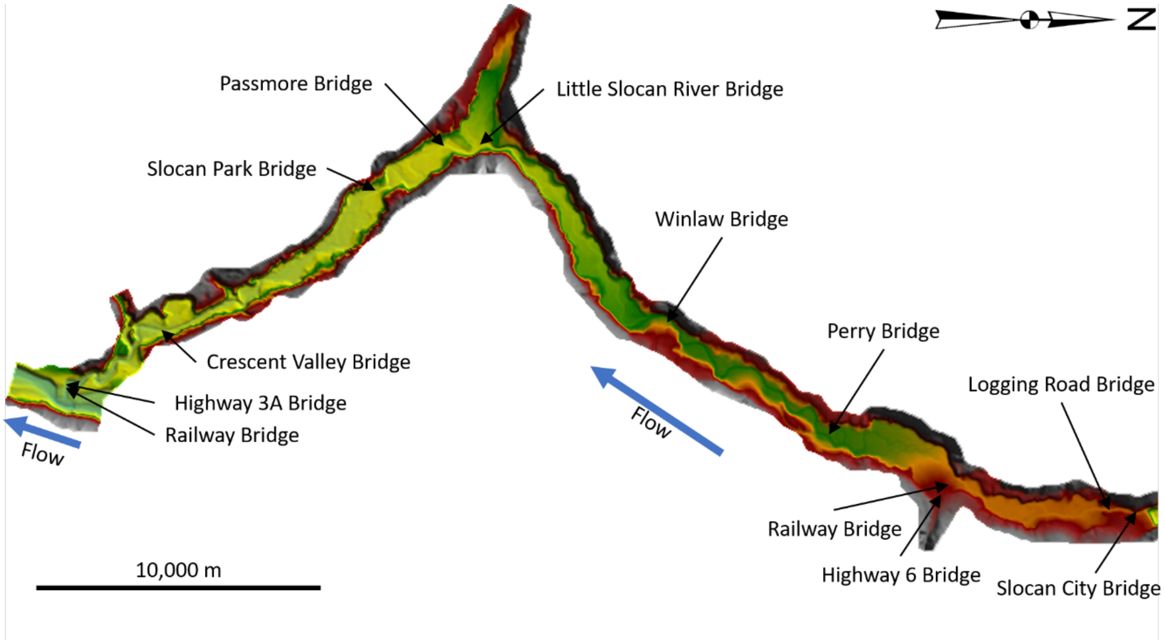



**Figure E-5. Bridge crossings within the study area.**

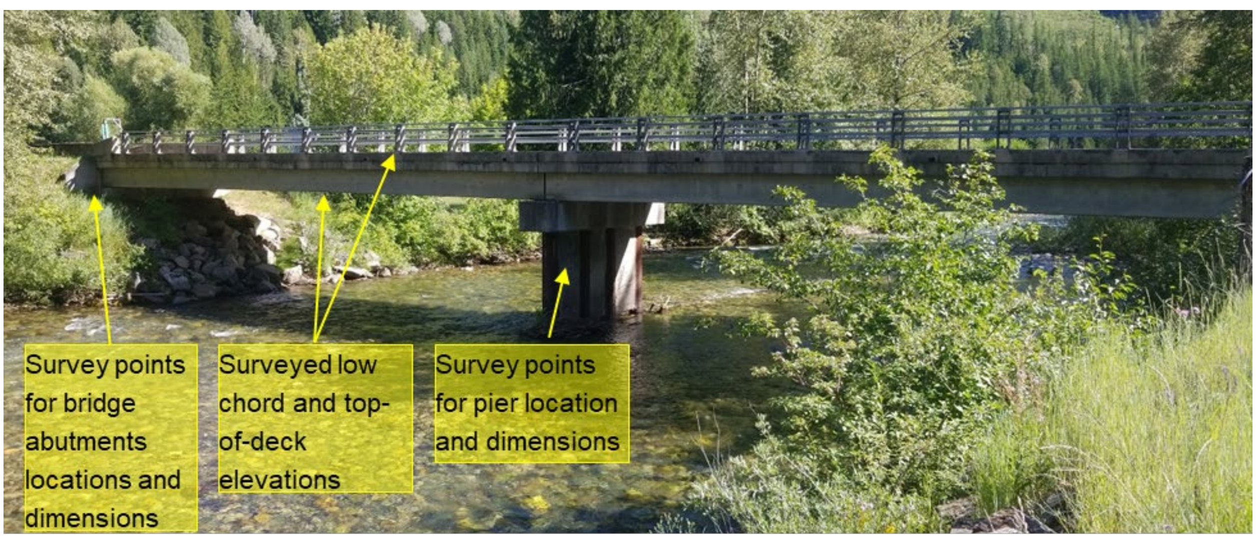



**Figure E-6. Example of surveyed bridge structure features.**

Village of Slocan Bridge

The Village of Slocan Bridge is located approximately 500 m from the Slocan Lake outlet on Park Avenue. The survey data indicates that it is 80 m long and 8 m wide. The bridge deck is located at the beginning of a mild bend and could be considered skewed at 80$^{o}$ to the main flow direction. It is supported by two 1 m wide piers each 1 m wide and elongated (measured at the top). Bridge abutments are sloped and armoured with riprap (Figure E-7, Figure E-8, and Figure E-9).

**Figure E-7. Slocan City Bridge over the Slocan River looking downstream. Photo: Midwest Survey July 8, 2019.**

**Figure E-8. Slocan City Bridge over the Slocan River looking upstream. Photo: Midwest Survey July 8, 2019.**


**Figure E-9. Slocan City Bridge over the Slocan River looking at pier. Photo: Midwest Survey July 8, 2019.**

Lemon Creek Highway 6 Bridge

The Lemon Creek Highway 6 Bridge is located on Lemon Creek fan approximately 1 km upstream of the confluence with the Slocan River. It is perpendicular to the flow direction and is supported by a central elongated pier (Figure E-11). The dimensions of the bridge were not surveyed.


**Figure E-10. Highway 6 bridge over Lemon Creek standing on the left abutment looking across. Photo: Brian Cutts March 29, 2020.**

**Figure E-11. Highway 6 bridge over Lemon Creek standing in the channel looking upstream. Photo: Brian Cutts March 29, 2020.**

<u>Lemon Creek Railway Bridge</u>

The Lemon Creek Railway Bridge is a decommissioned CPR bridge and is now part of the Slocan Valley Rail Trail. It is located on Lemon Creek fan approximately 400 m upstream of the confluence with the Slocan River. It is perpendicular to the flow direction and the dimensions of the bridge were not surveyed (Figure E-12).

**Figure E-12. Slocan Valley Rail Trail Bridge over Lemon Creek. Photo taken standing on right bank looking downstream. Photo: Brian Cutts March 29, 2020.**

Logging Road Bridge (Gravel Pit Road)

The Logging Road Bridge is located approximately 1.6 km downstream of the Slocan Lake outlet on Gravel Pit Road (Figure E-13, Figure E-14). The bridge is generally perpendicular to the flow direction. The deck is composed of timber and is supported by two 5 m wide piers blocks (Figure E-15). Each pier block is made from two series of three joined piers, 5 m apart. The two series are attached together with a triangular nose on the upstream face. The surveyed length is 64 m and the surveyed width is 4 m. The embankments are built with concrete blocks and no erosion protection was observed during the field visit and survey.

**Figure E-13. Logging Road Bridge over the Slocan River looking downstream. Photo: Midwest Survey July 8, 2019.**

**Figure E-14. Logging Road Bridge over the Slocan River looking upstream. Photo: Midwest Survey July 8, 2019.**

**Figure E-15. Logging Road Bridge over the Slocan River looking at pier. Photo: Midwest Survey July 8, 2019.**

Perry Bridge

Perry Bridge is located in the community of Perry Siding, also known as Perry's Siding, Perry's, and Perrys. The bridge is located approximately 13 km downstream of Slocan Lake outlet. The surveyed dimensions of the deck are 100 m long and 4 m wide (Figure E-16, Figure E-17). The bridge is deck is generally perpendicular to the flow direction. The bridge is supported with three 1 m wide elongated piers located in the channel with one in the middle and one on each side of the channel. The bridge is considered perched because the deck elevation is higher than the approaches and the floodplain.

**Figure E-16. Perry Bridge over the Slocan River looking downstream. Photo: Midwest Survey July 15, 2019.**

**Figure E-17. Perry Bridge over the Slocan River looking upstream. Photo: Midwest Survey July 15, 2019.**

<u>Winlaw Bridge</u>

The Winlaw Bridge is located in the unincorporated Village of Winlaw, 19 km downstream of Slocan Lake (Figure E-18). The bridge is perpendicular to the flow direction and is supported by two in-channel 1.3 m wide elongated piers. The surveyed length is 80 m and the surveyed width is 8 m. The two embankments are sloped and armoured.

**Figure E-18. Winlaw Bridge over the Slocan River looking upstream from the right bank. Photo: Midwest Survey July 7, 2019.**

Little Slocan Bridge

The Little Slocan Bridge is located on the Little Slocan River approximately 400 m upstream from the confluence with Slocan River (Figure E-19). The bridge is generally perpendicular to the flow direction and is supported by one central 0.6 m wide (1.2 m at the top) elongated pier. The embankments are sloped and armoured. The surveyed dimensions are 67 in length and 11 m in width.

**Figure E-19. Little Slocan Bridge over the Little Slocan River from right bank looking upstream. Photo: Midwest Survey July 8, 2019.**

Passmore Bridge

Passmore Bridge is located approximately 1.5 km downstream of the confluence of the Slocan River with the Little Slocan River and approximately 22 km upstream from the mouth along the thalweg. The bridge is perpendicular to the flow direction and is supported by two 1 m wide elongated piers (Figure E-20, Figure E-21). The surveyed length of the bridge is 90 m and the surveyed width is 6 m. The sloped abutments are armoured.

**Figure E-20. Passmore Bridge over the Slocan River from left bank looking downstream. Photo: Midwest Survey July 8, 2019.**

**Figure E-21. Passmore Bridge over the Slocan River from the channel looking upstream. Photo: Midwest Survey July 8, 2019.**

Slocan Park Bridge

Slocan Park Bridge is located approximately 6.5 km downstream of the confluence of the Slocan River with the Little Slocan River and approximately 17 km upstream from the mouth along the thalweg. The bridge is perpendicular to the flow direction and is supported by two 1 m wide elongated piers that are outside the channel (Figure E-22, Figure E-23). The surveyed length of the bridge is 70 m and the surveyed width is 6 m. The banks in the vicinity of the bridge are armoured.

**Figure E-22. Slocan Park Bridge over the Slocan River from the channel looking downstream. Photo: Midwest Survey July 8, 2019.**

**Figure E-23. Slocan Park Bridge over the Slocan River from the channel looking upstream. Photo: Midwest Survey July 8, 2019.**

Crescent Valley Bridge

Crescent Valley Bridge is located approximately 6 km upstream from the mouth along the thalweg. The bridge is perpendicular to the flow direction and is supported by one central 0.6 m wide elongated pier (Figure E-24). The surveyed length of the bridge is 96 m and the surveyed width is 10 m.

**Figure E-24. Crescent Valley Bridge over the Slocan River from right bank looking downstream. Photo: Midwest Survey July 8, 2019.**

Highway 3A and Railway Bridges

The Highway 3A Bridge and the Railway Bridge are located approximately 500 m upstream from the mouth. The bridges are perpendicular to the flow direction and are both supported by two piers on the banks (Figure E-25, Figure E-26). The surveyed length and width are provided in Table E-4.

**Figure E-25. Highway 3A and Railway Bridges over the Slocan River from left bank looking downstream. Photo: Midwest Survey July 12, 2019.**

**Figure E-26. Highway 3A and Railway Bridges over the Slocan River from left bank looking upstream. Photo: Midwest Survey July 4, 2019.**

**Table E-4. Bridge crossings within the Slocan River study area.**

| Bridge Crossing | Latitude (°) | Longitude (°) | Length (m) | Width (m) | Deck orientation to flow direction (°) | Low chord elevation (m) | Number of in-channel piers | 2D hydraulic model 200-year flood water surface elevation (m) | Freeboard (m) | 1D hydraulic model | | Impact of the Bridge on flood extent |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | (Yes/No) | Rationale | |
| **Slocan River** | | | | | | | | | | | | |
| Village of Slocan Bridge | 49.7660 | -117.4732 | 80 | 8 | 80 | 539.90 | 2 | 539.29 | 0.61 | Yes | In-channel obstruction (two piers) expected to reduce flow conveyance. | No measurable impact observed in model results |
| Logging Road Bridge (Gravel Pit Road) | 49.7545 | -117.4751 | 64 | 4 | 90 | 538.38 | 2 | 538.35 | 0.02 | Yes | In-channel obstruction (two large piers of 5m) expected to reduce flow conveyance. | 10 cm increase in the WSE upstream from the pier was observed in the 1D model. Flow contained in channel. |
| Perry Bridge | 49.6647 | -117.5113 | 100 | 4 | 90 | 523.10 | 3 | 522.75 | 0.35 | Yes | Perched bridge with overland flow over the road. | No measurable impact observed in the model results |
| Winlaw Bridge | 49.6157 | -117.5665 | 80 | 9 | 90 | 521.60 | 2 | 520.37 | 1.23 | Yes | In-channel obstruction (two piers) expected to reduce flow conveyance. | Between 4 to 7 cm increase in the WSE upstream was observed in the 1D model minor additional flooding on the right bank. |
| Passmore Bridge | 49.5405 | -117.6535 | 90 | 6 | 90 | 494.31 | 2 | 492.82 | 1.49 | Yes | In-channel obstruction (two piers) expected to reduce flow conveyance. | 25 cm increase in the WSE at the bridge centerline. Backwater effect persists for approximately 75 m upstream. No significant additional flood extent. |
| Slocan Park Bridge | 49.5188 | -117.6302 | 70 | 6 | 90 | 484.63 | 0 | 483.11 | 1.51 | No | No in-channel obstruction (piers). Representation of bridge opening in the terrain model used for 2D simulations is adequate. | No measurable impact expected. |
| Crescent Valley Bridge | 49.4511 | -117.5607 | 96 | 10 | 90 | 474.87 | 1 | 470.56 | 4.31 | No | One central pier aligns with the flow. Enough freeboard with elevated bank crests. | No measurable impact expected. |
| Highway 3A Bridge | 49.4199 | -117.5312 | 123 | 10 | 90 | No survey | 0 | 454.09 | - | No | No in-channel obstruction (piers). Representation of bridge opening in the terrain model used for 2D simulations is adequate. | No measurable impact expected |
| Railway Bridge | 49.4199 | -117.5307 | 107 | 7 | 90 | No survey | 0 | 453.56 | - | No | No in-channel obstruction (piers). Representation of bridge opening in the terrain model used for 2D simulations is adequate. | No measurable impact expected |
| **Lemon Creek** | | | | | | | | | | | | |
| Highway 6 Bridge | 49.7017 | -117.4796 | 32 | 11 | 90 | No survey | | | | No | Not surveyed | |
| Slocan Valley Rail Trail Bridge | 49.7048 | -117.4889 | 32 | 6 | 90 | No survey | | | | No | Not surveyed | |
| **Little Slocan River** | | | | | | | | | | | | |
| Little Slocan Bridge | 49.5505 | -117.6570 | 67 | 11 | 90 | 499.99 | 1 | 498.78 | 1.12 | Yes | | Complex geometry at the confluence with flow over north embankment of Passmore Lower Road causing 1D results to be potentially inaccurate. Increase of 6 cm at the bridge centerline. |

Note: Bridge crossings are listed in a downstream direction.

## E.6. SIMULATION SETTINGS

The HEC-RAS 2D model was run using the full momentum equation with a Courant-controlled time step. The full momentum equations provide accurate representation of flow dynamics especially where sharp construction/expansions/changes in direction are observed. The initial time step was 5 seconds, and the maximum Courant number was 2. The model was run to simulate a 48-hour period and a constant discharge was reached at the downstream boundary.

## E.7. MODELLING SCENARIOS

Scenarios were run for 20, 50, 200 and 500-year flood events. Details on the methods to determine the peak discharges and inflows for the two flood scenarios are provided in Sections 4.3, 4.4 and 5.2.2. A summary of the modeled events is given in Table E-5. Sensitivity analyses were performed on the results of the 200-year flow for Manning's n values of +/-10%. The influence of the downstream boundary was evaluated using three different water surface elevations. The sensitivity of the results to the grid size was performed by comparing the results of the 200-year flow (15 m cell base) to results from grids with 25 m and 50 m cells.

**Table E-5. Modelled scenarios.**

| Scenario | Slocan Lake Boundary Condition ($m^3/s$) | Lemon Creek Boundary Condition ($m^3/s$) | Little Slocan Boundary Condition ($m^3/s$) | Kootenay River Boundary Condition (m) |
|---|---|---|---|---|
| **Flood Scenario 1 - Slocan River Flood Scenario** | | | | |
| 20-year | 445 | 89 | 290 | 450.3 |
| 50-year | 495 | 99 | 325 | 450.3 |
| 200-year (Normal Upper Stage) | 575 | 115 | 373 | 450.3 |
| 200-year (Max. Stage) | 575 | 115 | 373 | 450.8 |
| 200-year (NHC 1989 Kootenay River Stage) | 575 | 115 | 373 | 452.6 |
| 500-year | 620 | 124 | 405 | 450.8 |
| **Roughness Sensitivity Analysis** | | | | |
| 200-year (+10% Manning's n) | 575 | 115 | 373 | 450.8 |
| 200-year (-10% Manning's n) | 575 | 115 | 373 | 450.8 |
| **Flood Scenario 2 - Tributaries Flood Scenario** | | | | |
| 20-year | 385 | 85 | 350 | 450.3 |
| 50-year | 430 | 100 | 391 | 450.3 |
| 200-year | 485 | 125 | 450 | 450.8 |
| 500-year | 520 | 140 | 490 | 450.8 |
| **Grid Sensitivity Analysis** | | | | |
| 200-year (25m Grid) | 575 | 115 | 373 | 450.8 |
| 200-year (50m Grid) | 575 | 115 | 373 | 450.8 |

## E.8. SENSITIVITY ANALYSIS

### E.8.1. Downstream Boundary

The sensitivity of the model to the water elevation was examined by re-running the 200-year flood scenario (Flood Scenario 1) on the Slocan River with the downstream boundary condition on Kootenay River at 450.3 m (-0.5 m) and 452.6 m (+1.8 m). The resulting water surface profiles are shown in Figure E-27. The water profiles show that there is very little difference between the profiles for the 450.3 m and 450.8 m water levels in the Kootenay River and the effect is limited to approximately 100 m from the downstream boundary. The difference is more pronounced between the 450.8 m and the 452.6 m water levels in the Kootenay River with a noticeable backwater effect up to 1,200 m upstream from the boundary. The Highway 3A and the Railway Bridge are located approximately at station 500 m on Figure E-27. The two bridges have high clearance from the river and are not expected to be impacted by a change in the boundary condition. The reach of the Slocan River upstream of the bridges is confined with high banks and changes in the water surface elevation (WSE) is expected to translate into small differences in the flood extent.

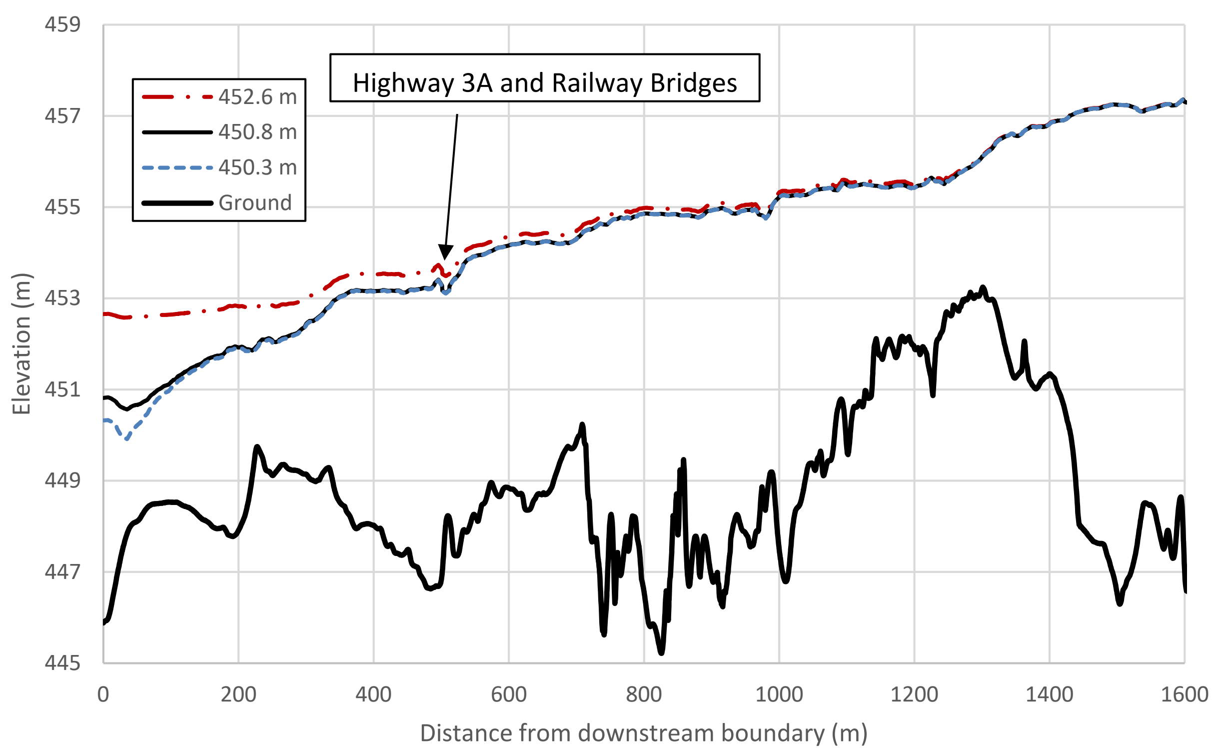



**Figure E-27. Change in WSE with the downstream boundary.**

### E.8.2. Channel Roughness

As there are limited data available for model calibration, a sensitivity analysis for Manning's n was performed. For the 200-year flood event two additional scenarios were run with the channel Manning's n increased by 10% and decreased by 10% along the channel of the Slocan River, Lemon Creek and the Little Slocan River. When the value of the channel Manning's n was increased by 10% the water surface elevations were found to increase by 0-25 cm in both the main channel and the floodplain. Similarly, a decrease in the value of channel Manning's n by 10% resulted in a decrease in water surface elevations of 1-25 cm. The change in the water surface elevation along the channel thalweg of Slocan River is shown in Figure E-28. The uncertainty associated with the roughness sensitivity is mitigated with the addition of the freeboard.

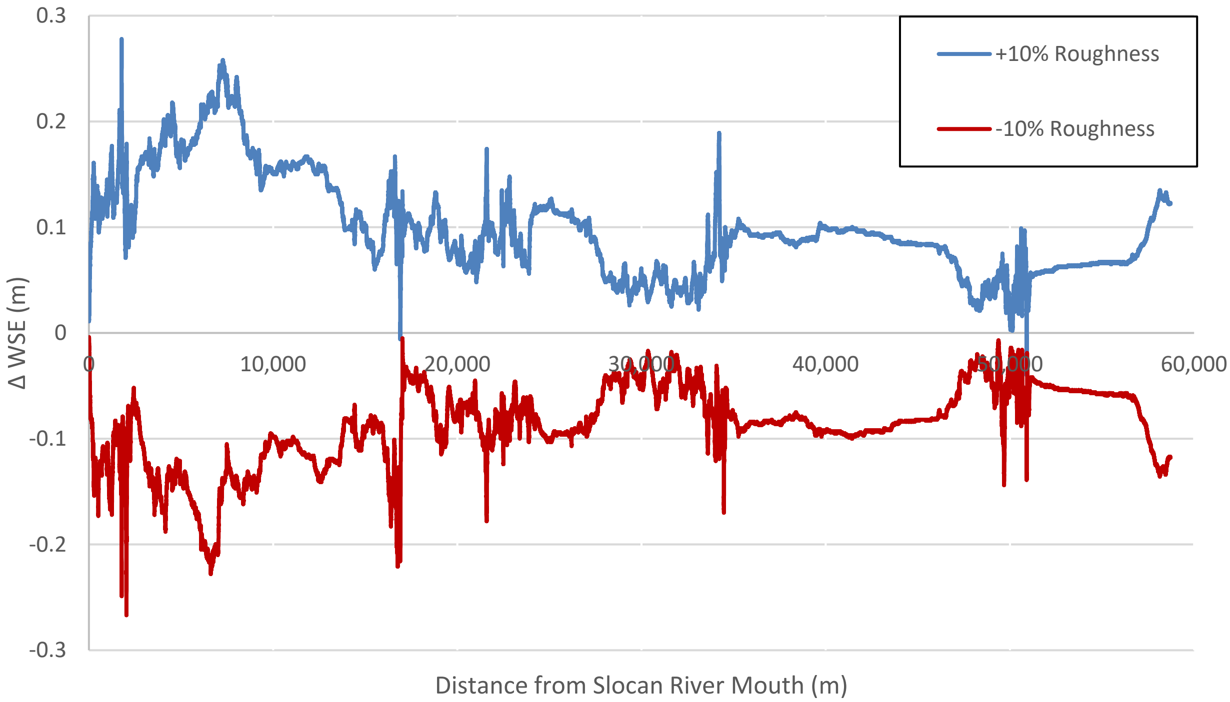



**Figure E-28. Change in WSE along the channel thalweg of the Slocan River.**

The effect of Manning's n on the WSE is generally cumulative progressing upstream until it reaches control sections where the effect is almost negligible. The downstream values in all scenarios being fixed at 450.8 m on the Kootenay River. The Manning's n sensitivity on the inundation areas for the 200-year flood event are shown in Figure E-29 to Figure E-36. The increase and decrease in roughness value both do not result in significant changes in the predicted flood extent across the study area.

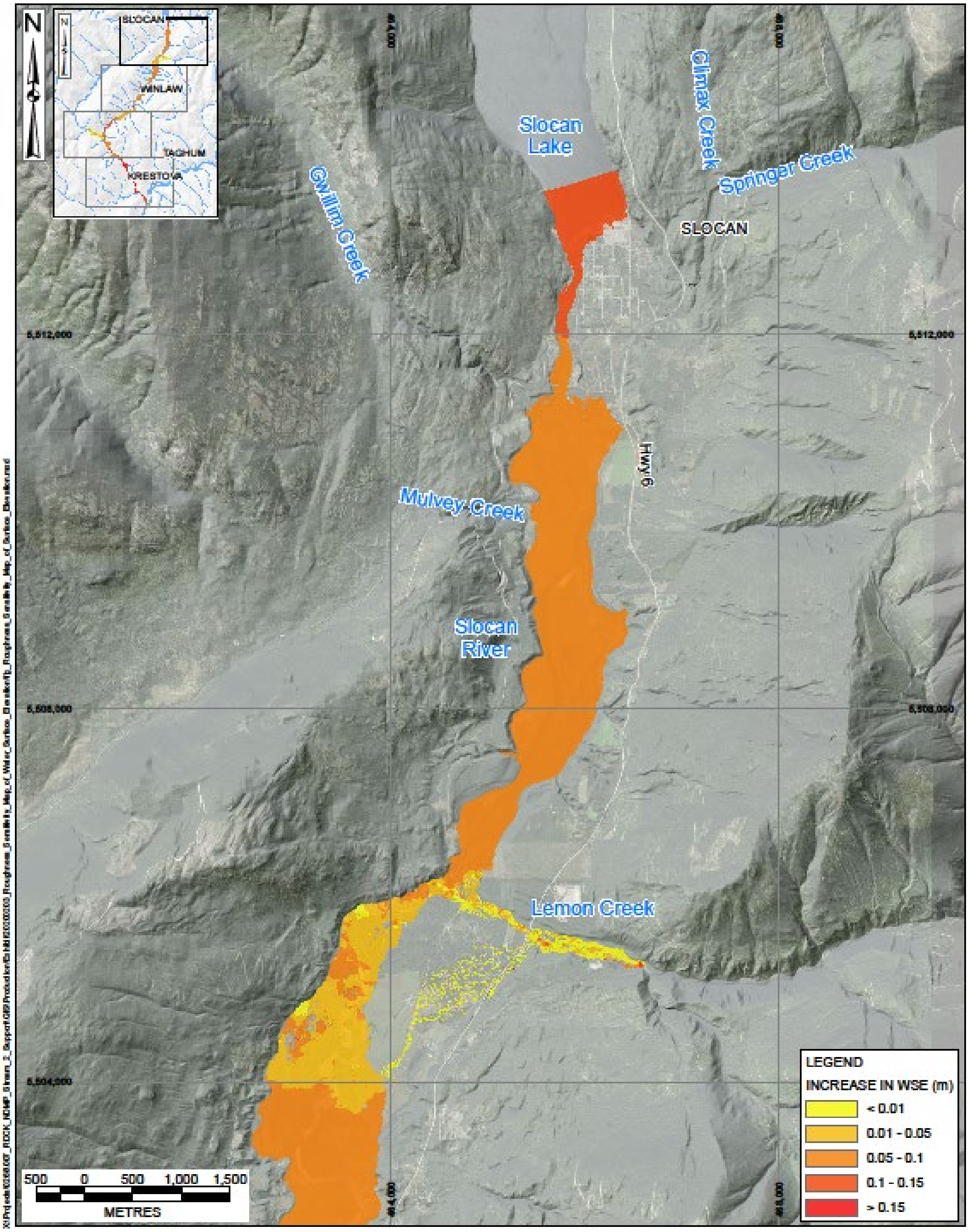



**Figure E-29. Change in WSE for 10% increase in Manning's n (200-yr flood event) Slocan Lake to Lemon Creek.**

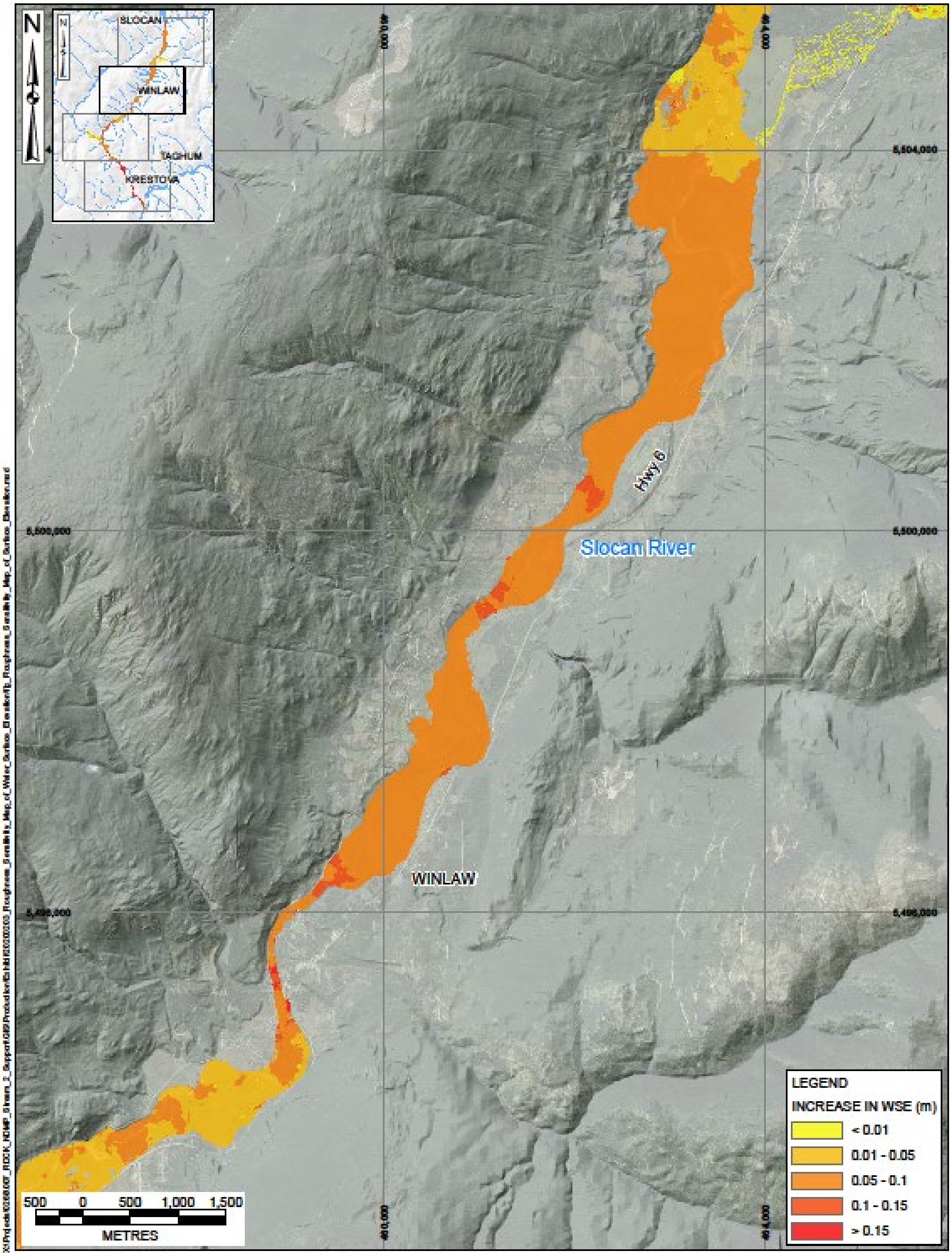



**Figure E-30. Change in WSE for 10% increase in Manning's n (200-yr flood event) Lemon Creek to Winlaw.**

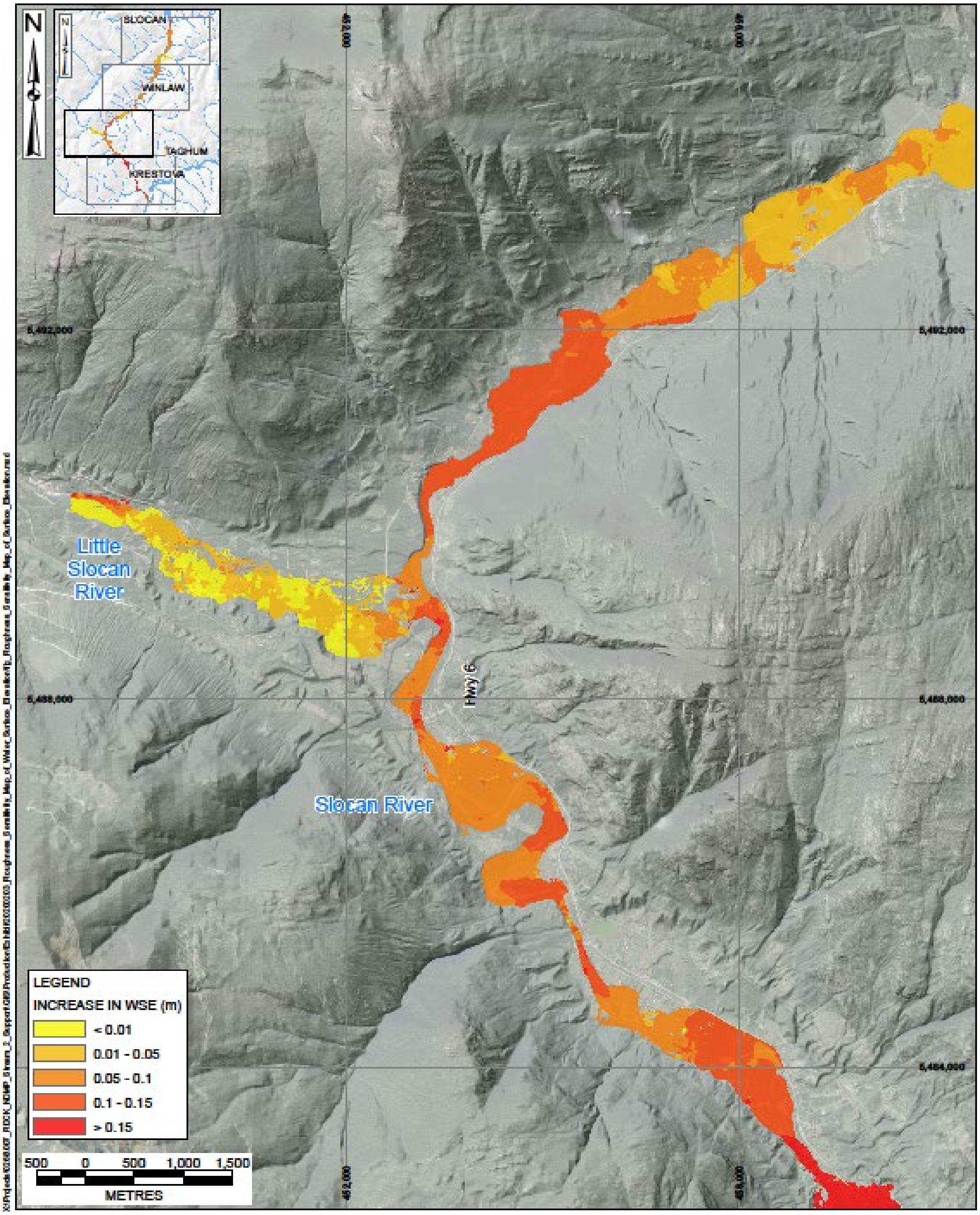



**Figure E-31. Change in WSE for 10% increase in Manning's n (200-yr flood event) Winlaw to Passmore.**

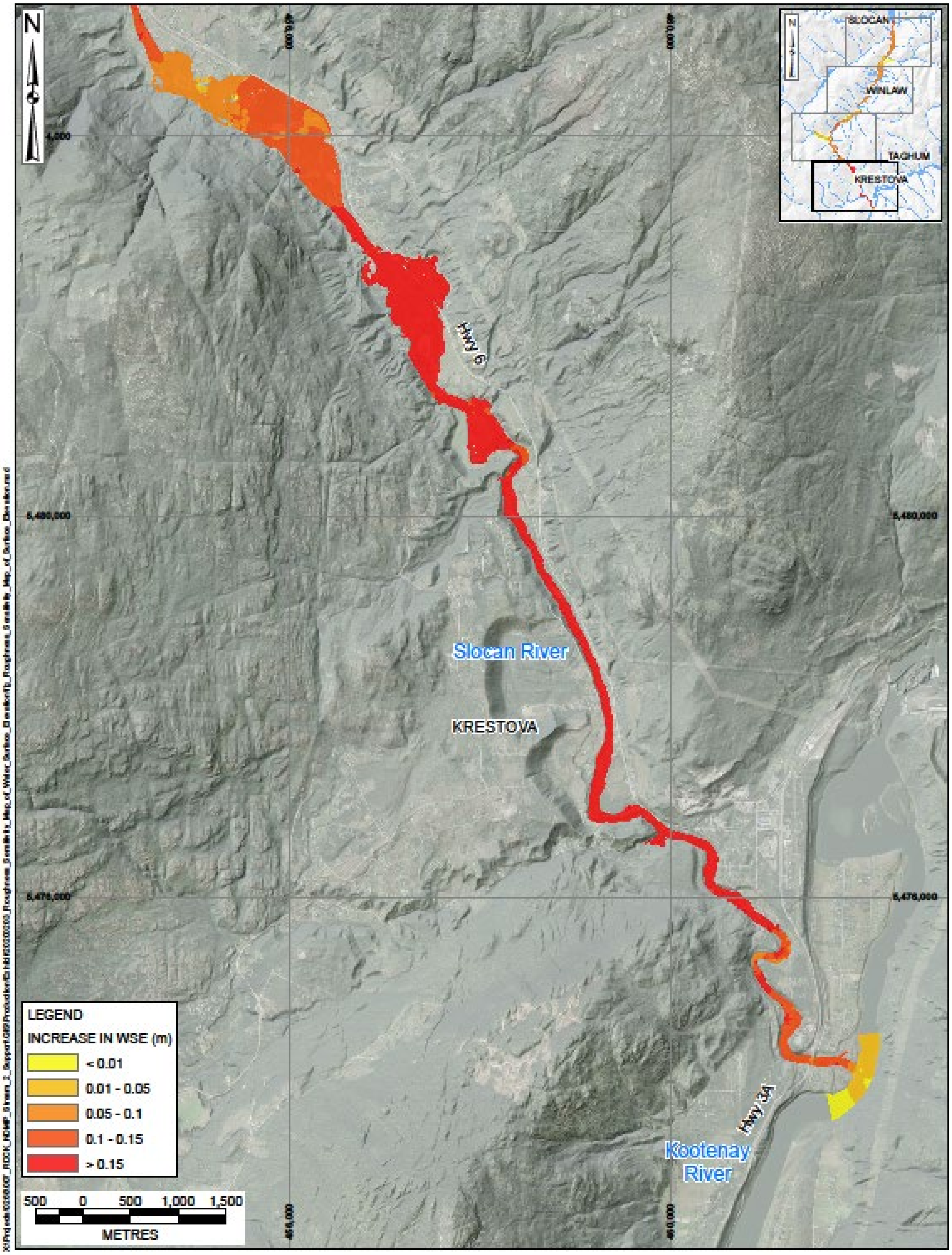



**Figure E-32. Change in WSE for 10% increase in Manning's n (200-yr flood event) Passmore to the Kootenay River.**

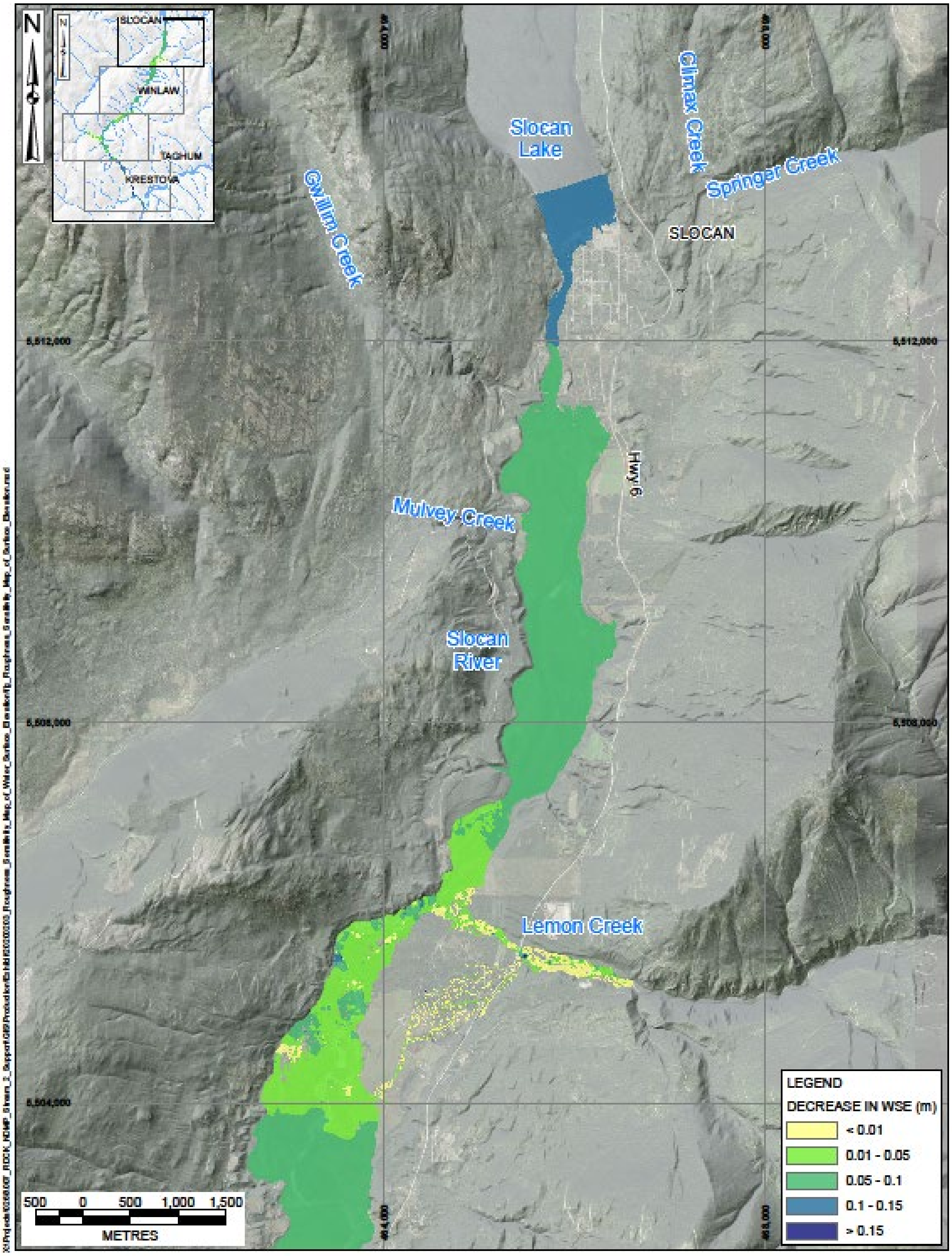



**Figure E-33. Change in WSE for 20% Decrease in Manning's n (200-yr flood event) Slocan Lake to Lemon Creek.**

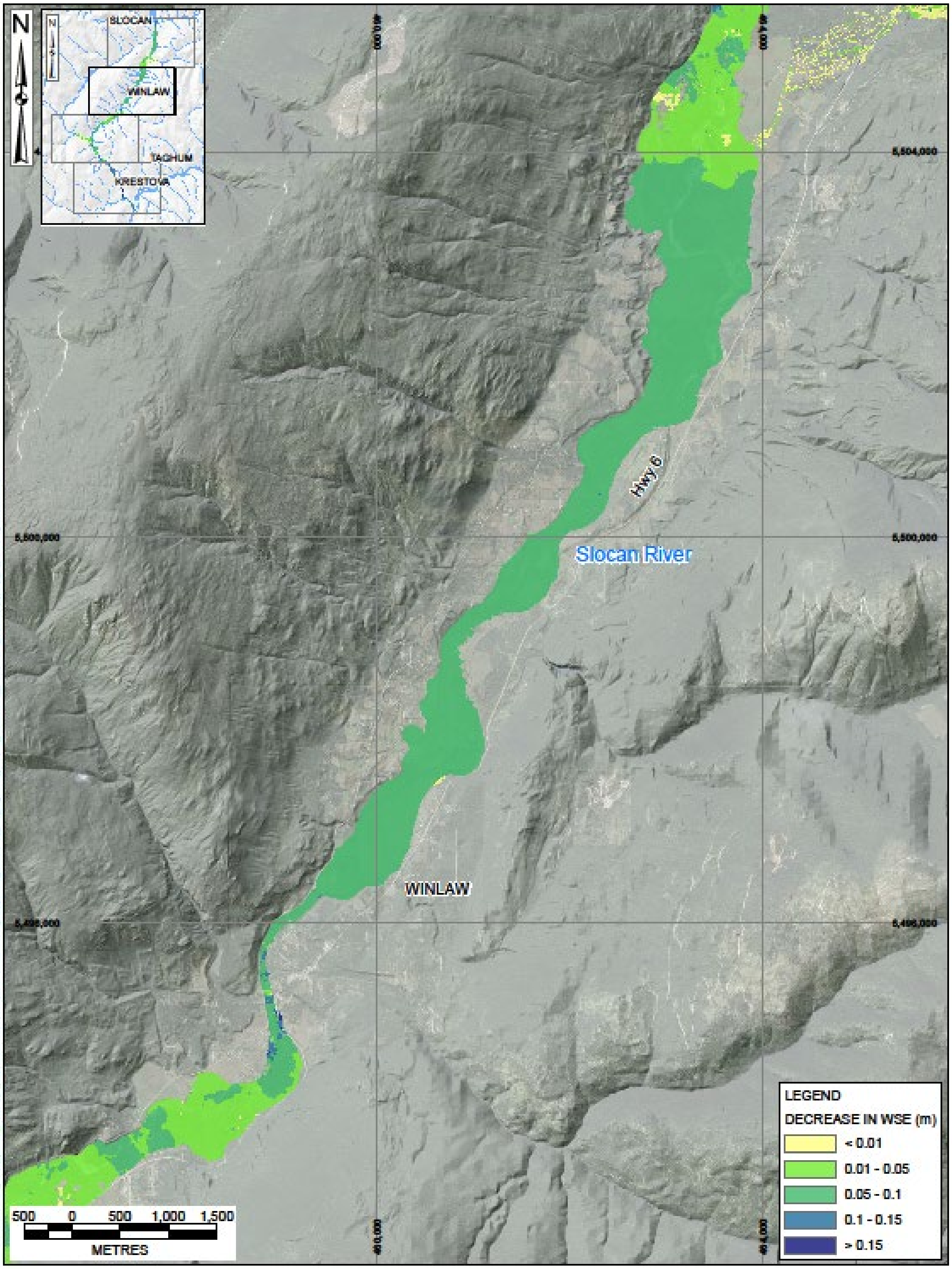



**Figure E-34. Change in WSE for 20% Decrease in Manning's n (200-yr flood event) Lemon Creek to Winlaw.**

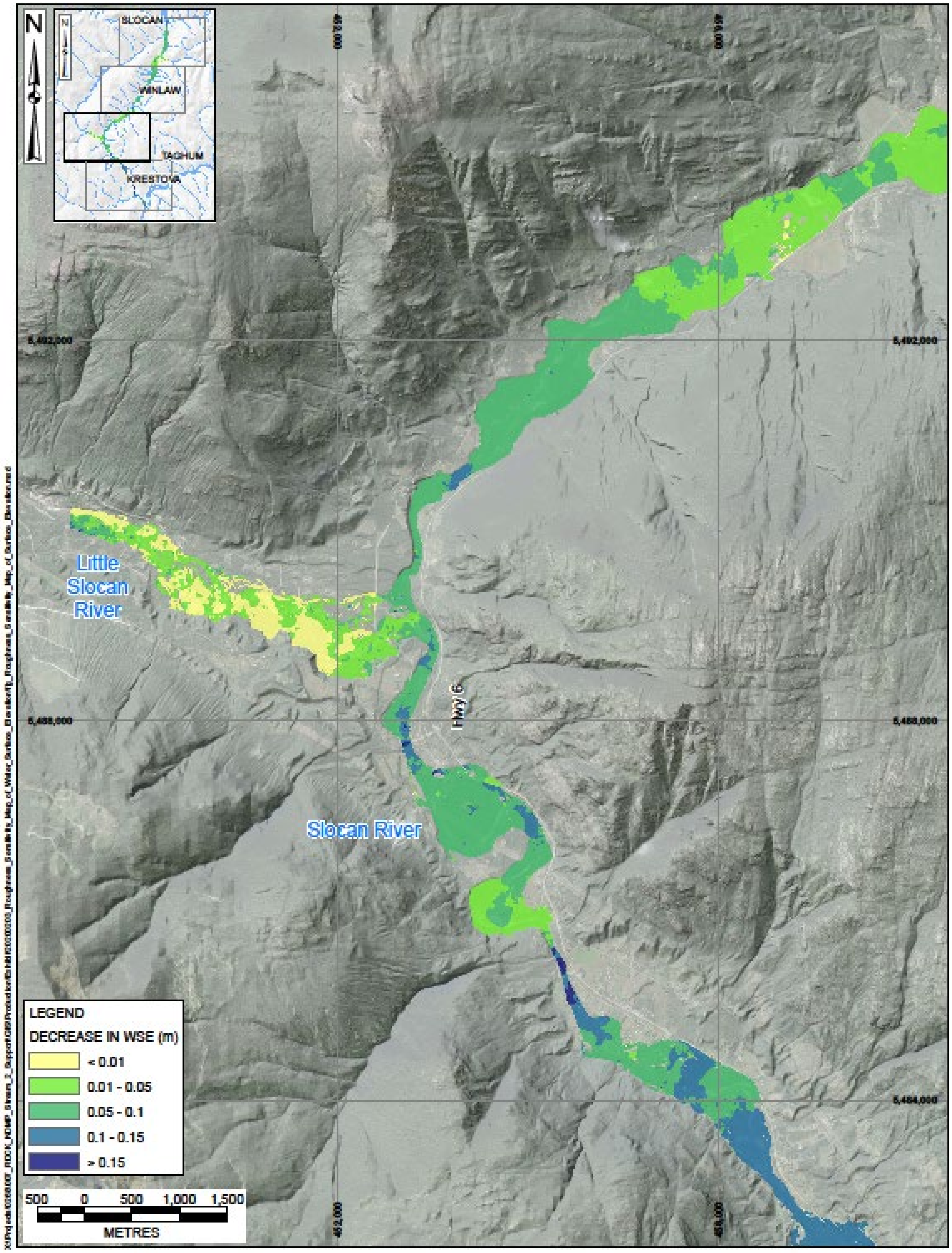



**Figure E-35. Change in WSE for 20% Decrease in Manning's n (200-yr flood event) Winlaw to Passmore.**

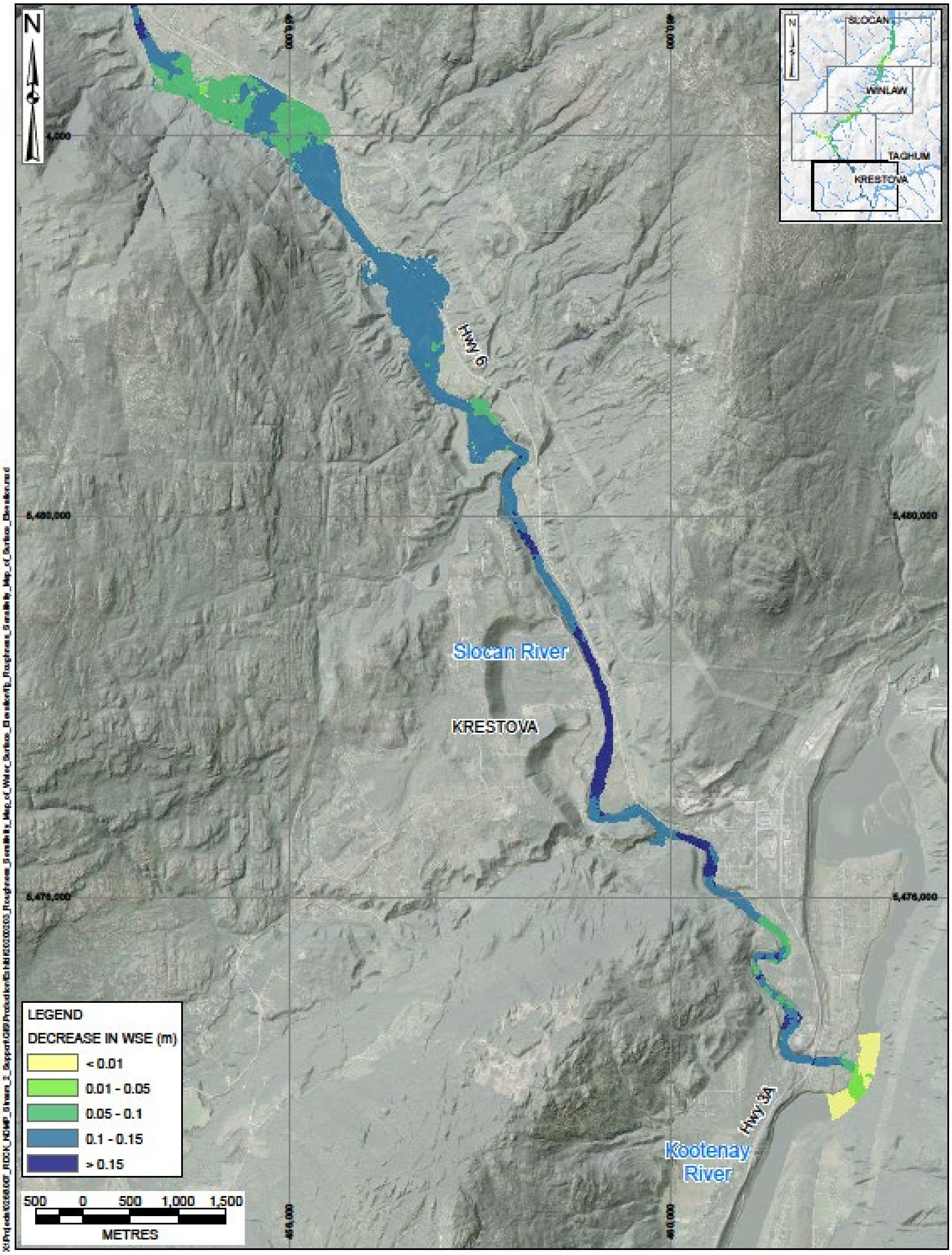



**Figure E-36. Change in WSE for 20% Decrease in Manning's n (200-yr flood event) Winlaw to Passmore.**

### E.8.3. Grid Sensitivity

The sensitivity to the grid cell size was explored following the HEC-RAS 2D user manual (Brunner & CEIWR-HEC, 2016). The final mesh has base elements of 15 m and is refined with breaklines as described in Section E.5.2. The results of the 200-year WSE were compared to results from grids with cell sizes of 25 m and 50 m. The same breaklines were enforced, although without refining the cell size. The resulting flood elevations are on average 6 cm higher for the 25 m grid and 25 cm higher on average for the 50 m grid. At narrow reaches (e.g., the confluence with Lemon Creek), both grids sometimes have only a few cells carrying the flow which is known to lead to numerical instability and inaccurate results.

## E.9. SLOCAN LAKE LEVELS

Slocan Lake is the upstream boundary of the study area and the lake levels govern the discharge at the lake outlet into the Slocan River. Three previous studies provide estimates for the flood lake levels (MoE, 1986; NHC, 1989).

In 1975, MoE performed a statistical analysis of the 31 years of maximum annual daily levels available from WSC gauge 08NJ137 (*Slocan Lake at Slocan City*). They estimated a 20-year lake level of 538.11 m (converted to CGVD 2013) and a 200-year lake level of 538.76 m using a log-normal probability distribution (MoE, 1986).

In 1986, MoE conducted a second study on the lake level frequency analysis. They developed a stage-discharge relationship using Slocan Lake maximum annual daily levels and concurrent annual maximum discharges at WSC gauge 08NJ014 (*Slocan River at Slocan City*). Averaging estimates from the log-normal and Gumbel distribution, they estimated a 20-year level of 538.03 m and a 200-year level of 538.57 m (MoE, 1986). They also performed a flood frequency analysis on the lake discharges and converted the estimated 20- and 200-year discharges to corresponding lake levels using the stage-discharge relationship. For the 20-year return period, the level obtained from the level frequency analysis and the level converted flood frequency analysis agreed closely. For the 200-year level, their estimate of the lake level from the level frequency analysis was higher than the value estimated from the level converted from the flood frequency analysis. As a result, MoE decided to lower the 200-year lake level from 538.57 m to 538.37 m. No instantaneous lake stage records were available. MoE examined the maximum daily lake level rise close to the peak and added 20 cm to the 20-year daily level to estimate the 20-year peak instantaneous level. This adjustment was judged too high for the 200-year, instead a value of 0.1 m was added to the 200-year lake level to estimate the 200-year peak level.

The present study used the results of the HEC-RAS 2D model with a steady-state inflow hydrograph into the lake to define the lake levels for the selected return periods (i.e., results are based on the channel hydraulics at the lake outlet). The simulated lake levels (without freeboard) are shown in Table E-6. The lake levels for each return period cannot be compared to previous studies because the present study uses climate adjusted peak discharges.

**Table E-6. Simulated Slocan Lake levels.**

| Return Period (years) | AEP | Slocan Lake Outflow ($m^3/s$) | Slocan Lake Levels (m) |
|---|---|---|---|
| 20 | 0.05 | 445 | 538.92 |
| 50 | 0.02 | 495 | 539.20 |
| 200 | 0.005 | 575 | 539.58 |
| 500 | 0.002 | 620 | 539.81 |

Figure E-37 shows the Slocan Lake stage-discharge relationship built using concurrent data from WSC gauges 08NJ014 (*Slocan River at Slocan City*) and 08NJ137 (*Slocan Lake at Slocan City*). The gauges were operational until 1968 and 31 years of concurrent data are available. Because the most recent data at the gauge is five decades old, it was not used to estimate Slocan Lake levels for the current study. BGC simulation results are shown in green and plot at a higher level for the same discharge than previous studies. However, the simulated lake level for the 1986 peak discharge fits closely to the curve. The differences in results are considered within the range of uncertainties and are not unreasonable in that the BGC results are based on the channel outlet hydraulics.

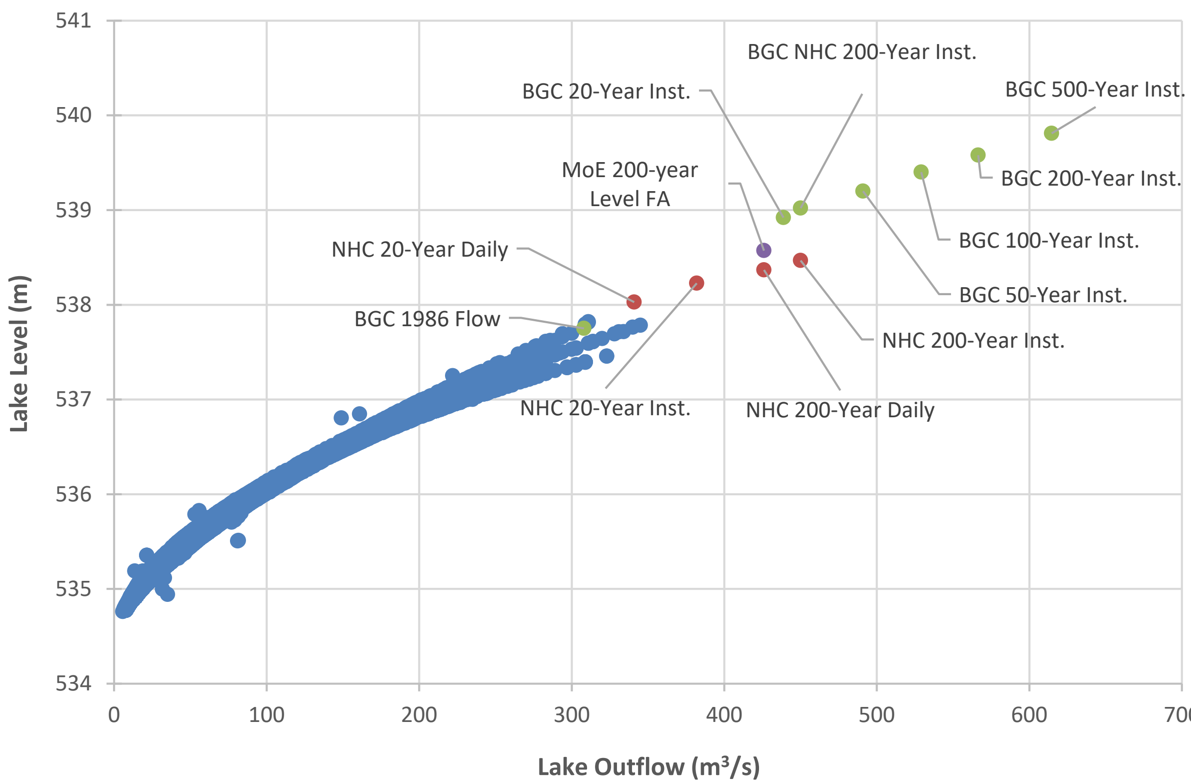



**Figure E-37. Slocan Lake stage-discharge relationship showing historical daily observations (blue), MoE estimates (purple), NHC estimates (red), and BGC estimates (green).**

#### E.9.1.1. Wave Height Prediction

Wave analysis are out of the scope of the current study. NHC (1989) analyzed the wave runup for Slocan Lake and concluded that for a combined joint frequency of 200-year return period, the 200-year daily lake level plus the 1-year storm wave height (0.72 m) governed flooding conditions on the lake.

## E.10. WATER SURFACE ELEVATION PROFILES

The simulated flood profiles along the Slocan River for the 20-year and the 200-year flood events are shown in Figure E-38 to Figure E-49. The bridge openings are indicated on the figures with the observed water elevation from June 5, 1986. The Highway 6 elevation is shown in areas where it is impacted, or water is flowing along the embankment.

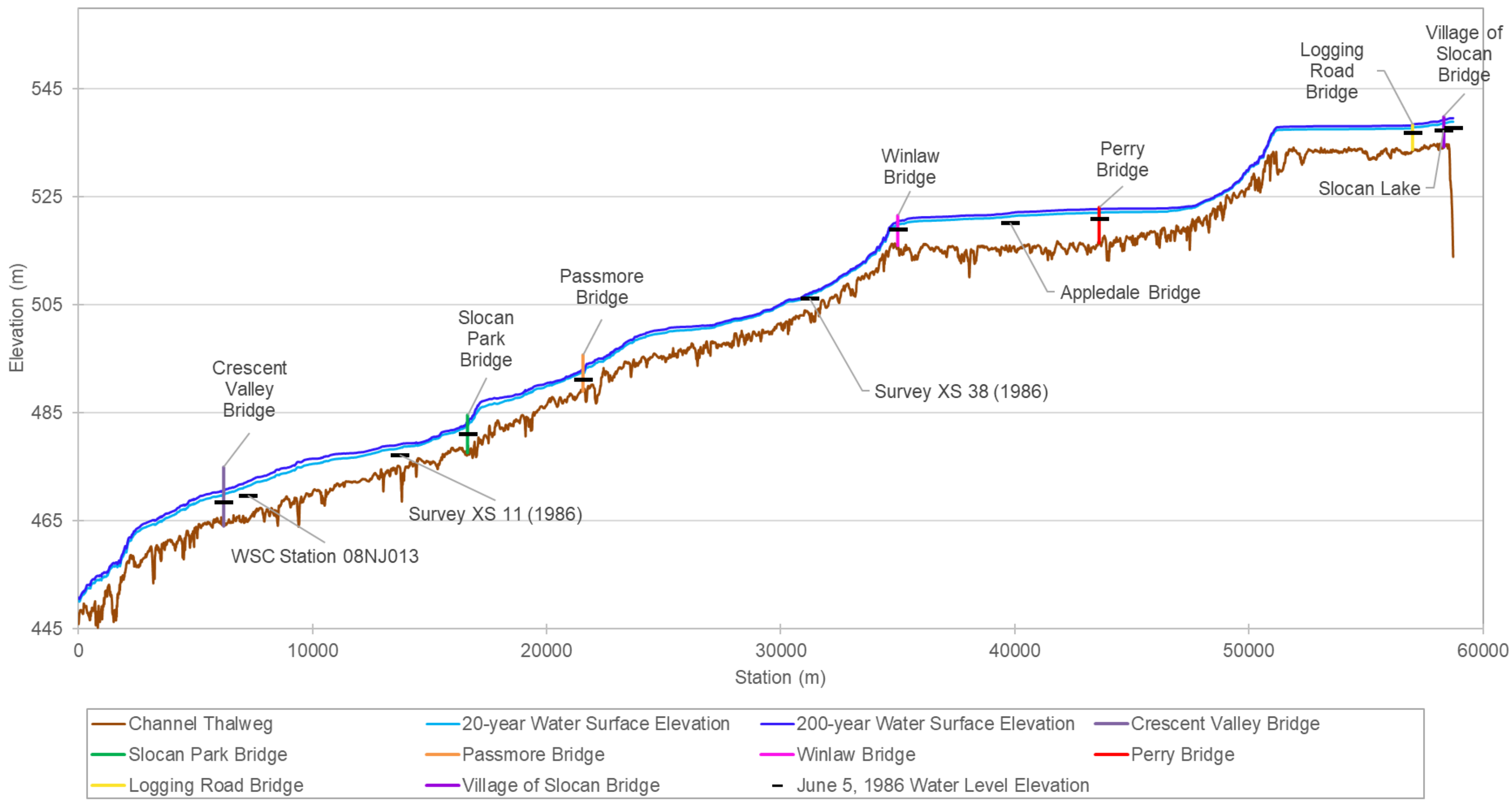



**Figure E-38. WSE profiles for 20-year and 200-year events for the Slocan River from the Kootenay River (Station 0) to Slocan Lake (Station 58650).**

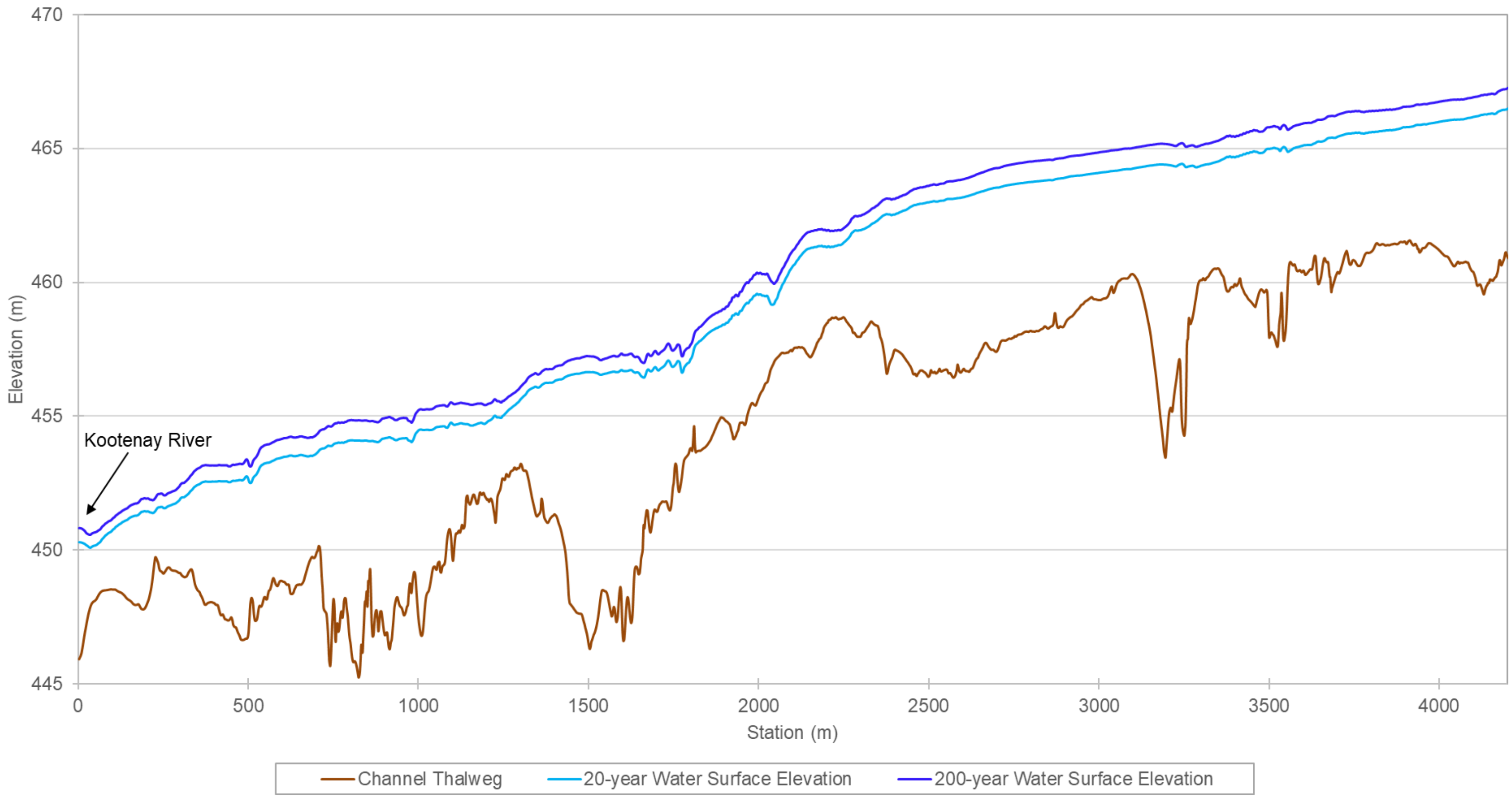



**Figure E-39. WSE profiles for 20-year and 200-year events for the Slocan River from station 0 m (Kootenay River) to 4,200 m.**

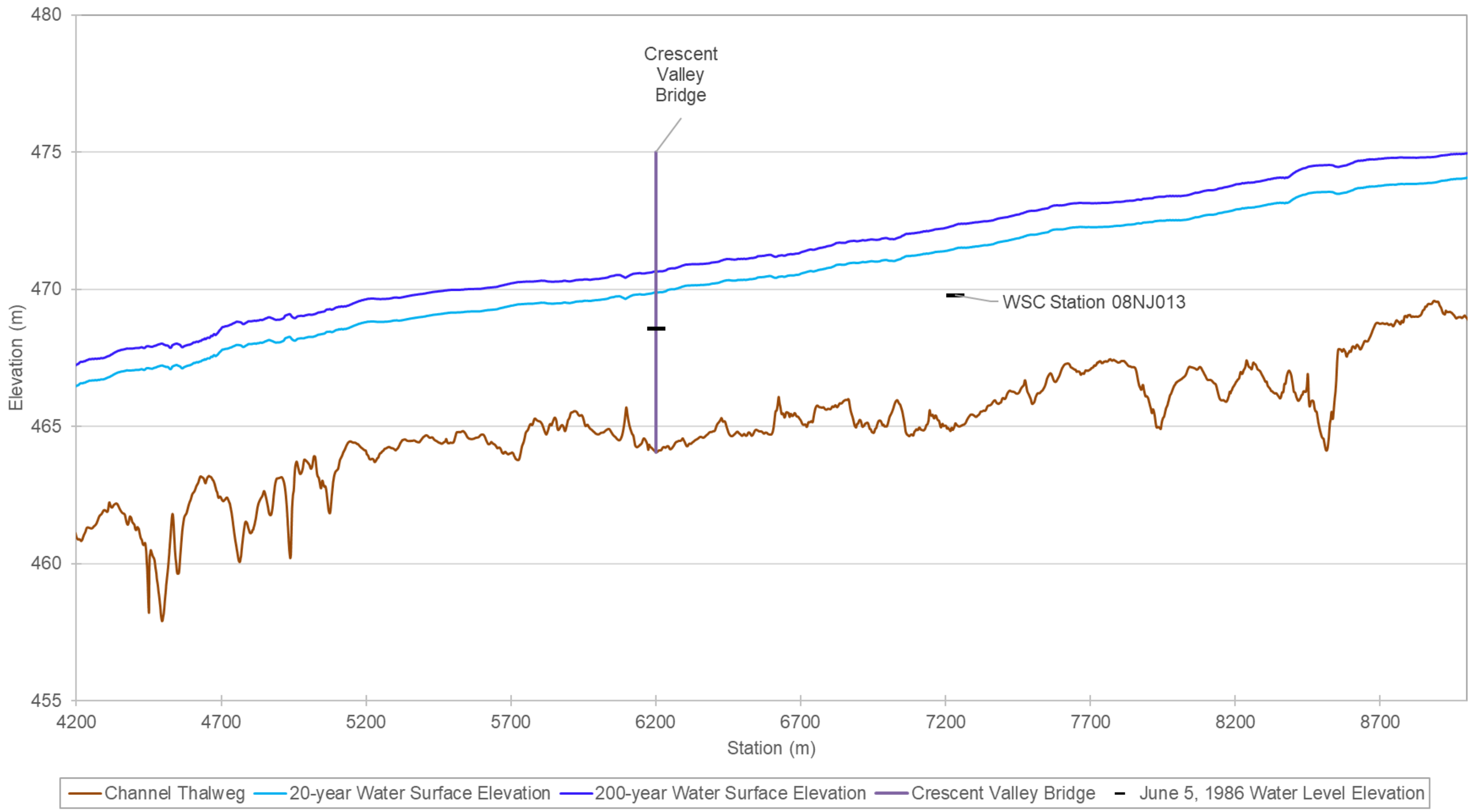



**Figure E-40. WSE profiles for 20-year and 200-year events for the Slocan River from station 4,200 m to 9,200 m.**

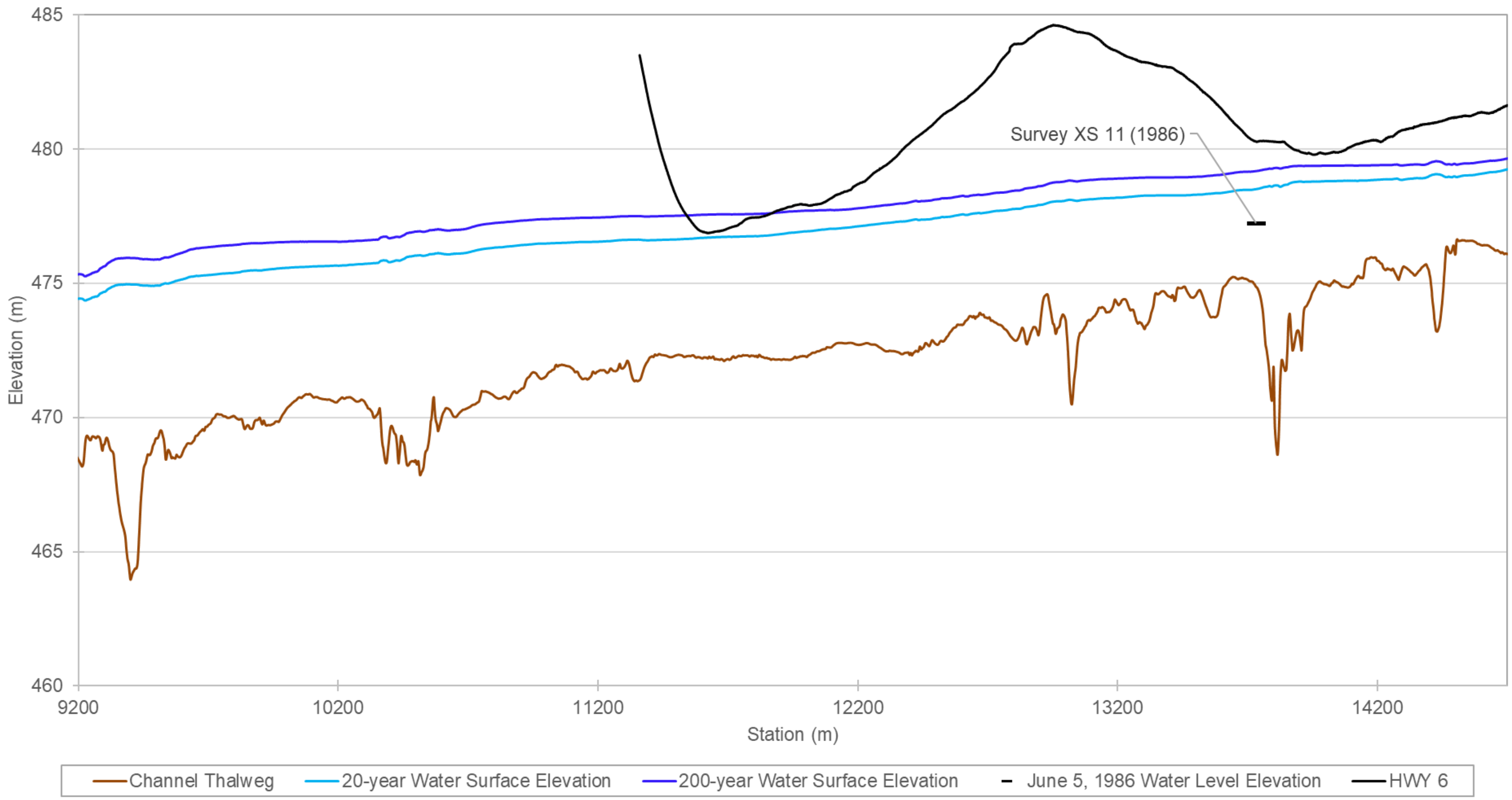



**Figure E-41. WSE profiles for 20-year and 200-year events for the Slocan River from station 9,200 m to 14,700 m.**

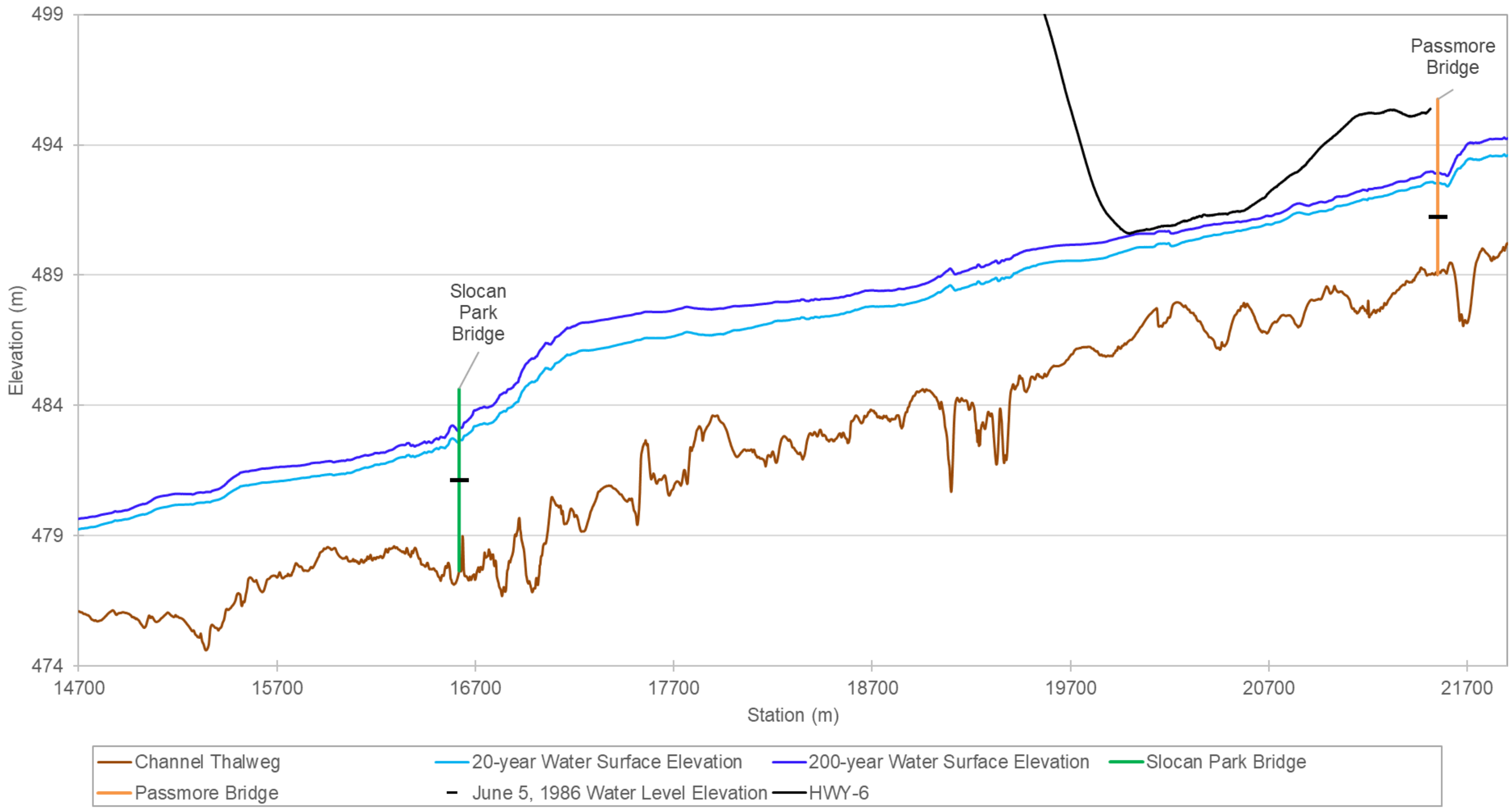



**Figure E-42. WSE profiles for 20-year and 200-year events for the Slocan River from station 14,700 m to 21,900 m.**

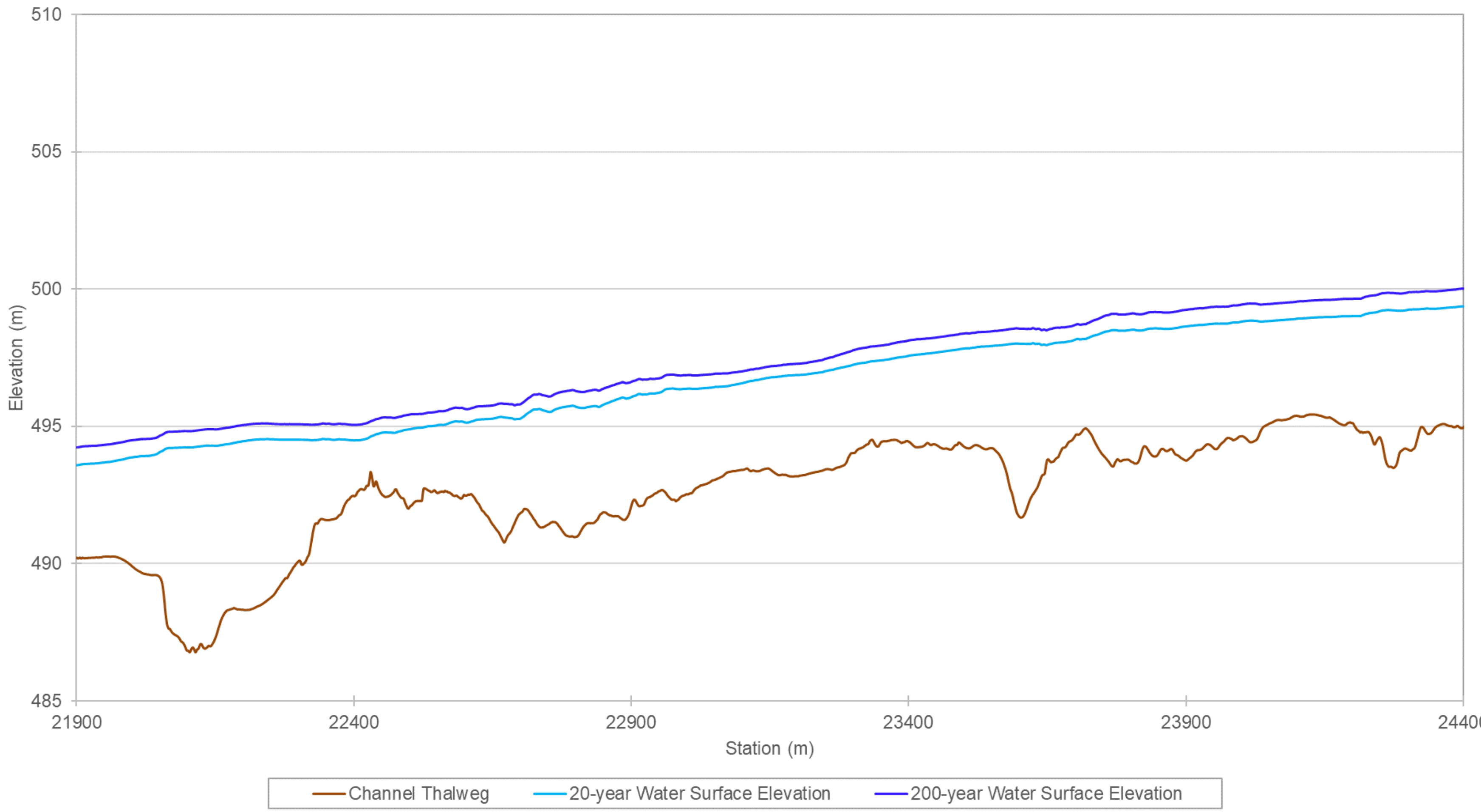



**Figure E-43. WSE profiles for 20-year and 200-year events for the Slocan River from station 21,900 m to 24,400 m.**

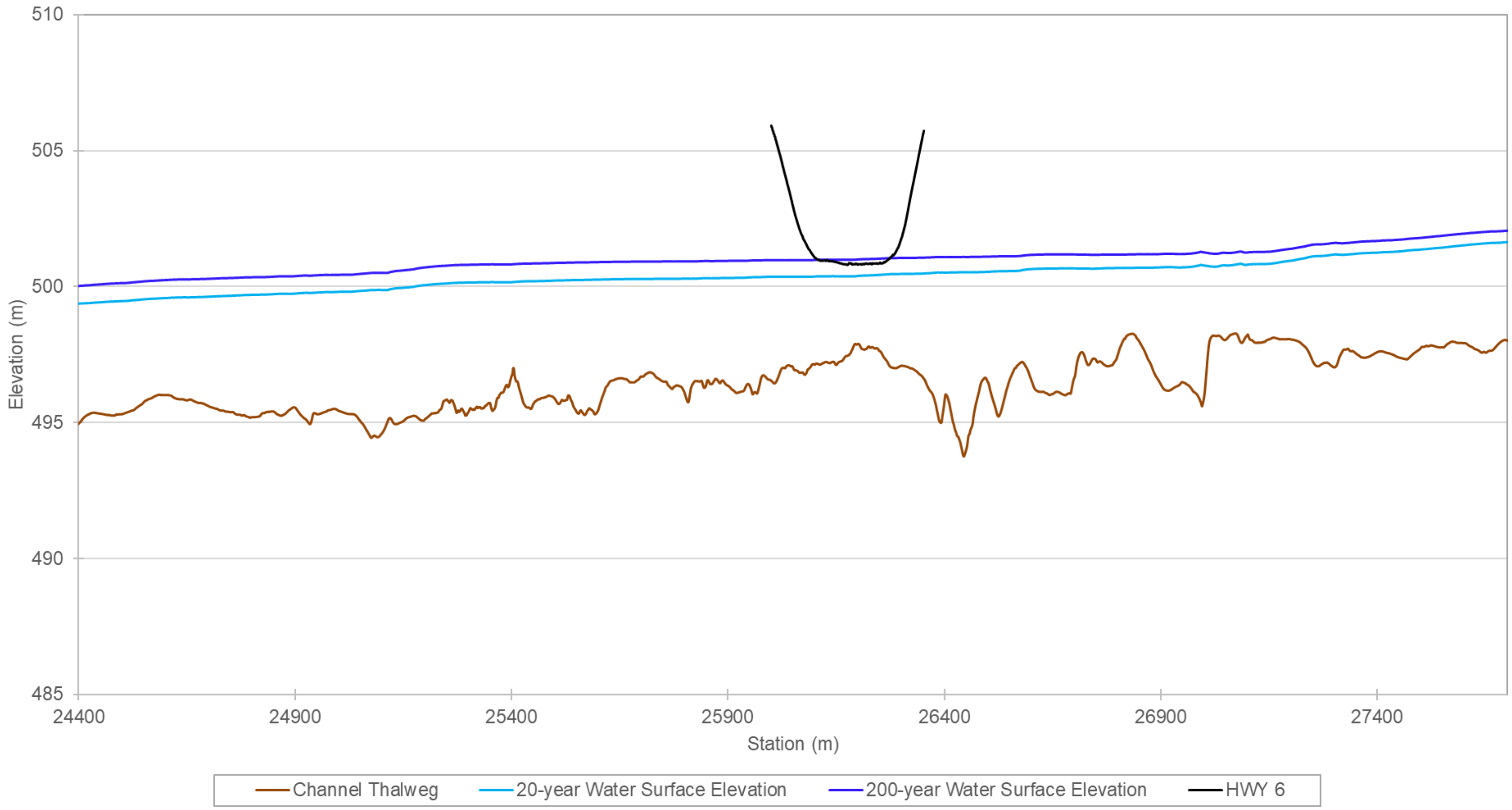



**Figure E-44. WSE profiles for 20-year and 200-year events for the Slocan River from station 24,400 m to 27,700 m.**

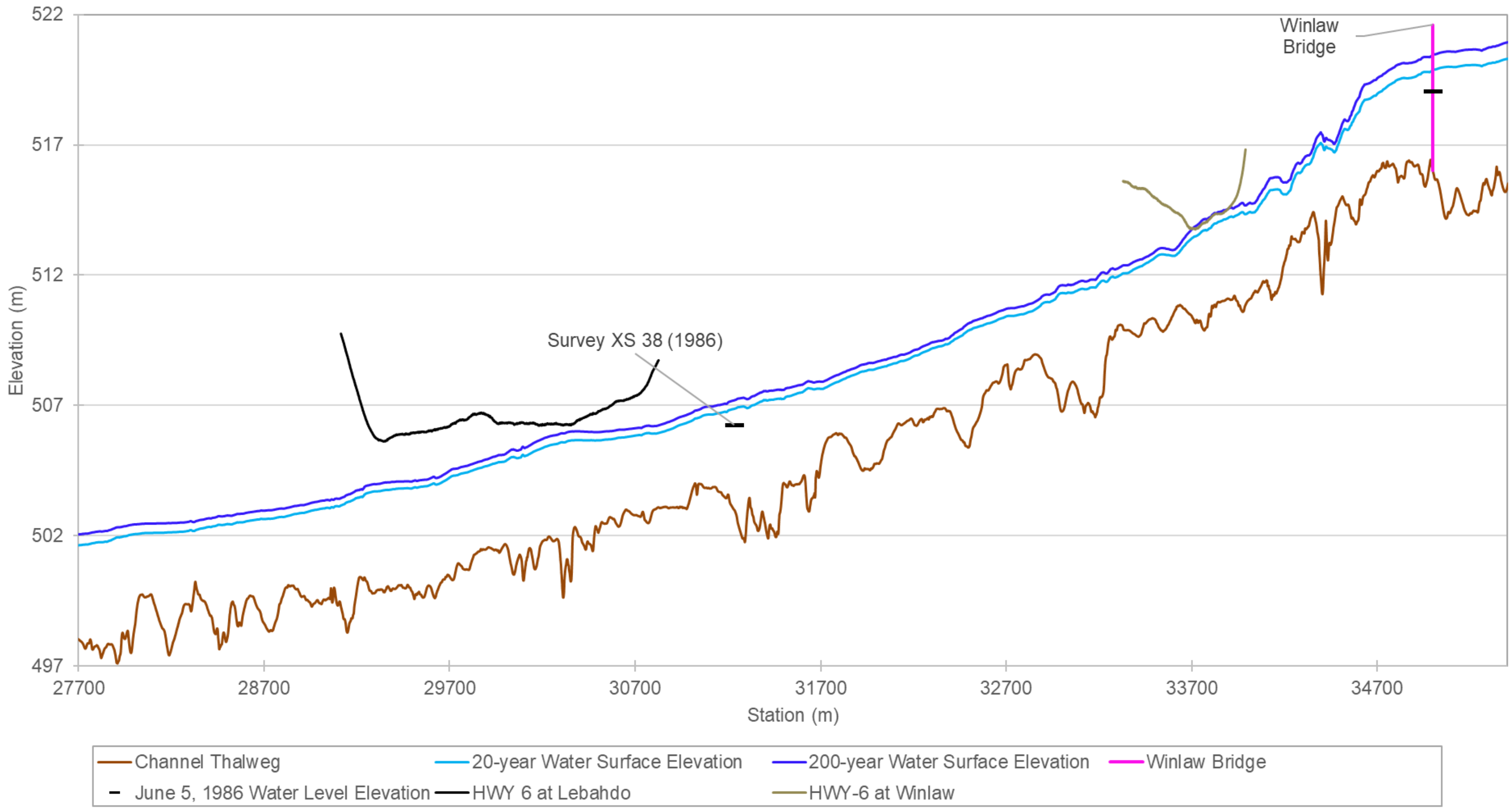



**Figure E-45. WSE profiles for 20-year and 200-year events for the Slocan River from station 27,700 m to 35,400 m.**

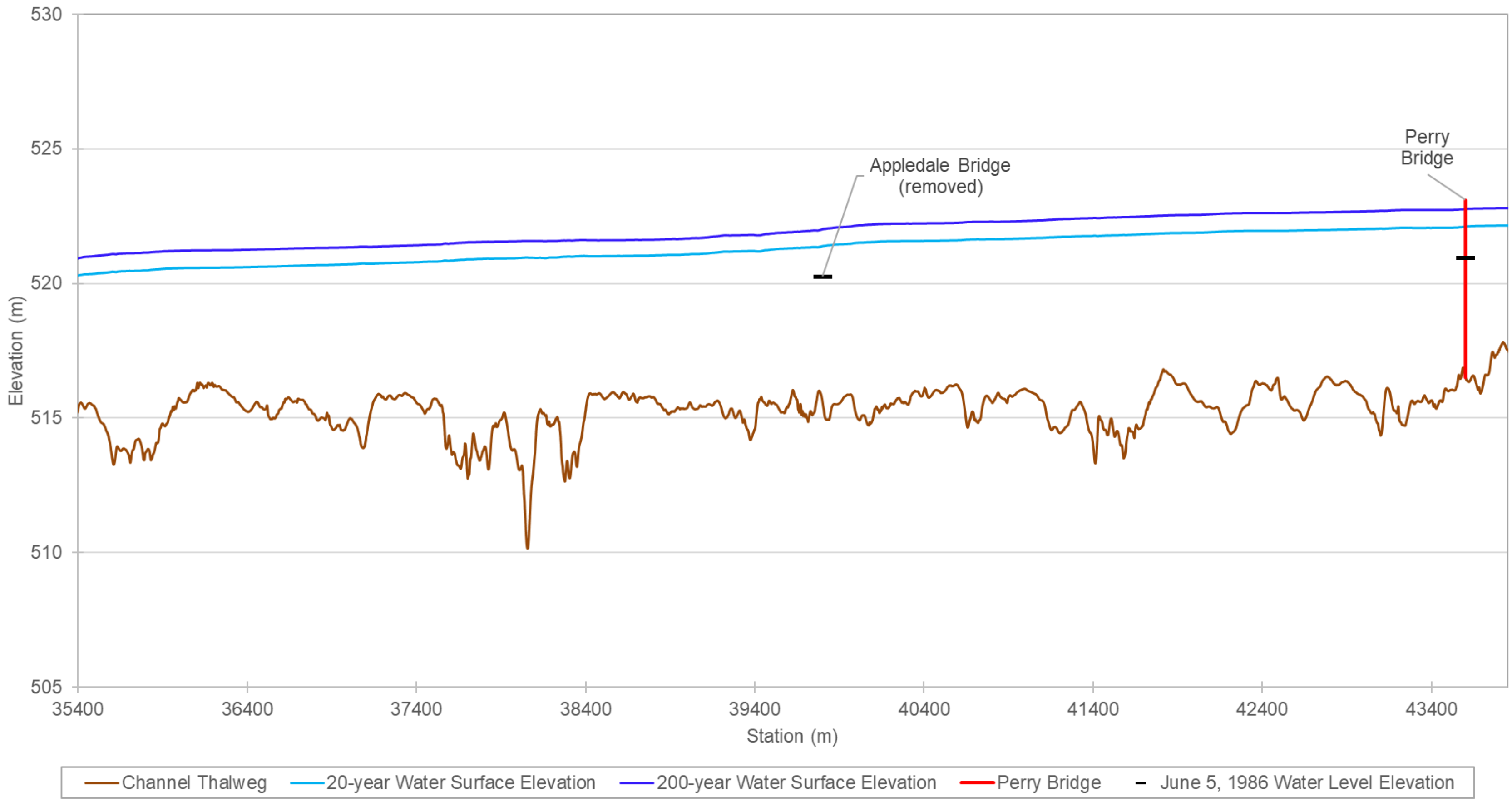



**Figure E-46. WSE profiles for 20-year and 200-year events for the Slocan River from station 35,400 m to 43,850 m.**

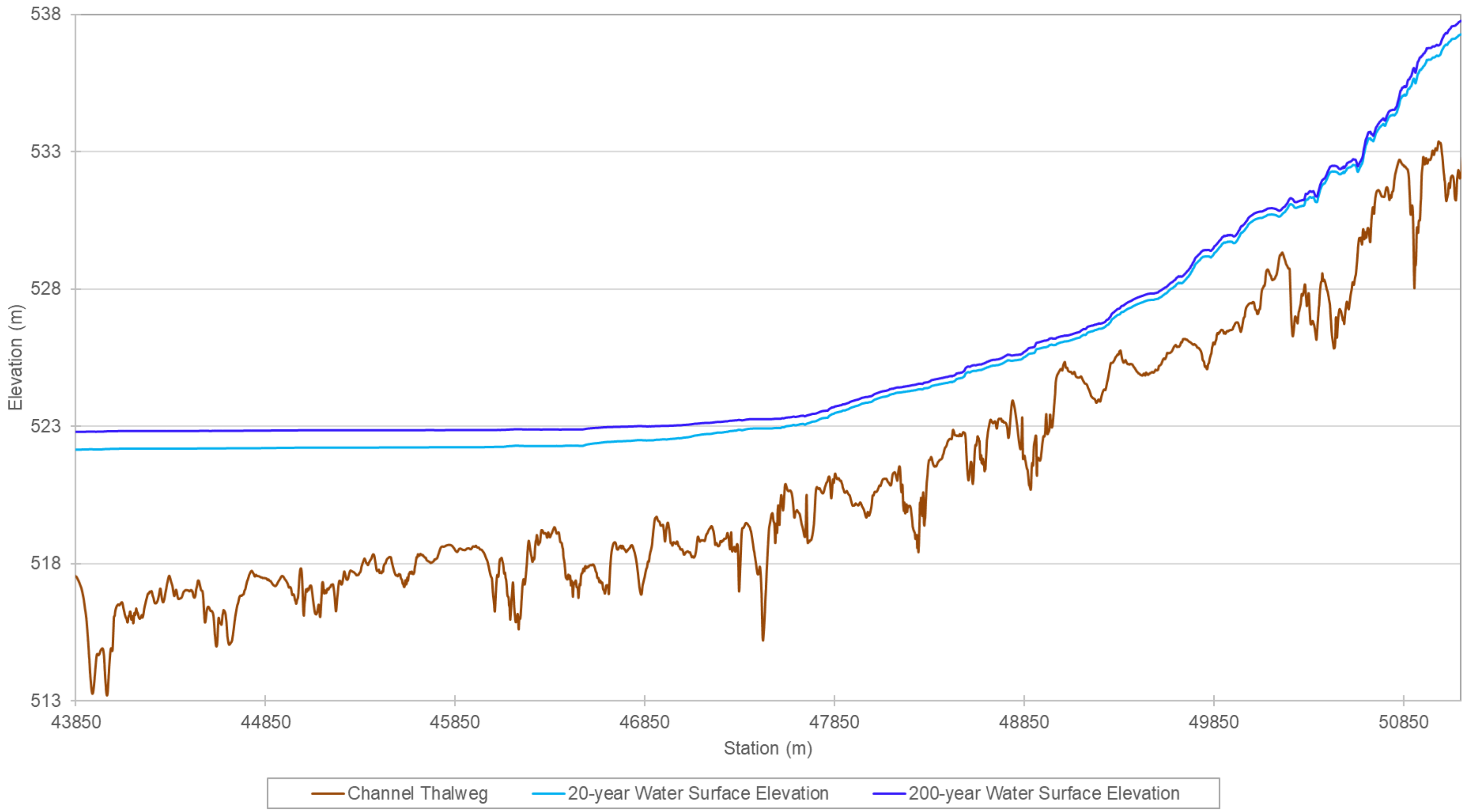



**Figure E-47. WSE profiles for 20-year and 200-year events for the Slocan River from station 43,850 m to 51,150 m.**

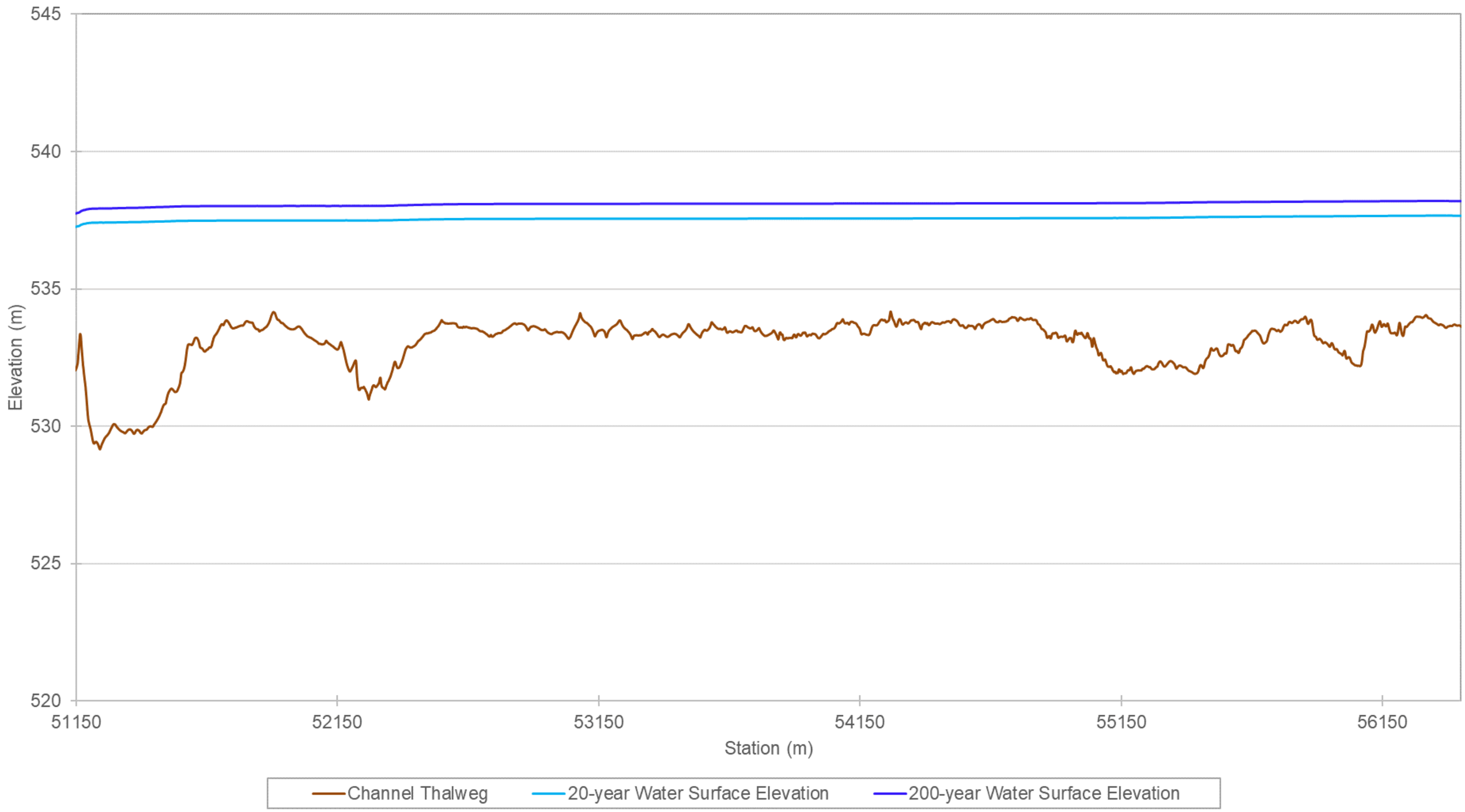



**Figure E-48. WSE profiles for 20-year and 200-year events for the Slocan River from station 51,150 m to 56,450 m.**

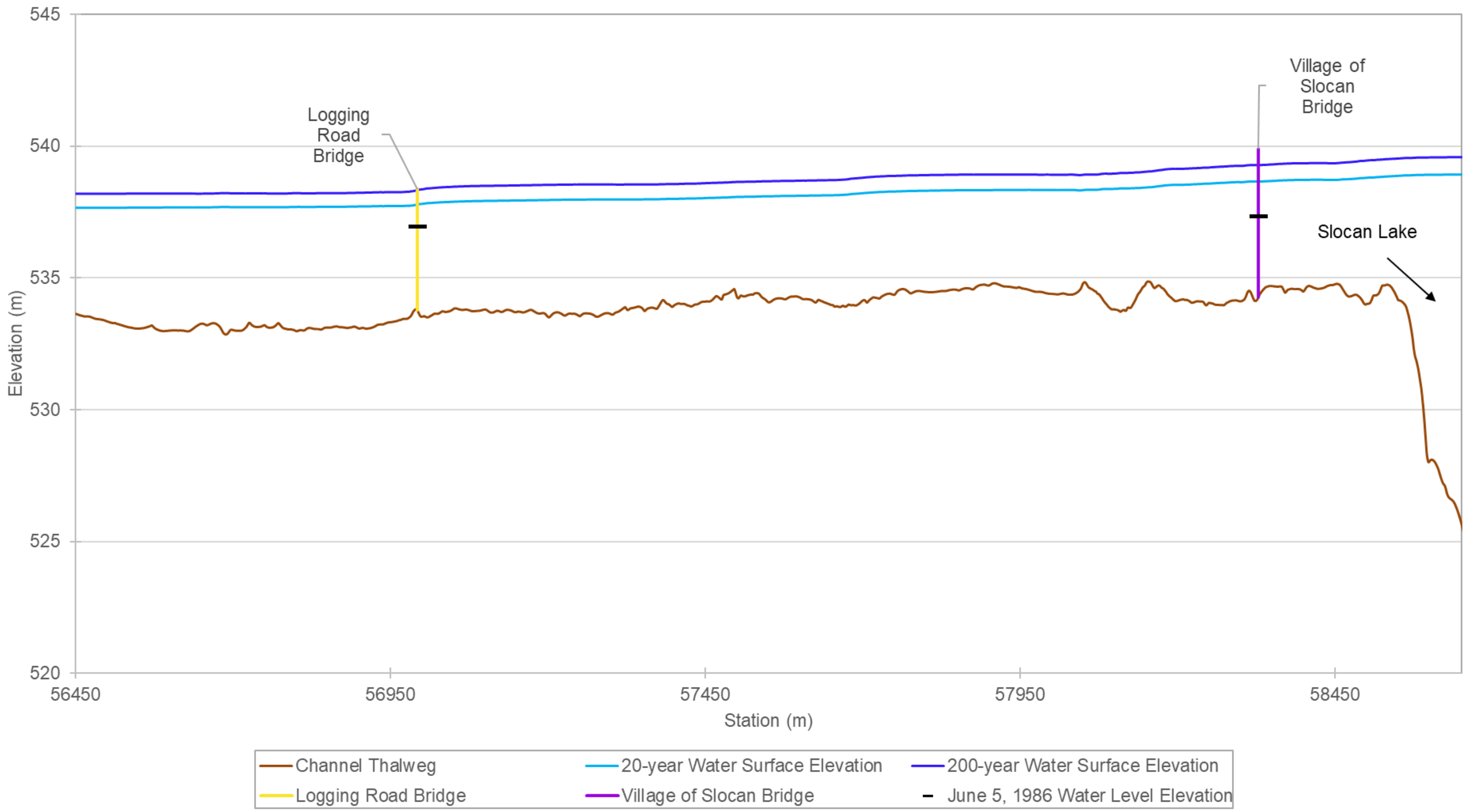



**Figure E-49. WSE profiles for 20-year and 200-year events for the Slocan River from station 56,450 m to 58,650 m.**

# REFERENCES

BC Ministry of Environment, Water Investigations Branch. (1986). *Slocan River Area Frequency Analysis (Memorandum)*.

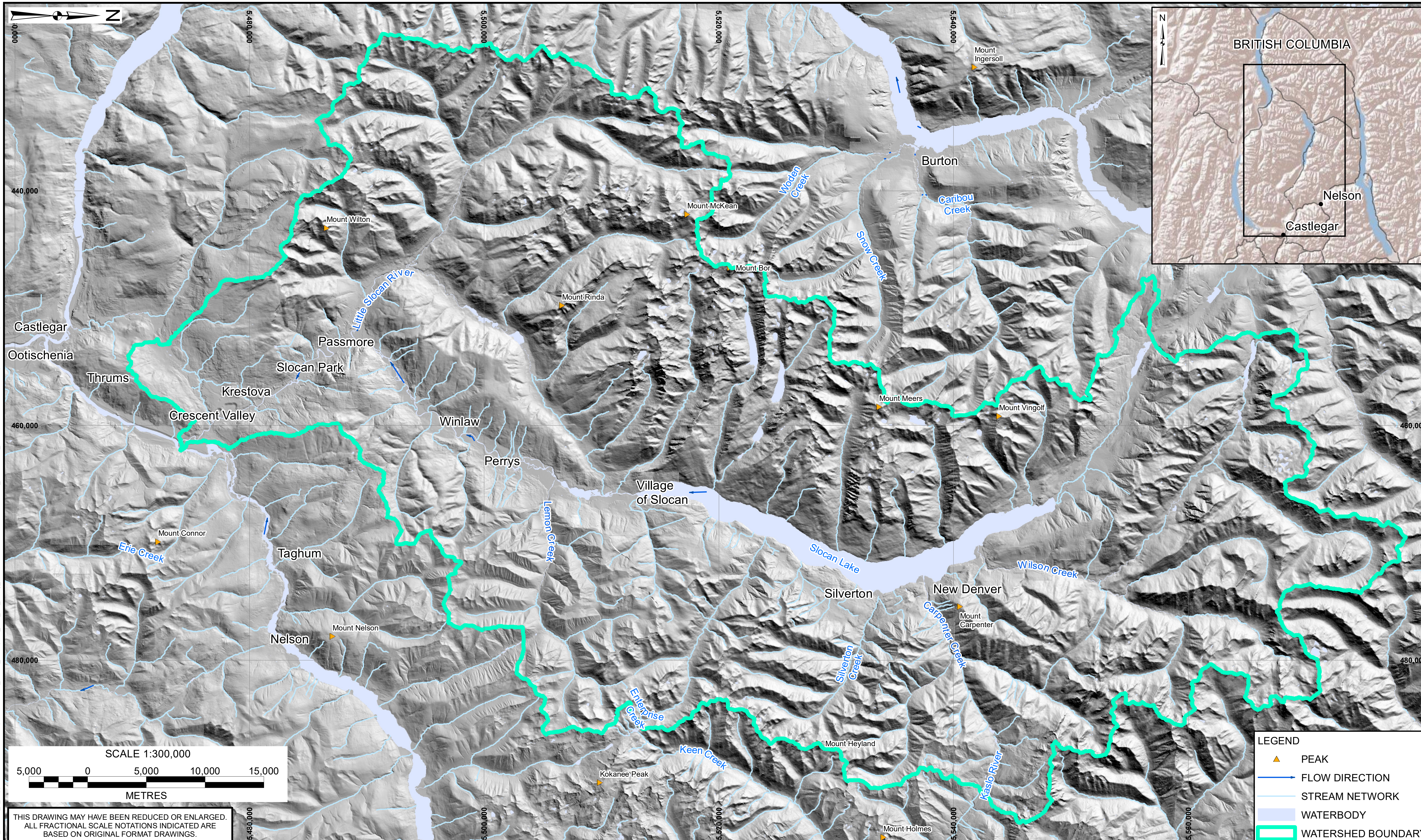
Brunner, G. W., & CEIWR-HEC. (2016). HEC-RAS River Analysis System 2D Modeling User's Manual. Retrieved from www.hec.usace.army.mil

Chow, V.T. (1959). Open-channel hydraulics. New York, McGraw-Hill, 680 p.

Natural Resources Canada (NRCan). (2019, November 28). 2015 land cover of Canada – Landsat-8 [Data]. Resolution 30-metre. Retrieved from https://www.nrcan.gc.ca/science-and-data/science-and-research/earth-sciences/geography/topographic-information/whats-new/2015-land-cover-canada-landsat-8-30-metre-resolution-now-available/22427

Northwest Hydraulic Consultants. (1989, February). *Floodplain Mapping Study Slocan River, British Columbia – Design Brief*. Prepared for Water Management Branch, Ministry of Environment, Province of British Columbia.

# DRAWINGS




X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191030_RDCK_Floodplain_And_SC_Study_CLEARWATER\SlocanRiver\FINAL_COPIES\01_SlocanRiverSiteLocationMap.mxd Date: April 20, 2020 Time: 11:53 AM

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY - SLOCAN RIVER ", AND DATED MARCH 2020.
3. WHERE AVAILABLE, BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY REGIONAL DISTRICT OF CENTRAL KOOTENAY, DATED 2018 AND DISPLAYED AS A HILLSHADE. IF LIDAR WAS NOT AVAILABLE, BASE TOPOGRAPHIC DATA BASED ON SRTM DATA FROM 2018 AND CDED DATA FROM 2015.
4. COORDINATE SYSTEM IS NAD 1983 CSRS UTM Zone 11N.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT.
BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC.
ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

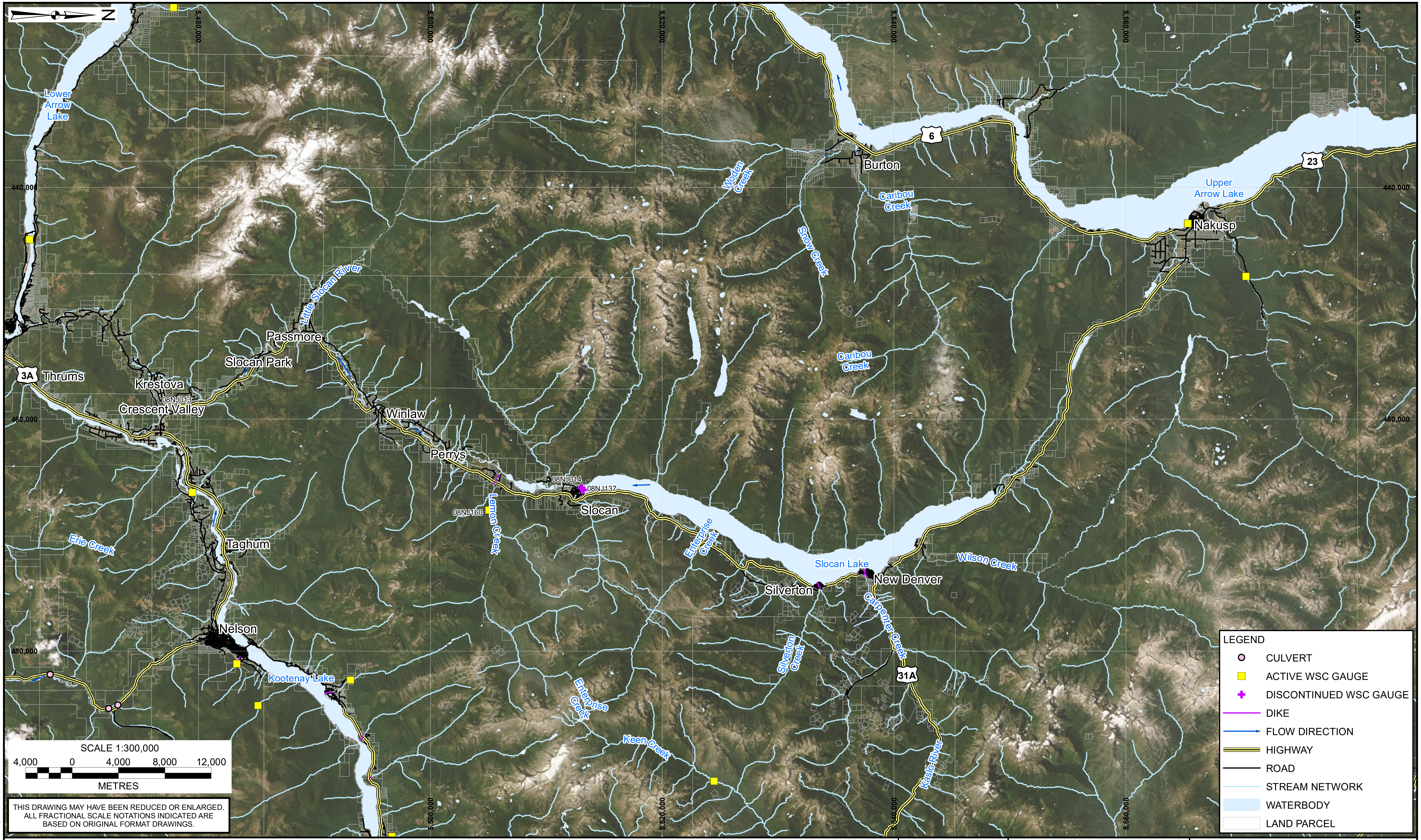
| | |
|---|---|
| SCALE: | 1:300,000 |
| DATE: | MAR 2020 |
| DRAWN: | MW |
| CHECKED: | ES |
| APPROVED: | HW |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY
CLIENT:

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY
SLOCAN RIVER

TITLE: SITE LOCATION MAP

| PROJECT No.: | DWG No.: |
|---|---|
| 0268-007 | 01 |




X:\Projects\0268007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191030_RDCK_Floodplain_And_SC_Study_CLEARWATER\SlocanRiver\FINAL_COPIES\02_SlocanRiverSiteWatershedMap.mxd Date: April 20, 2020 Time: 11:54 AM

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY - SLOCAN RIVER ", AND DATED MARCH 2020.
3. BASE IMAGERY SOURCED FROM ESRI GLOBAL IMAGERY SERVICE.
4. COORDINATE SYSTEM IS NAD 1983 CSRS UTM Zone 11N.
5. DIKE LOCATIONS FROM FLOOD AND PROTECTION WORKS: STRUCTURAL WORKS DATASET PROVIDED BY BC MFLNRO (2017).
6. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:300,000 |
| DATE: | MAR 2020 |
| DRAWN: | MW |
| CHECKED: | ES |
| APPROVED: | HW |

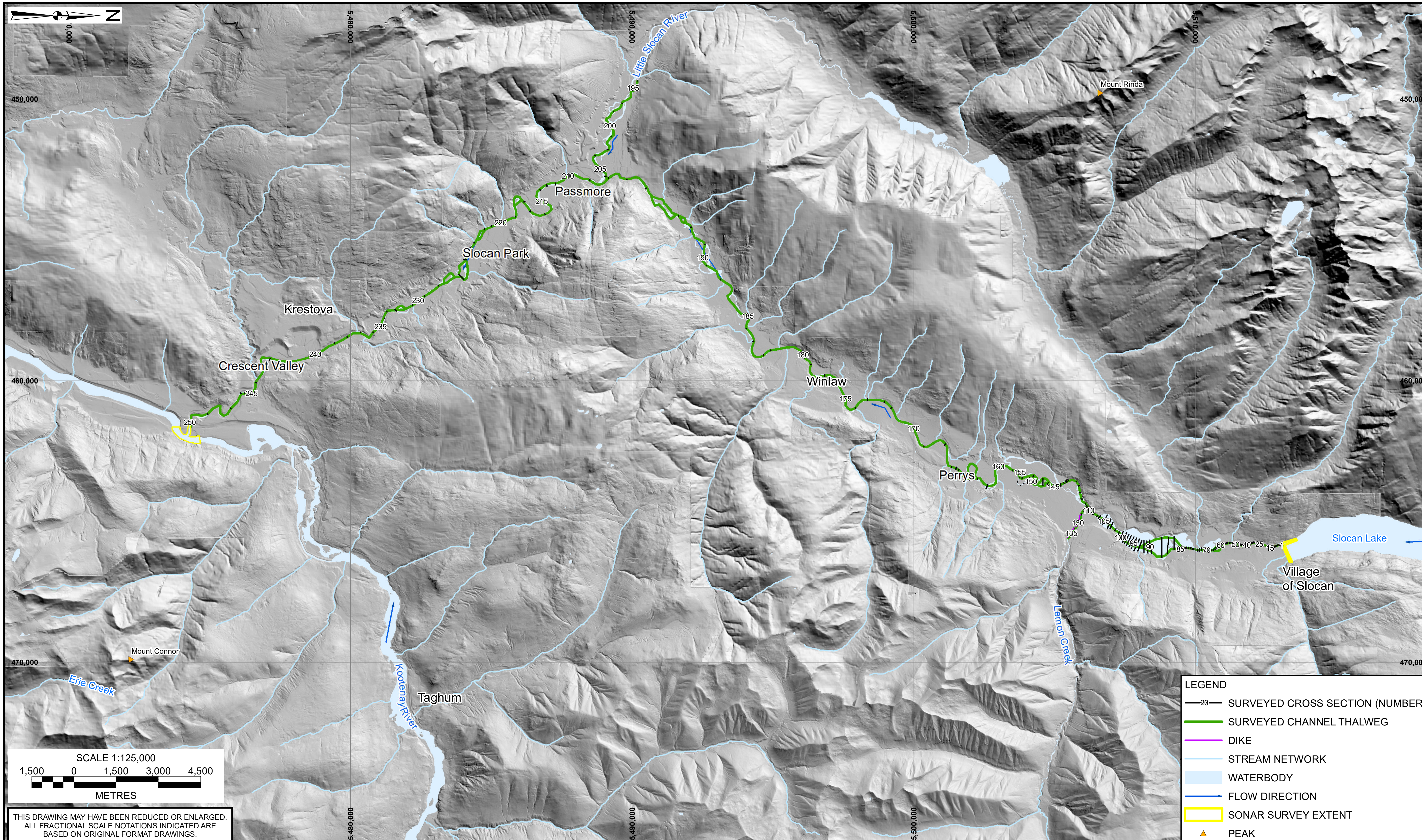
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY
SLOCAN RIVER

TITLE:
WATERSHED OVERVIEW MAP

| PROJECT No.: | DWG No: |
|---|---|
| 0268-007 | 02 |




NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY - SLOCAN RIVER ", AND DATED MARCH 2020.
3. WHERE AVAILABLE, BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY REGIONAL DISTRICT OF CENTRAL KOOTENAY, DATED 2018 AND DISPLAYED AS A HILLSHADE. IF LIDAR WAS NOT AVAILABLE, BASE TOPOGRAPHIC DATA BASED ON SRTM DATA FROM 2018.
4. COORDINATE SYSTEM IS NAD 1983 CSRS UTM ZONE 11N.
5. DIKE LOCATIONS FROM FLOOD PROTECTION WORKS: STRUCTURAL WORKS DATASET, AND CULVERT LOCATIONS FROM CULVERT DATASET, BOTH PROVIDED BY BC MFLNRO (2017).
6. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:125,000 |
| DATE: | MAR 2020 |
| DRAWN: | MW |
| CHECKED: | ES |
| APPROVED: | HW |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

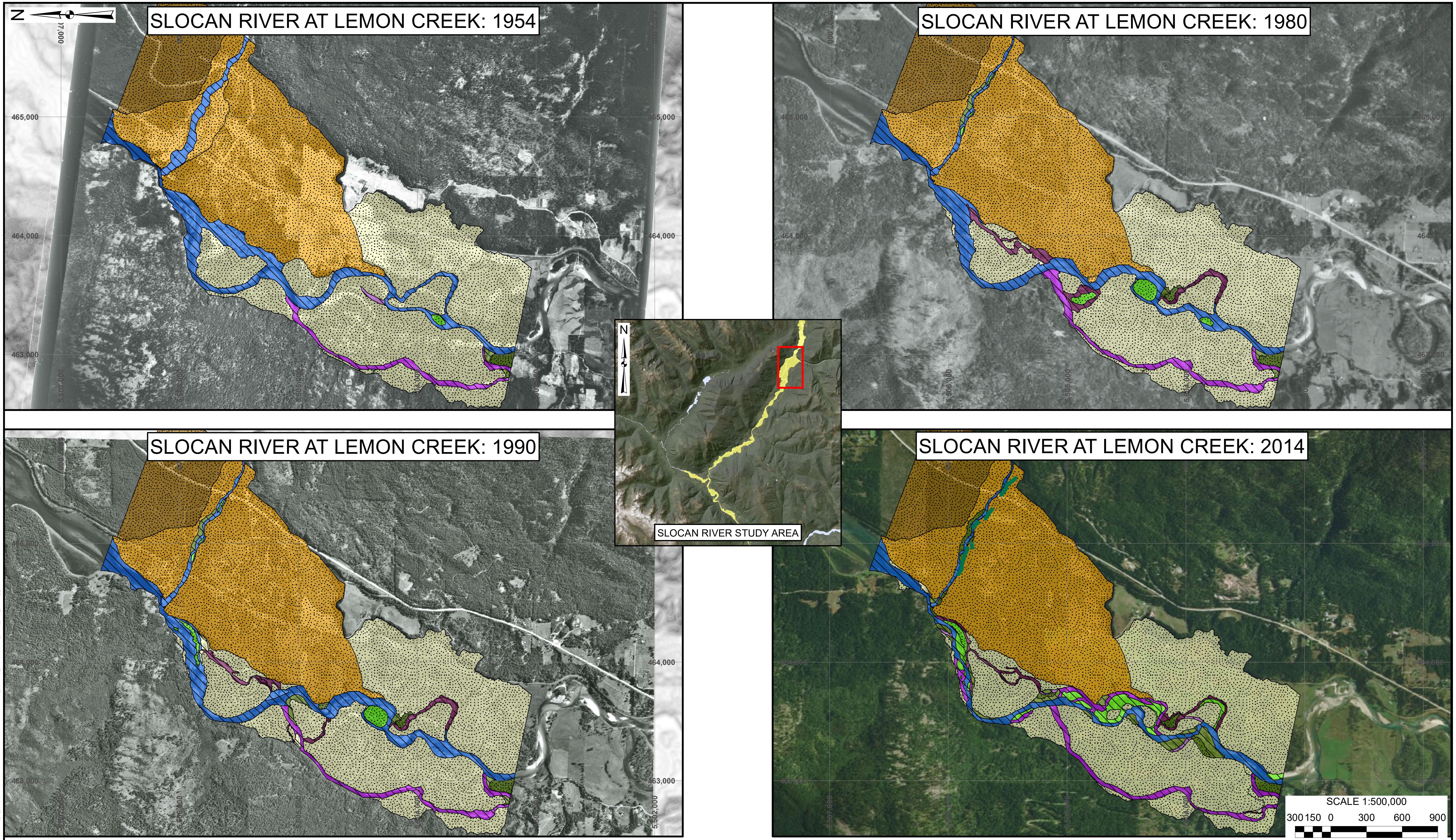
REGIONAL DISTRICT CENTRAL KOOTENAY

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER

TITLE: SURVEY LOCATIONS

| PROJECT No.: | DWG No: |
|---|---|
| 0268-007 | 03 |

X:\Projects\0268007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191030_RDCK_Floodplain_And_SC_Study_CLEARWATER\SlocanRiver\FINAL_COPIES\03_SlocanRiverSurveyLocationMap.mxd Date: April 20, 2020 Time: 12:58 PM




X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191030_RDCK_Floodplain_And_SC_Study_CLEARWATER\SlocanRiver\FINAL_COPIES\04_SlocanRiverAirPhotoComparison.mxd Date: April 20, 2020 Time: 12:48 PM

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY - SLOCAN RIVER", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY REGIONAL DISTRICT OF CENTRAL KOOTENAY DATED 2018. BASE IMAGERY REFERENCES IN TABLE 4-2 OF REPORT.
4. COORDINATE SYSTEM IS NAD 1983 UTM ZONE 11N.
5. MAPPED UNITS DETERMINED BASED ON CRITERIA OUTLINED IN TABLE 4-3 OF REPORT. ACTIVITY LEVEL OF MAPPED UNITS DETERMINED BASED ON CRITERIA OUTLINED IN TABLE 4-4 OF REPORT. GROUND MOVEMENT LOCATIONS BASED ON GEOMORPHOLOGICAL INTERPRETATION OF LIDAR DATA.
6. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

LEGEND

- MAIN-CHANNEL (Fmc)
- SIDE-CHANNEL (Fsc)
- FLOOD-CHANNEL (Ffc)
- BACK-CHANNEL (Fbc)
- MID-CHANNEL BAR (Fmb)
- LATERAL AND POINT BARS (Flb)
- ALLUVIAL FAN/DELTA (Ff)
- FLOODPLAIN (Fp)
- TERRACE (FLUVIAL) (Ft)
- TERRACE (GLACIOFLUVIAL) (FGt)
- DIKE
- SLOCAN RIVER STUDY AREA

FLUVIAL PROCESSES ACTIVITY LEVEL

- ACTIVE
- DORMANT

| | |
|---|---|
| SCALE: | 1:30,000 |
| DATE: | MAR 2020 |
| DRAWN: | MW |
| CHECKED: | ES/VC |
| APPROVED: | HW |

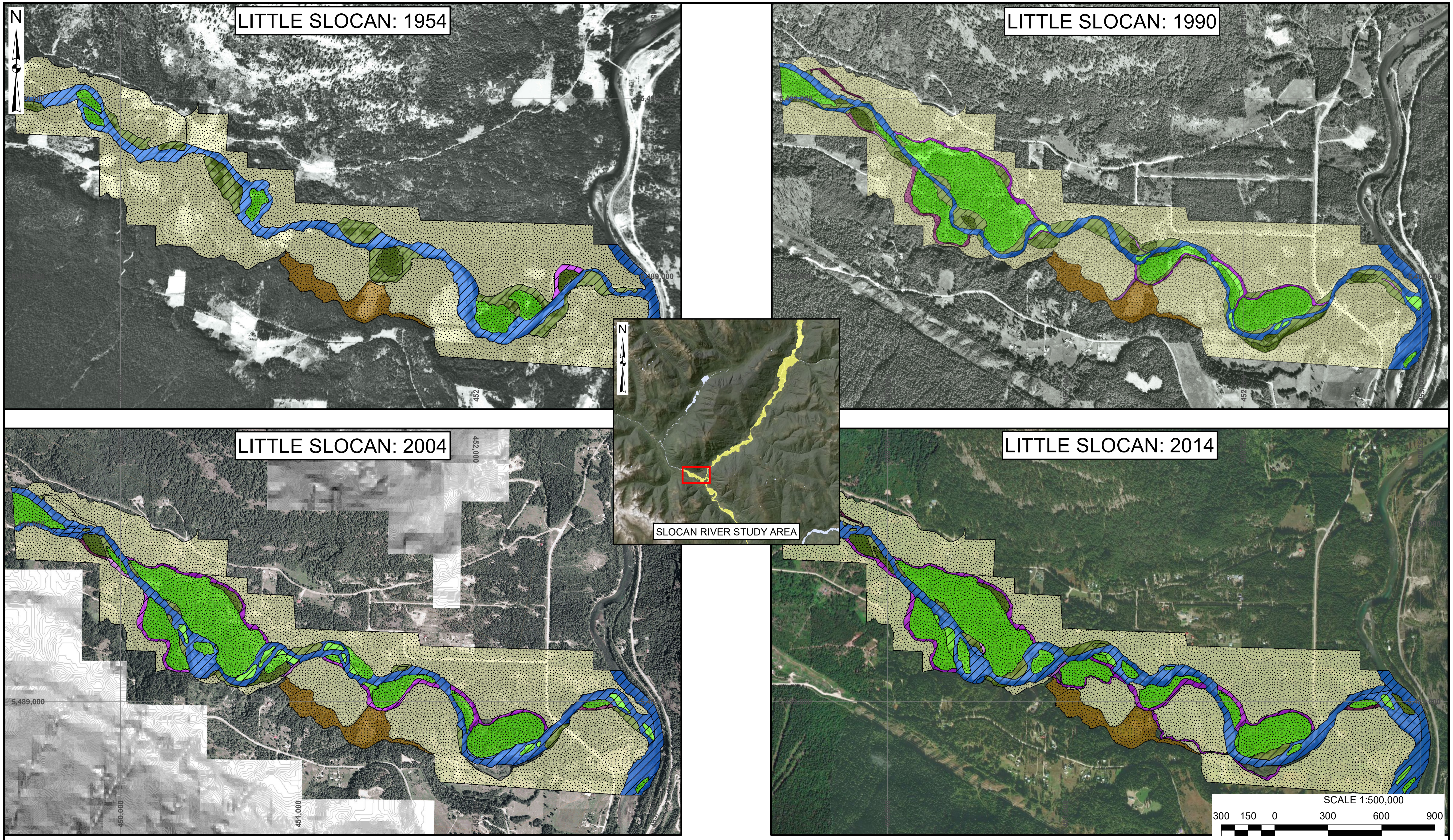
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: REGIONAL DISTRICT CENTRAL KOOTENAY

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER

TITLE: AERIAL PHOTOGRAPHS COMPARISON

| PROJECT No.: | DWG No: |
|---|---|
| 0268-007 | 04 - A |




X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191030_RDCK_Floodplain_And_SC_Study_CLEARWATER\SlocanRiver\FINAL_COPIES\04_SlocanRiverAirPhotoComparison.mxd Date: April 20, 2020 Time: 12:48 PM

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY - SLOCAN RIVER", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY REGIONAL DISTRICT OF CENTRAL KOOTENAY DATED 2018. BASE IMAGERY REFERENCES IN TABLE 4-2 OF REPORT.
4. COORDINATE SYSTEM IS NAD 1983 UTM ZONE 11N.
5. MAPPED UNITS DETERMINED BASED ON CRITERIA OUTLINED IN TABLE 4-3 OF REPORT. ACTIVITY LEVEL OF MAPPED UNITS DETERMINED BASED ON CRITERIA OUTLINED IN TABLE 4-4 OF REPORT. GROUND MOVEMENT LOCATIONS BASED ON GEOMORPHOLOGICAL INTERPRETATION OF LIDAR DATA.
6. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

LEGEND

- MAIN-CHANNEL (Fmc)
- SIDE-CHANNEL (Fsc)
- FLOOD-CHANNEL (Ffc)
- BACK-CHANNEL (Fbc)
- MID-CHANNEL BAR (Fmb)
- LATERAL AND POINT BARS (Flb)
- ALLUVIAL FAN/DELTA (Ff)
- FLOODPLAIN (Fp)
- TERRACE (FLUVIAL) (Ft)
- TERRACE (GLACIOFLUVIAL) (FGt)
- DIKE
- SLOCAN RIVER STUDY AREA

FLUVIAL PROCESSES ACTIVITY LEVEL

- ACTIVE
- DORMANT

| | |
|---|---|
| SCALE: | 1:20,000 |
| DATE: | MAR 2020 |
| DRAWN: | MW |
| CHECKED: | ES/VC |
| APPROVED: | HW |

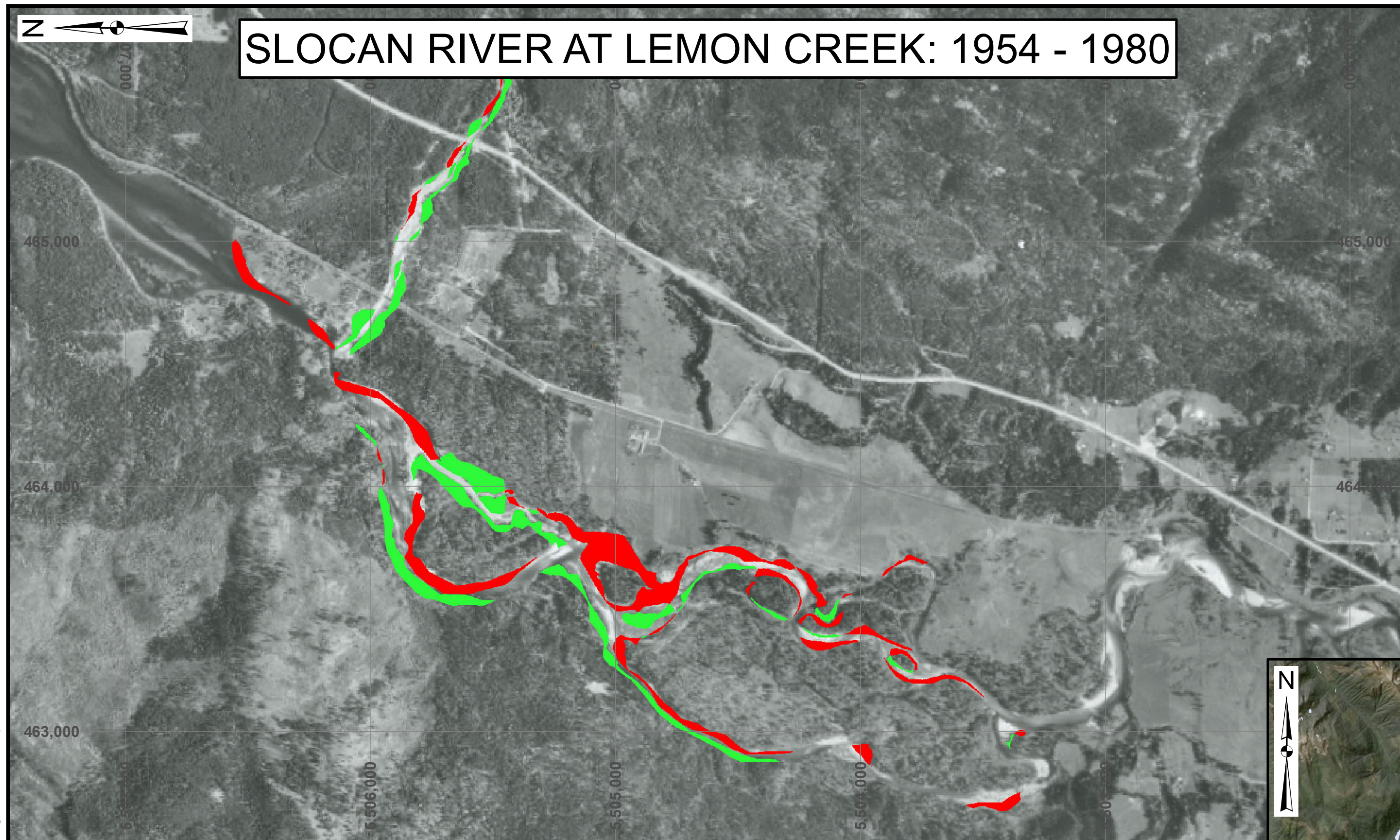
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

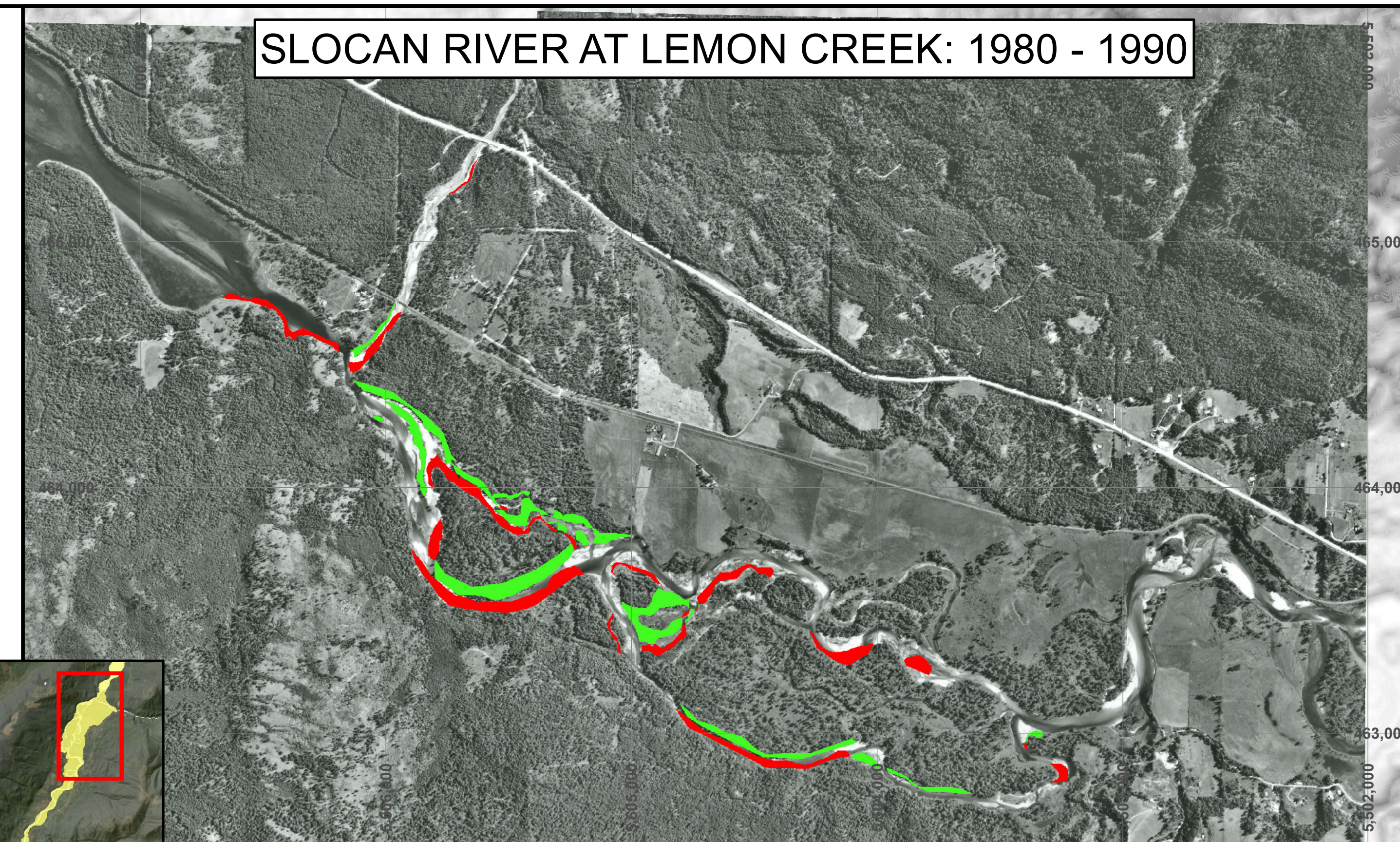
CLIENT: REGIONAL DISTRICT CENTRAL KOOTENAY

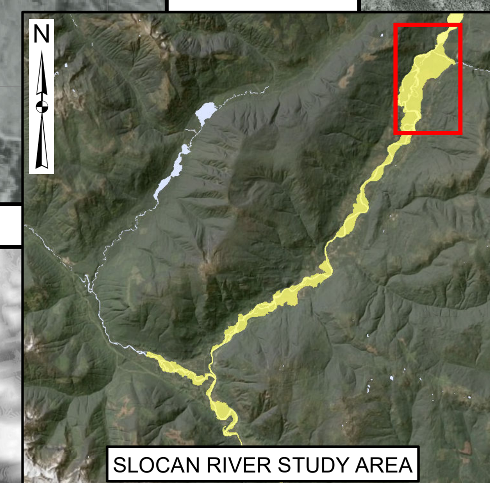
PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER

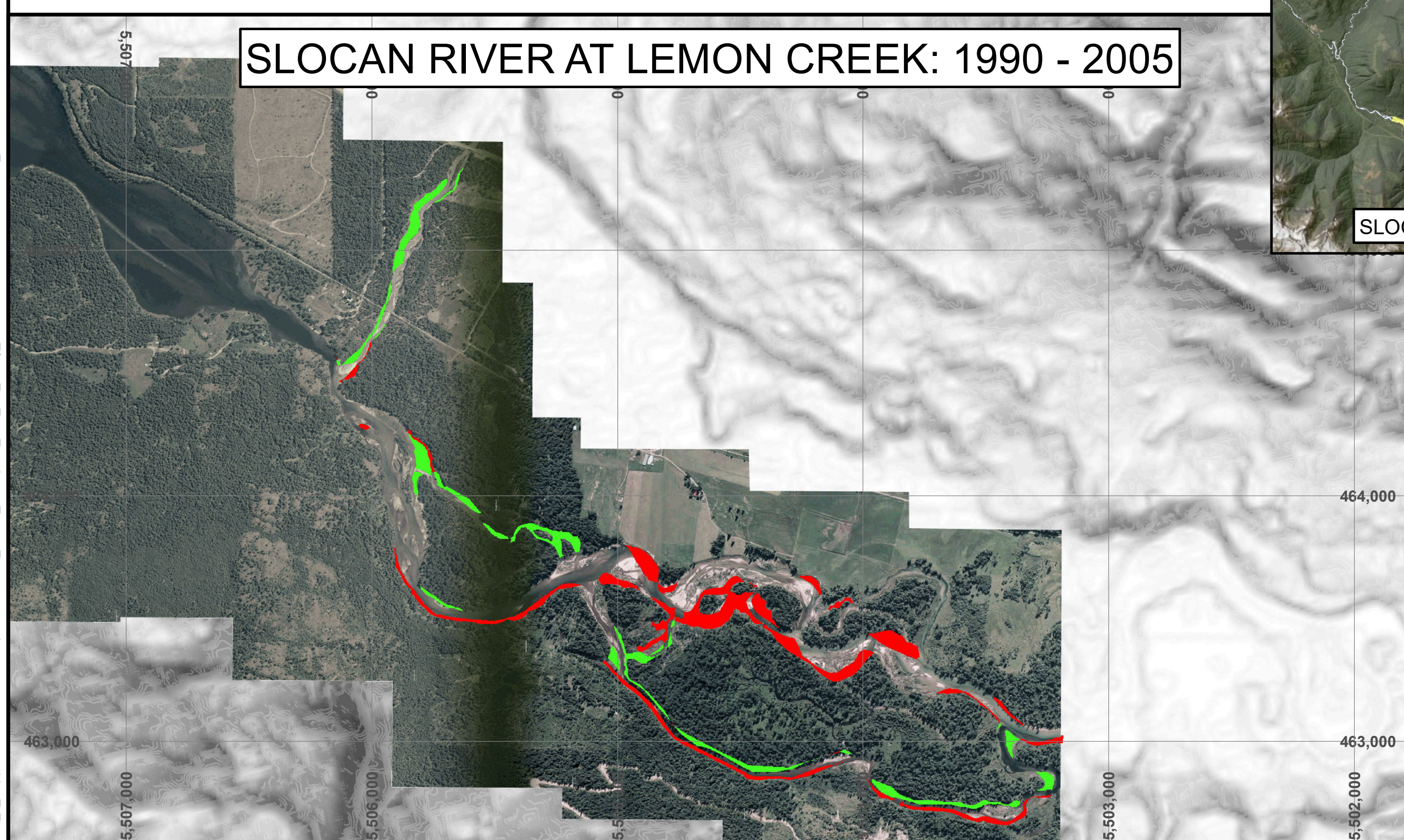
TITLE: AERIAL PHOTOGRAPHS COMPARISON

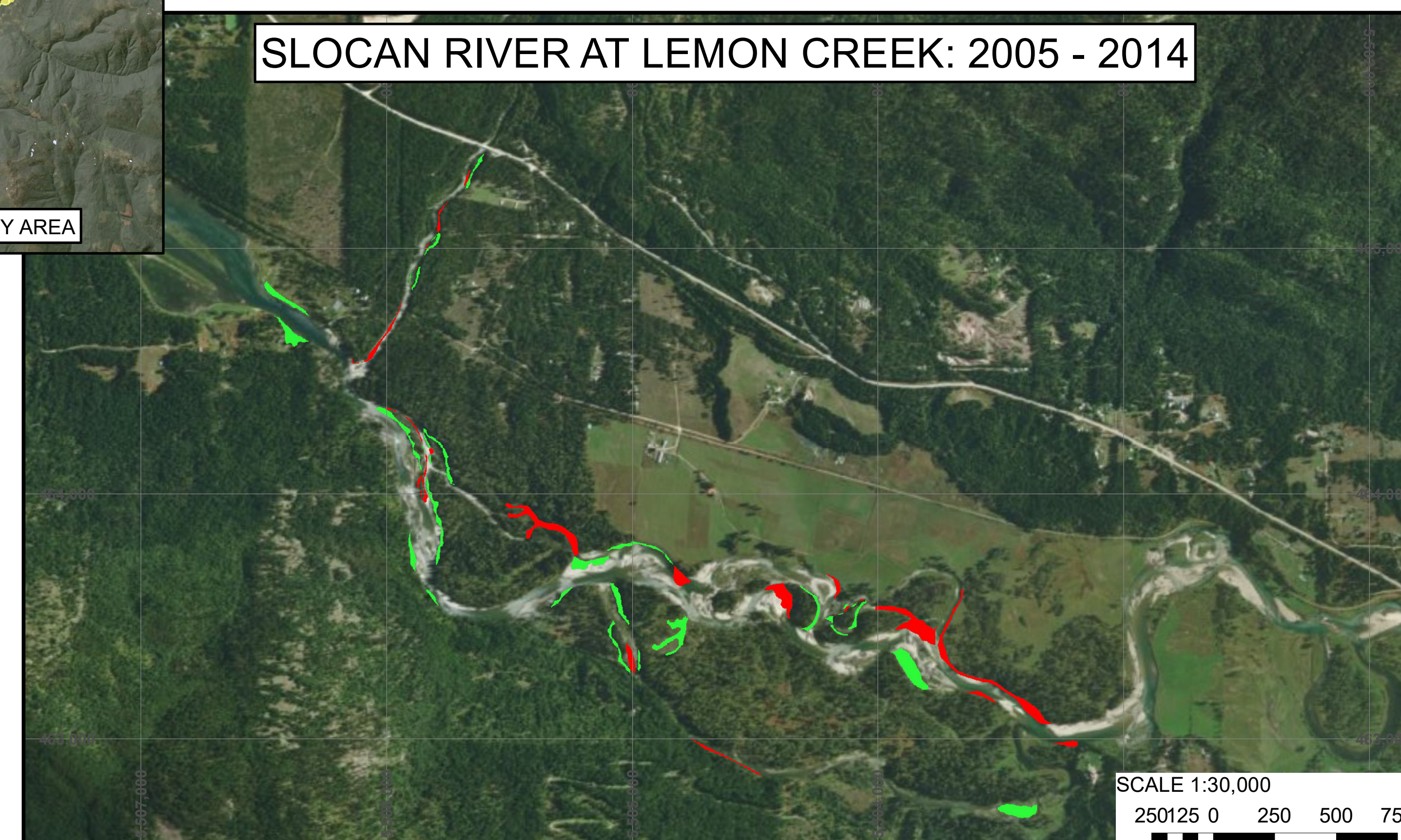
| PROJECT No.: | DWG No: |
|---|---|
| 0268-007 | 04 - B |




X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191030_RDCK_Floodplain_And_SC_Study_CLEARWATER\SlocanRiver\05_SlocanRiverHistoricalChannelChange.mxd Date: April 20, 2020 Time: 12:51 PM

LEGEND

- SLOCAN RIVER STUDY AREA
- BANK EROSION, CHANNEL MIGRATION
- DEPOSITION, STABILIZATION

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY - SLOCAN RIVER ", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY REGIONAL DISTRICT OF CENTRAL KOOTENAY DATED 2018. BASE IMAGERY REFERENCES IN TABLE 4-2 OF REPORT.
4. COORDINATE SYSTEM IS NAD 1983 UTM ZONE 11N.
5. CHANGE DETECTION CRITERIA DESCRIBED IN TABLE 4-5 OF REPORT. HISTORICAL THALWEGS INTERPRETED FROM PHOTOGRAPHS AND MANUALLY DIGITIZED.
6. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:30,000 |
| DATE: | MAR 2020 |
| DRAWN: | MW |
| CHECKED: | ES/VC |
| APPROVED: | HW |

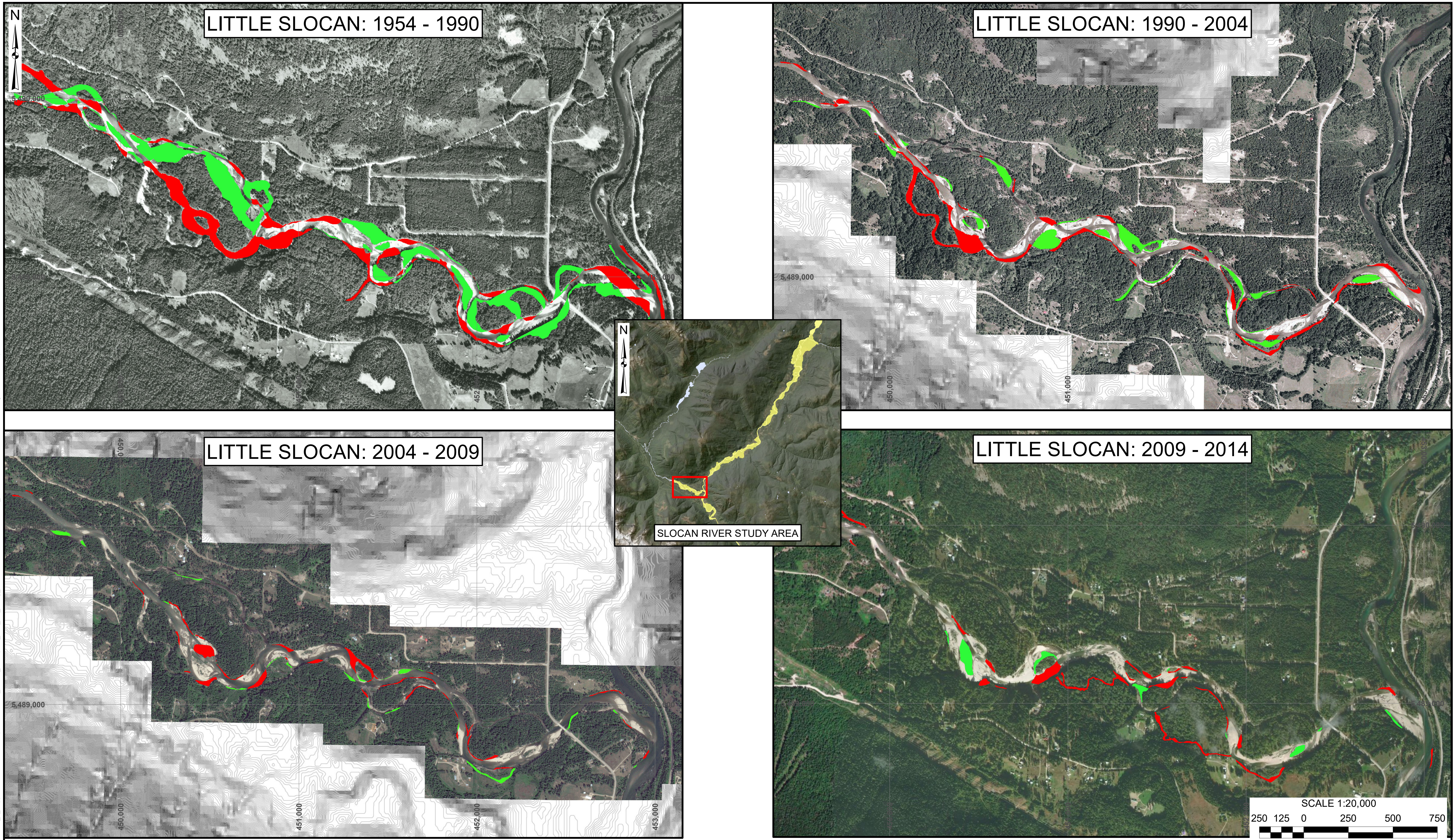
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: REGIONAL DISTRICT CENTRAL KOOTENAY

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER

TITLE: HISTORICAL CHANNEL CHANGE

| PROJECT No.: | DWG No: |
|---|---|
| 0268-007 | 05 - A |




LEGEND

- SLOCAN RIVER STUDY AREA
- BANK EROSION, CHANNEL MIGRATION
- DEPOSITION, STABILIZATION

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY - SLOCAN RIVER ", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY REGIONAL DISTRICT OF CENTRAL KOOTENAY DATED 2018. BASE IMAGERY REFERENCES IN TABLE 4-2 OF REPORT.
4. COORDINATE SYSTEM IS NAD 1983 UTM ZONE 11N.
5. CHANGE DETECTION CRITERIA DESCRIBED IN TABLE 4-5 OF REPORT. HISTORICAL THALWEGS INTERPRETED FROM PHOTOGRAPHS AND MANUALLY DIGITIZED.
6. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:20,000 |
| DATE: | MAR 2020 |
| DRAWN: | MW |
| CHECKED: | ES/VC |
| APPROVED: | HW |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

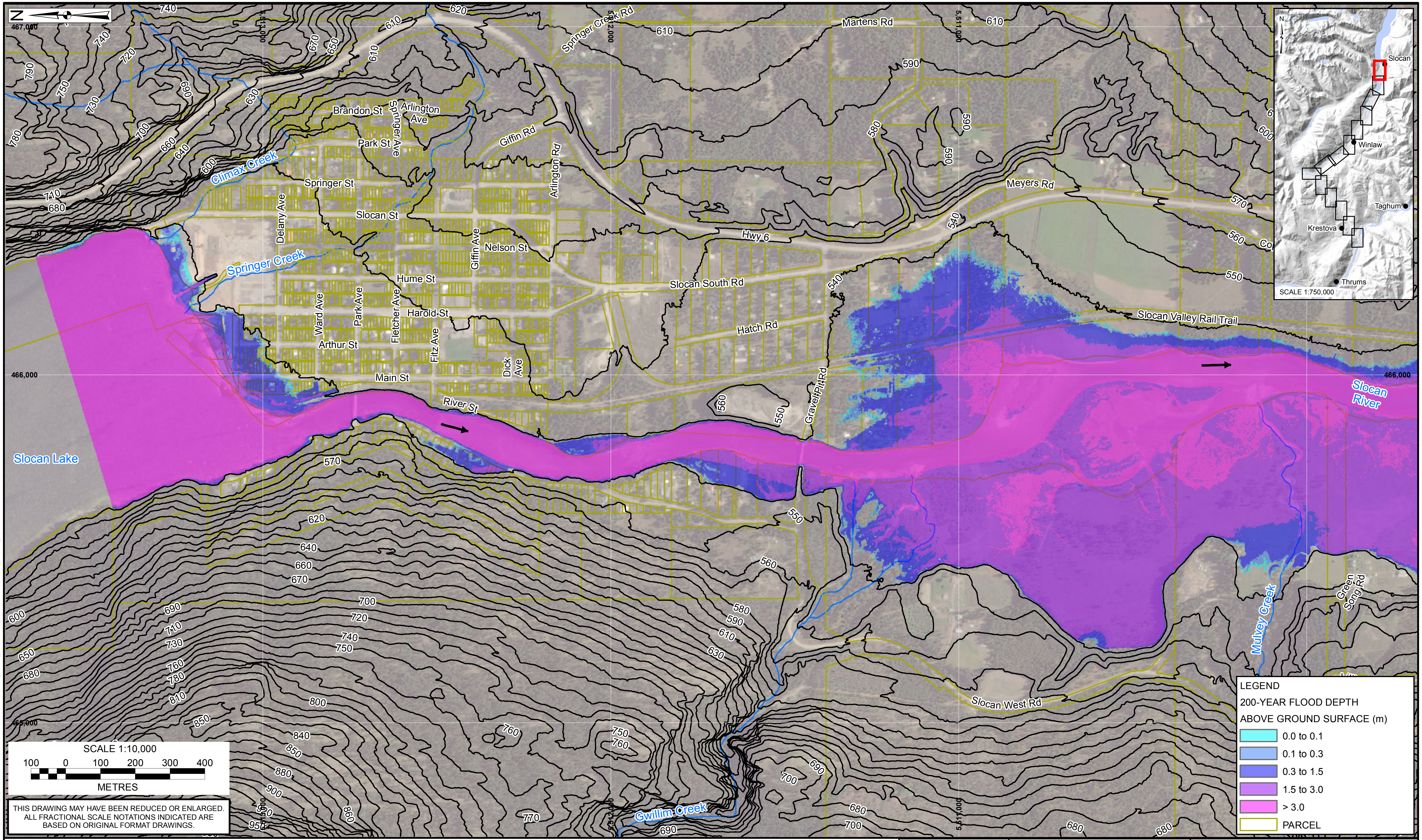
CLIENT:

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY
SLOCAN RIVER

TITLE: HISTORICAL CHANNEL CHANGE

| PROJECT No.: | DWG No: |
|---|---|
| 0268-007 | 05 - B |

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191030_RDCK_Floodplain_And_SC_Study_CLEARWATER\SlocanRiver\05_SlocanRiverHistoricalChannelChange.mxd Date: April 20, 2020 Time: 12:51 PM




X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191219_RDCK_Clearwater_FC\200-Year Flood_Hazard_DDP.mxd

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH.PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD DEPTH BASED ON THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

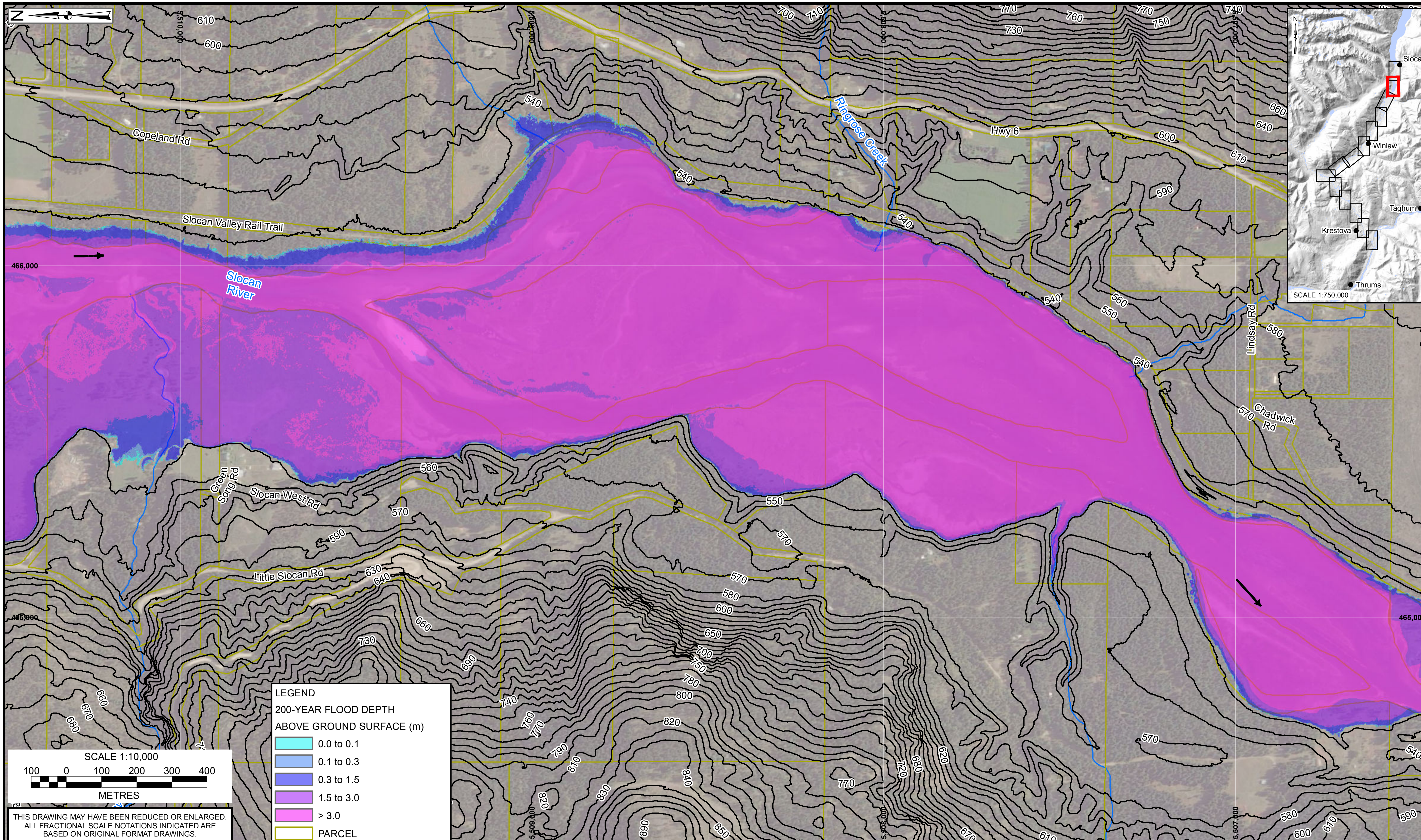
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER

TITLE: 200-YEAR FLOOD HAZARD (SHEET 01 OF 14)

| PROJECT No.: | DWG No: |
|---|---|
| 0268 007 | 06 |




NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH.PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD DEPTH BASED ON THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

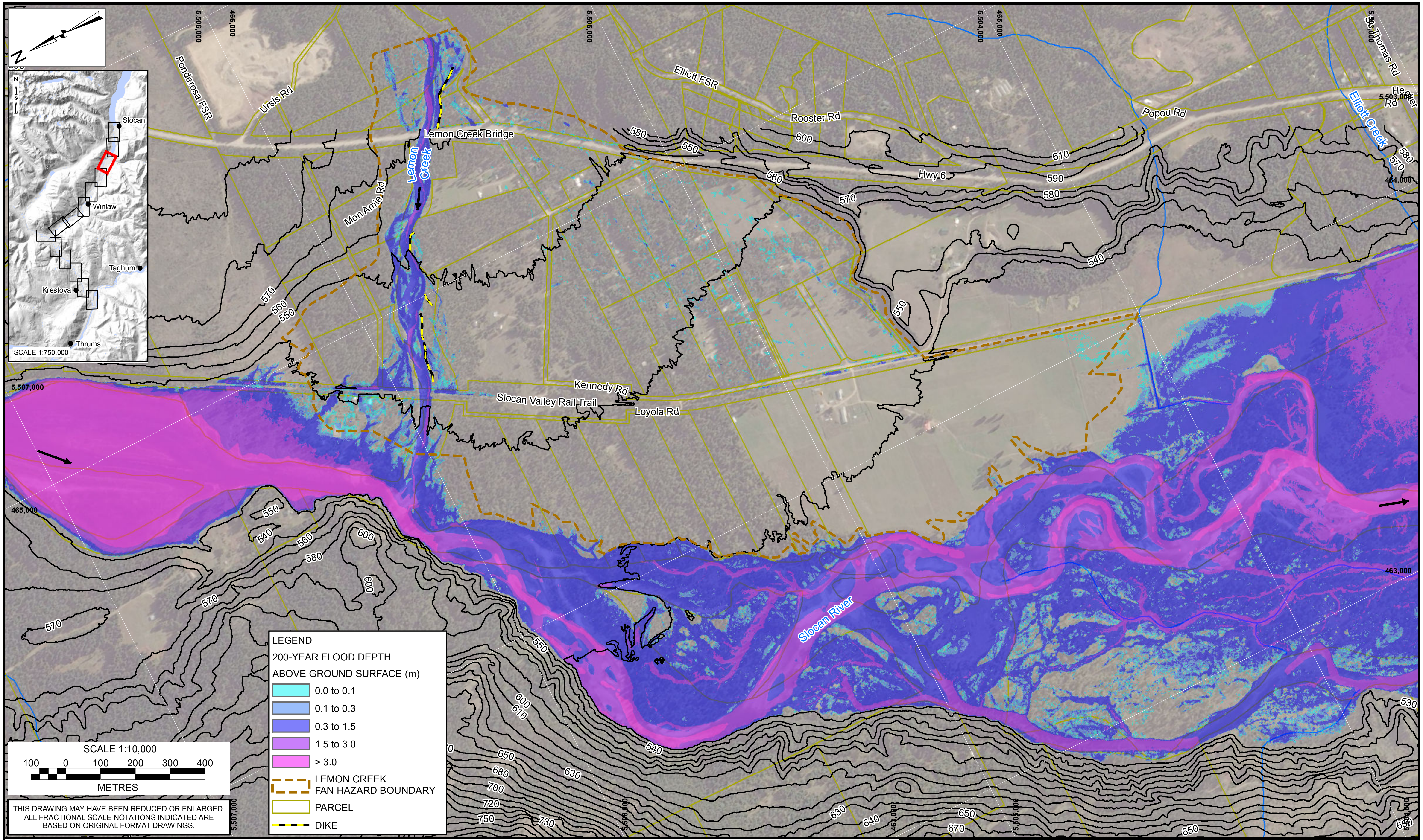
CLIENT:

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY
SLOCAN RIVER

TITLE:
200-YEAR FLOOD HAZARD
(SHEET 02 OF 14)

| PROJECT No.: | DWG No: |
|---|---|
| 0268 007 | 06 |

X:\Projects\0268007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year Flood_Hazard_DDP.mxd




NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH.PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD DEPTH BASED ON THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

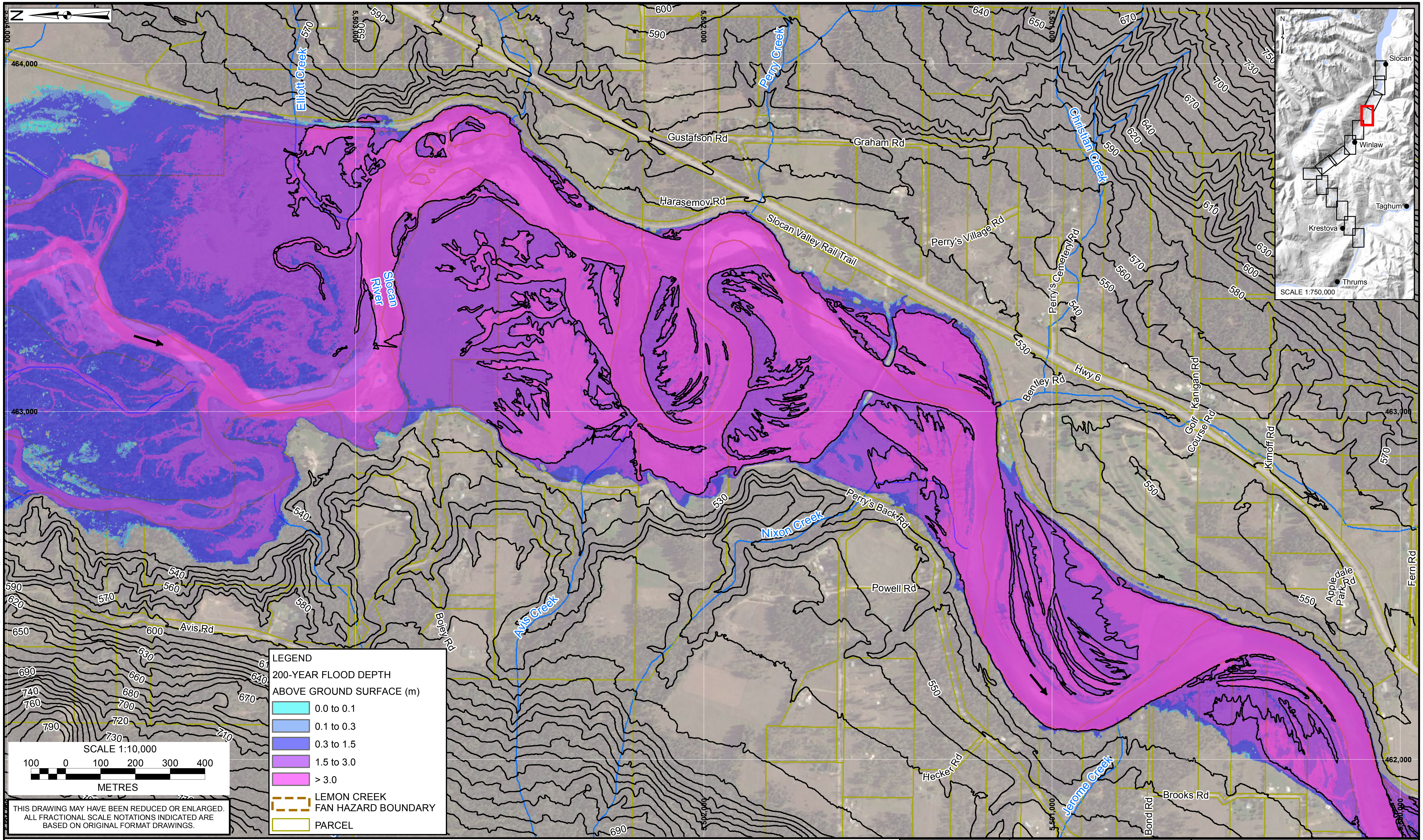
CLIENT:

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER

TITLE: 200-YEAR FLOOD HAZARD (SHEET 03 OF 14)

| PROJECT No.: | DWG No: |
|---|---|
| 0268 007 | 06 |

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year Flood_Hazard_DP.mxd




NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH.PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD DEPTH BASED ON THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

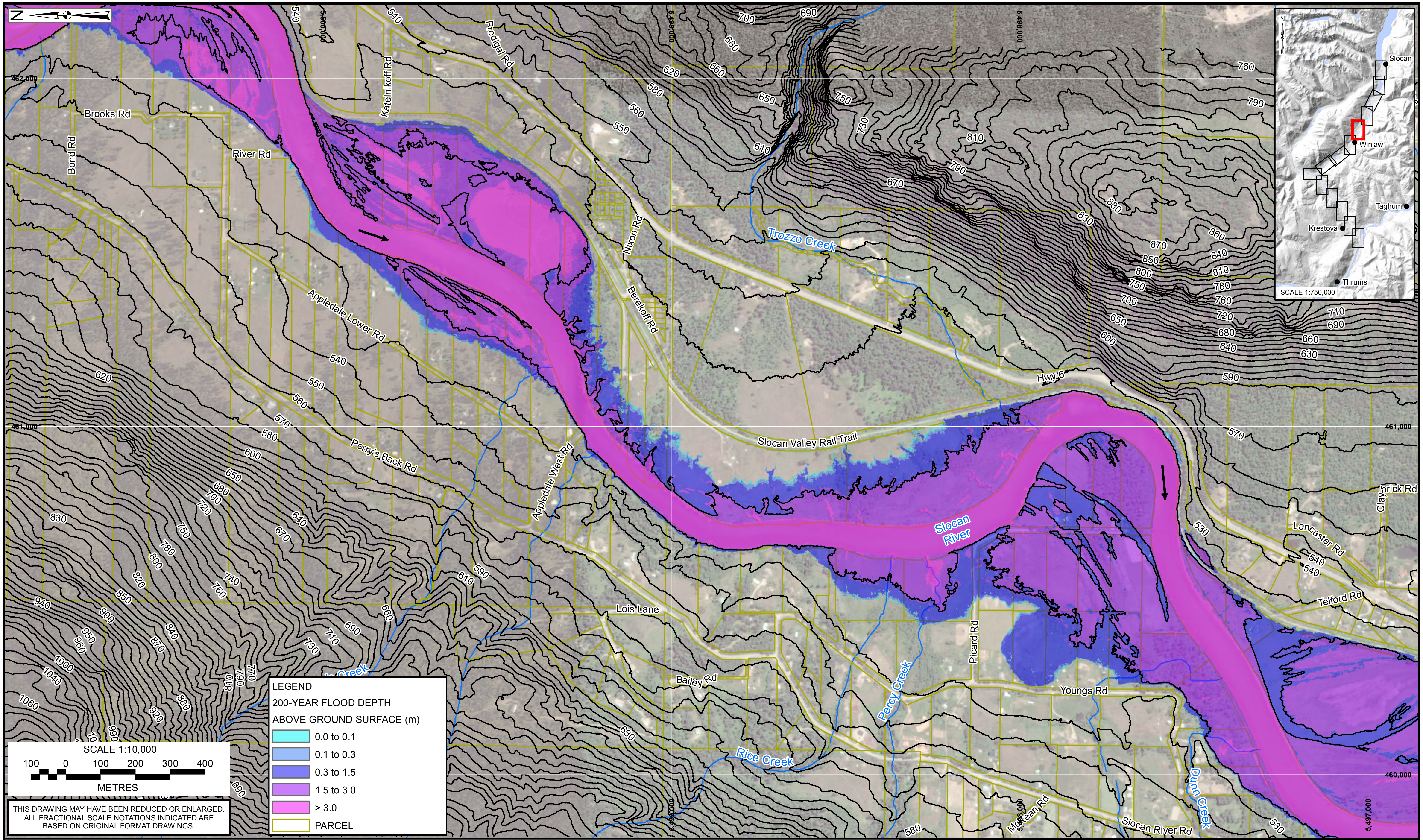
CLIENT:

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY
SLOCAN RIVER

TITLE:
200-YEAR FLOOD HAZARD
(SHEET 04 OF 14)

| PROJECT No.: | DWG No: |
|---|---|
| 0268 007 | 06 |

X:\Projects\0268007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year_Flood_Hazard_DDP.mxd




NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH.PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD DEPTH BASED ON THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

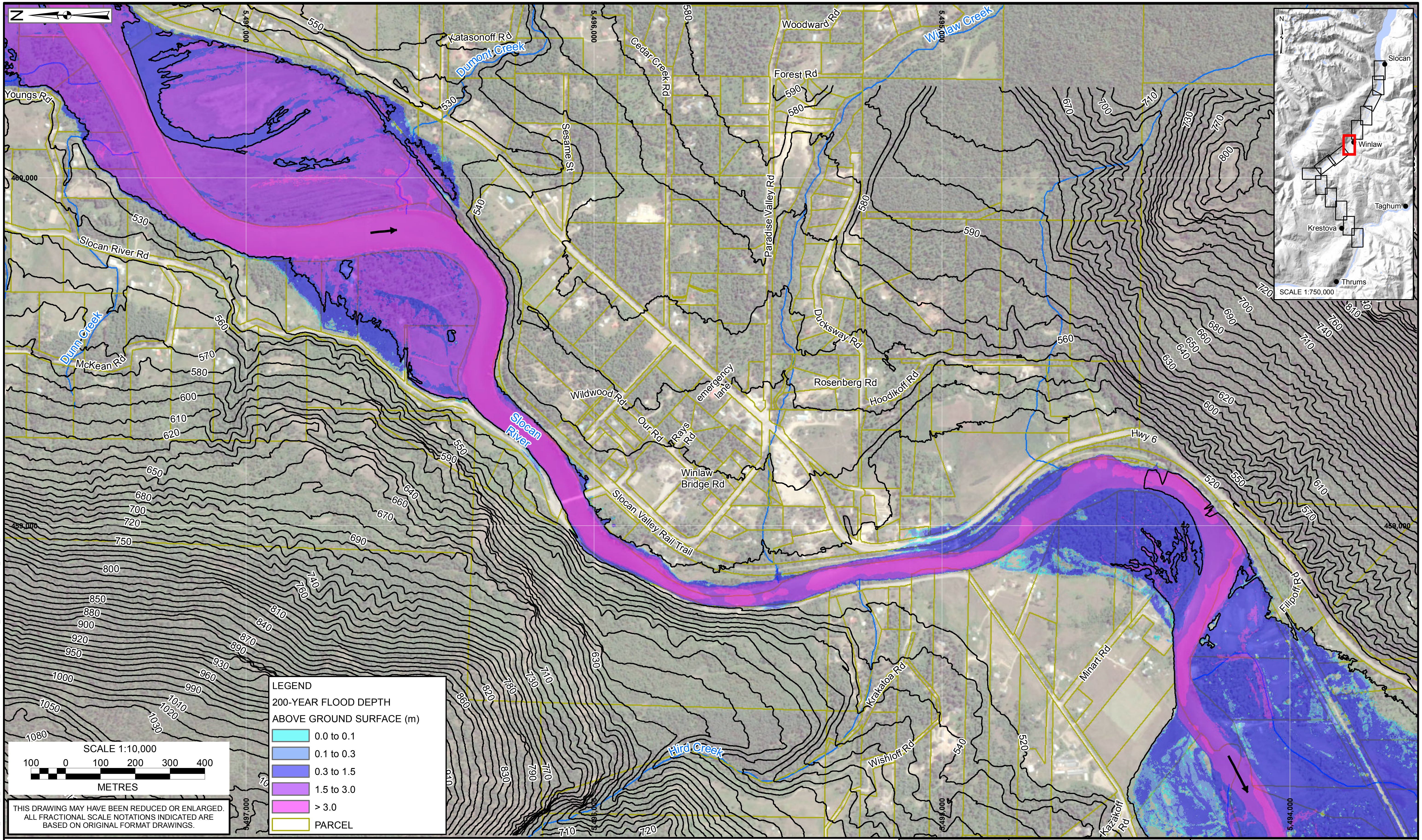
CLIENT:

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY
SLOCAN RIVER

TITLE:
200-YEAR FLOOD HAZARD
(SHEET 05 OF 14)

| PROJECT No.: | DWG No: |
|---|---|
| 0268 007 | 06 |

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\ProductionReport\20191218_RDCK_Clearwater_FCL\200-Year Flood_Hazard_DDP.mxd




NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH.PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD DEPTH BASED ON THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

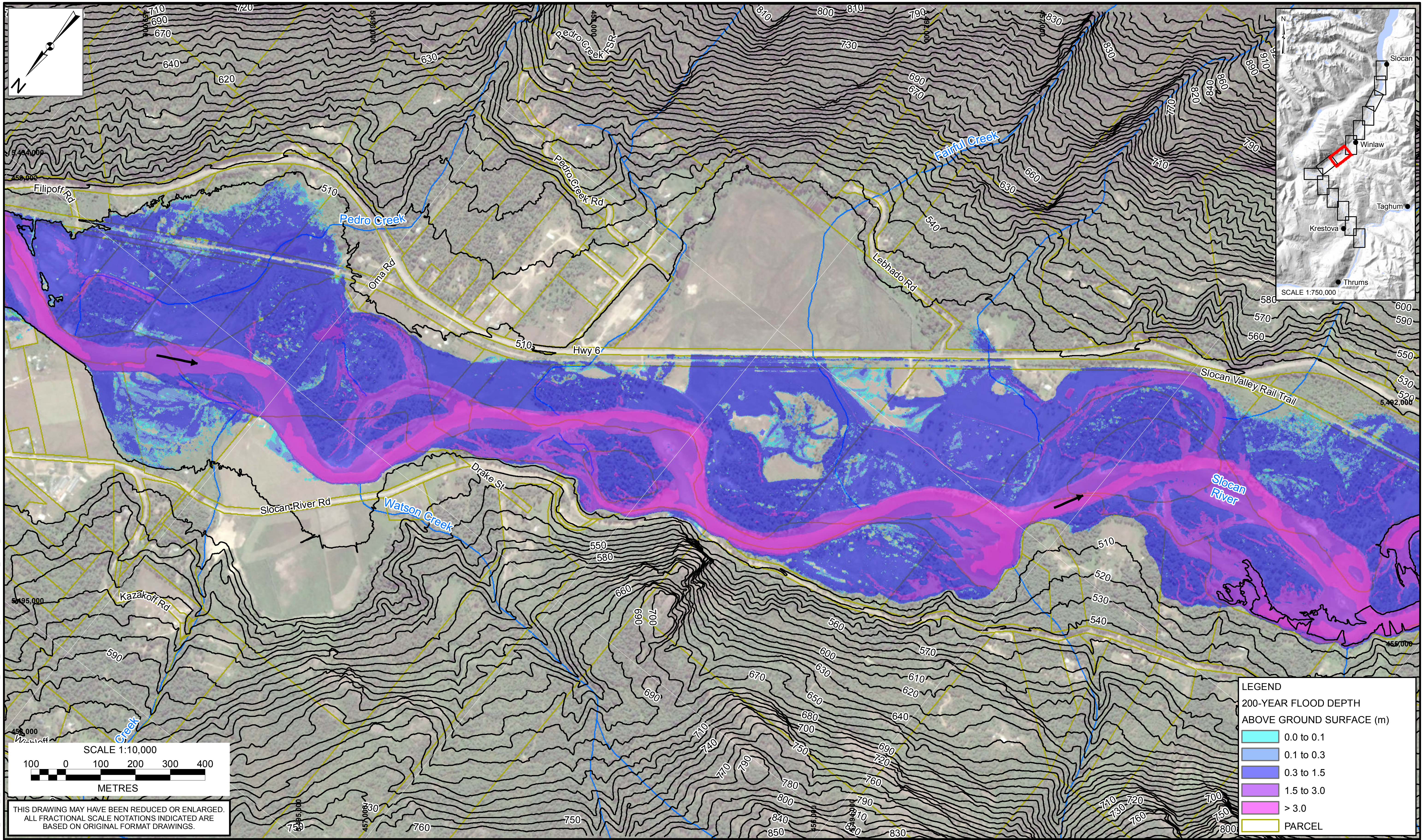
PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER

TITLE: 200-YEAR FLOOD HAZARD (SHEET 06 OF 14)

PROJECT No.: 0268 007

DWG No: 06

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year_Flood_Hazard_DDP.mxd




X:\Projects\0268007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year_Flood_Hazard_DDP.mxd

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH.PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD DEPTH BASED ON THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

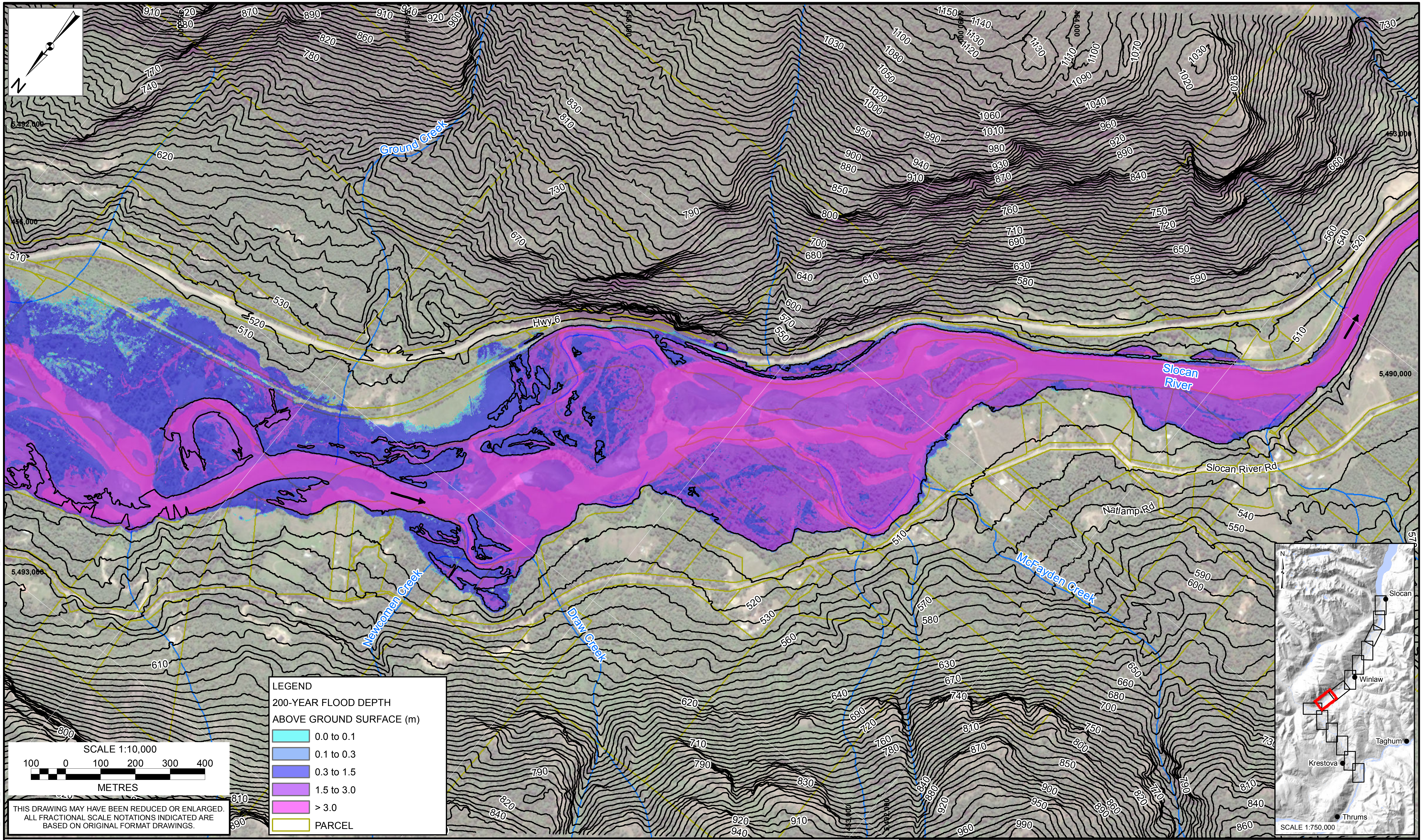
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY
SLOCAN RIVER

TITLE:
200-YEAR FLOOD HAZARD
(SHEET 07 OF 14)

| PROJECT No.: | DWG No: |
|---|---|
| 0268 007 | 06 |




X:\Projects\0268007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year Flood_Hazard_DDP.mxd

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH.PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD DEPTH BASED ON THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

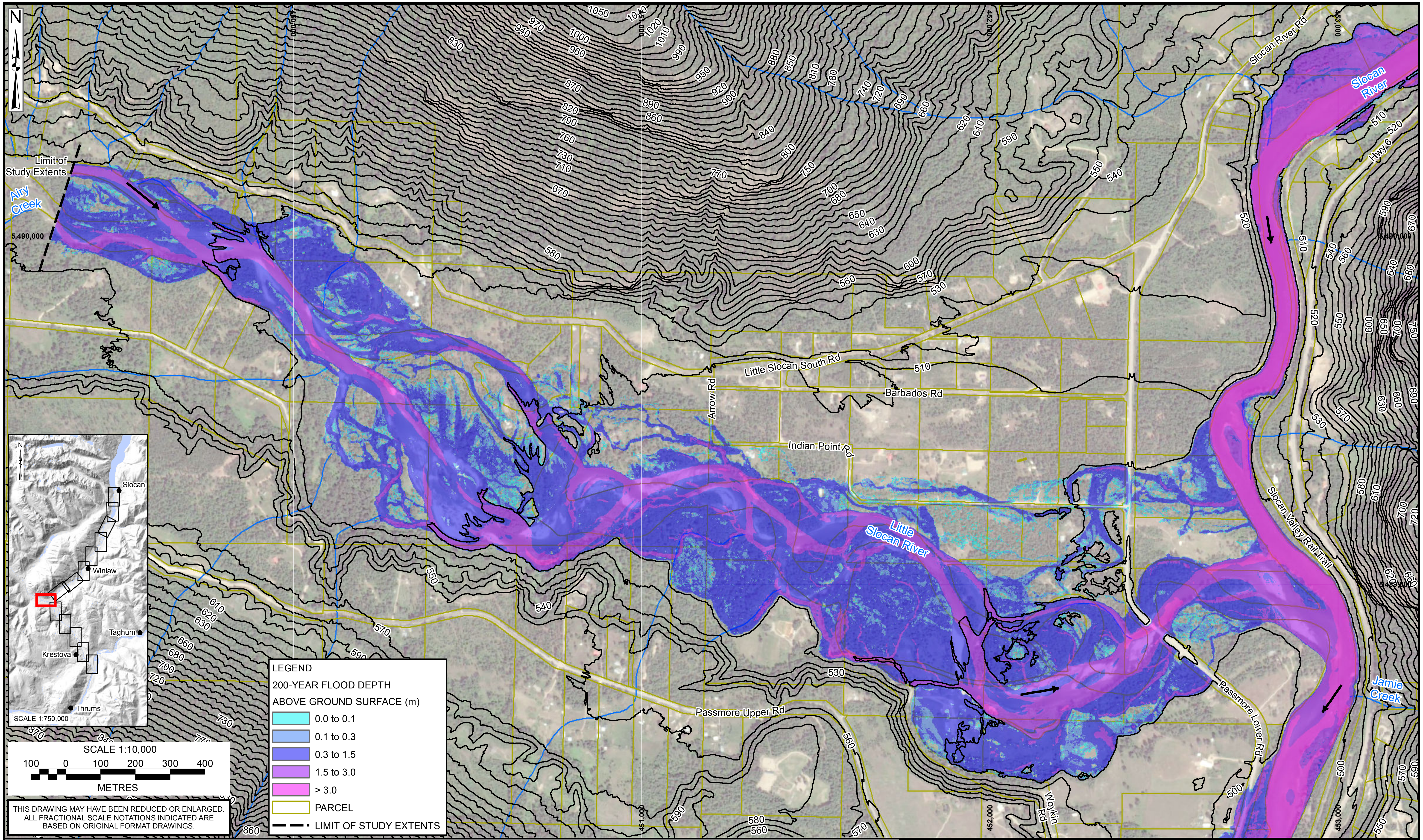
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
REGIONAL DISTRICT OF CENTRAL KOOTENAY

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY
SLOCAN RIVER

TITLE:
200-YEAR FLOOD HAZARD
(SHEET 08 OF 14)

| PROJECT No.: | DWG No: |
|---|---|
| 0268 007 | 06 |




NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH.PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD DEPTH BASED ON THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

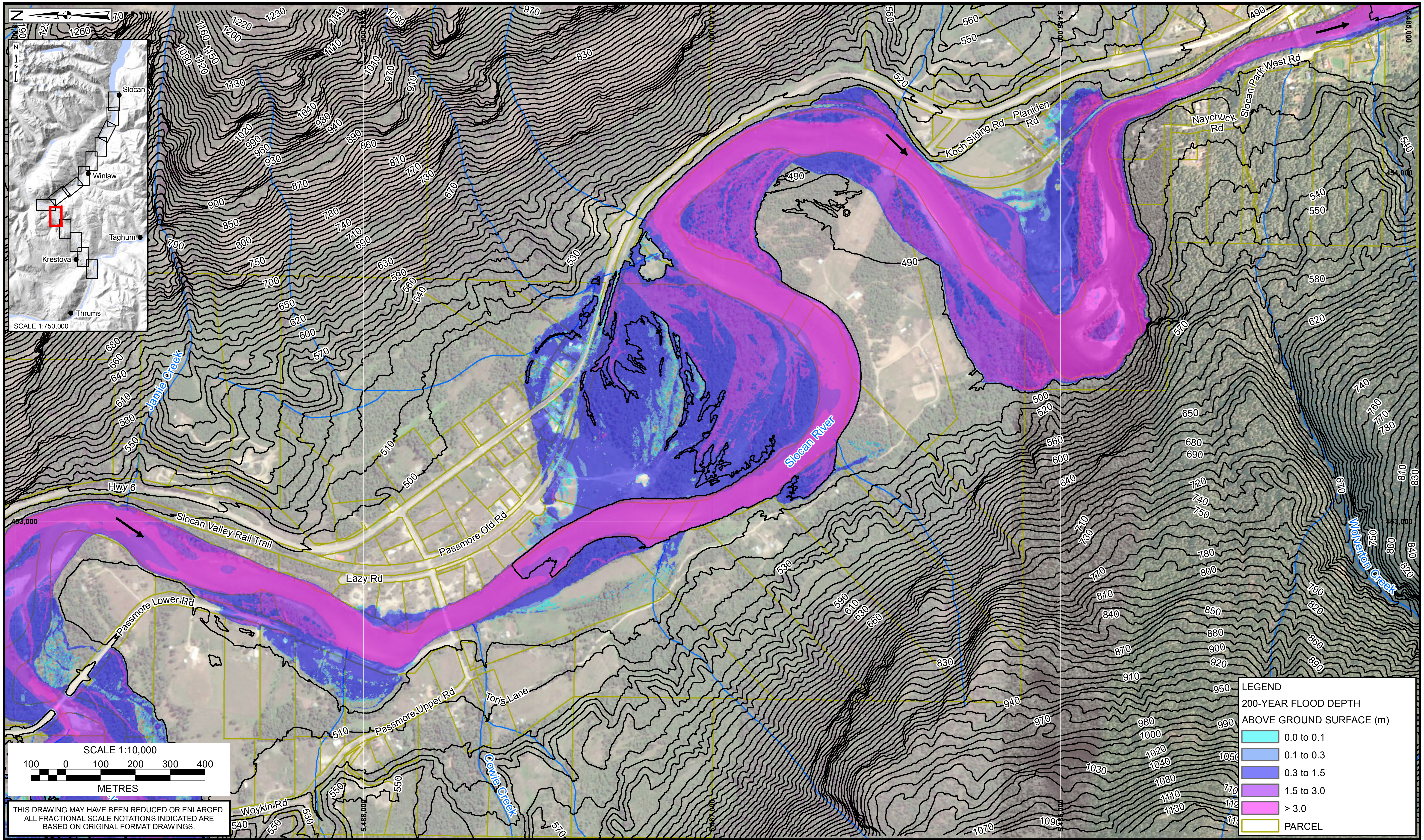
CLIENT:

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY
SLOCAN RIVER

TITLE:
200-YEAR FLOOD HAZARD
(SHEET 09 OF 14)

| PROJECT No.: | DWG No: |
|---|---|
| 0268 007 | 06 |

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year_Flood_Hazard_DDP.mxd




X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year Flood_Hazard_DDP.mxd

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH.PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD DEPTH BASED ON THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

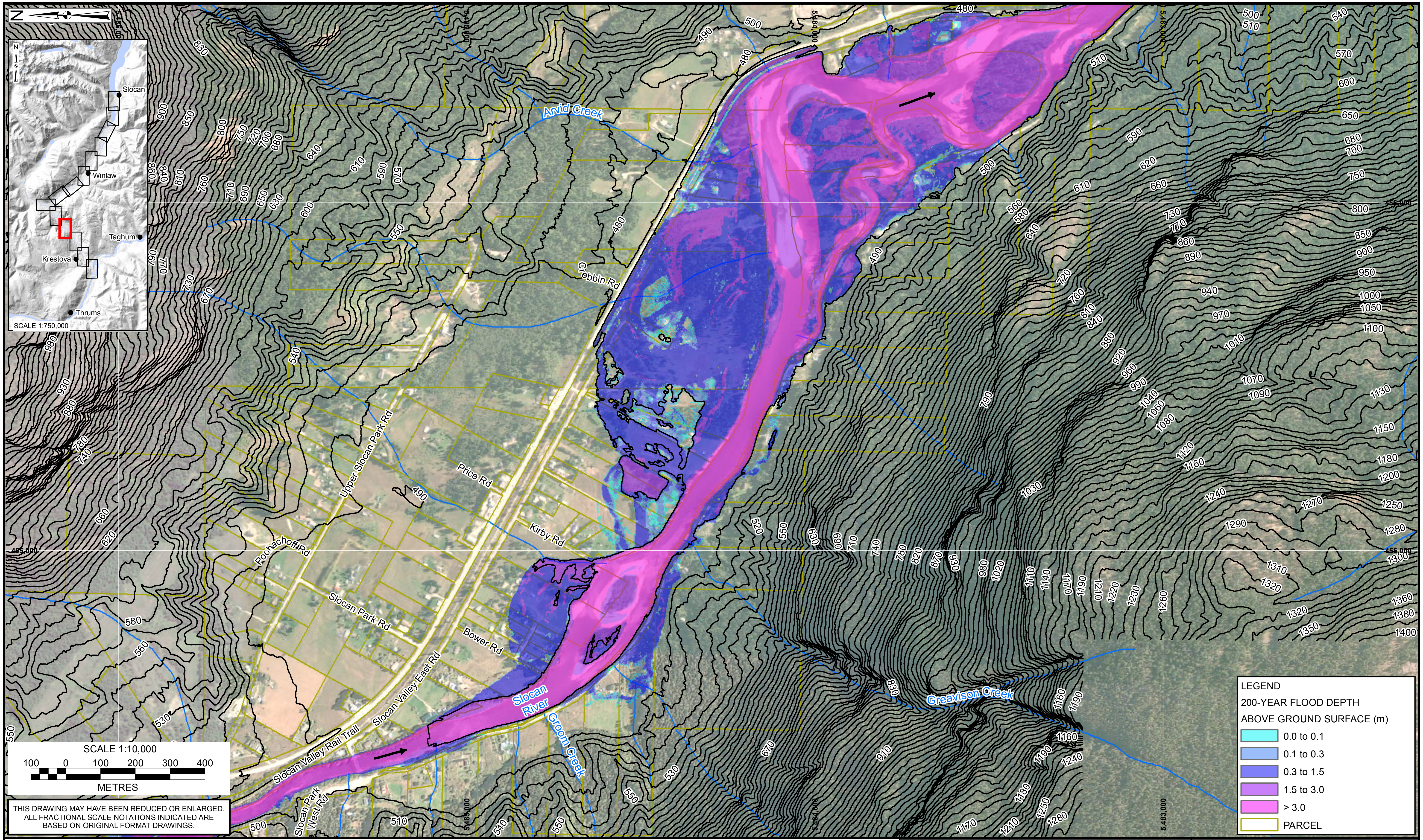
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY
SLOCAN RIVER

TITLE:
200-YEAR FLOOD HAZARD
(SHEET 10 OF 14)

| PROJECT No.: | DWG No: |
|---|---|
| 0268 007 | 06 |




NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH.PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD DEPTH BASED ON THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: REGIONAL DISTRICT CENTRAL KOOTENAY

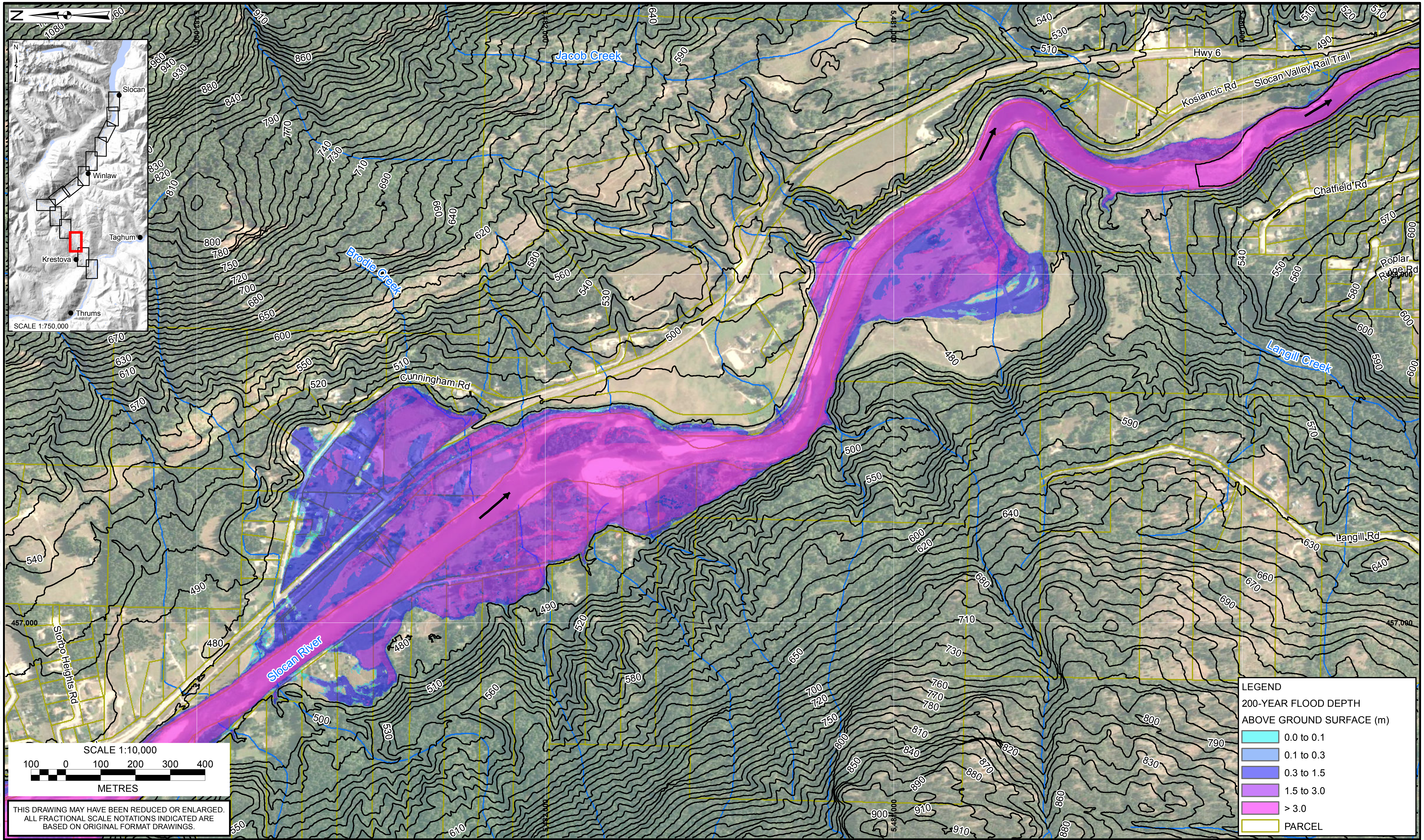
PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER

TITLE: 200-YEAR FLOOD HAZARD (SHEET 11 OF 14)

PROJECT No.: 0268 007

DWG No: 06

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year_Flood_Hazard_DDP.mxd




NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH.PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD DEPTH BASED ON THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

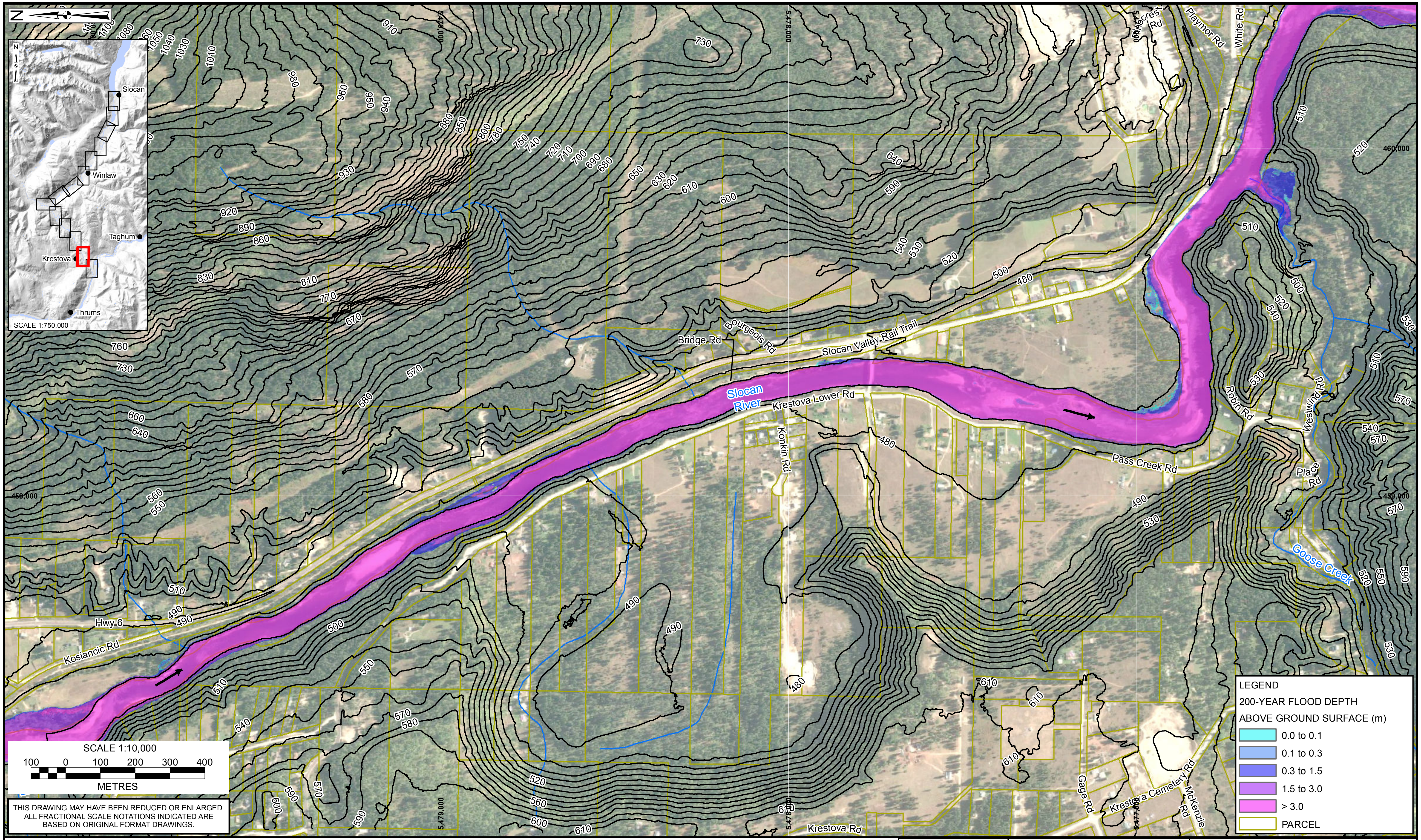
CLIENT:

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY
SLOCAN RIVER

TITLE:
200-YEAR FLOOD HAZARD
(SHEET 12 OF 14)

| PROJECT No.: | DWG No: |
|---|---|
| 0268 007 | 06 |

X:\Projects\0268\007_RDCK_NDMP_Stream_2_SupportGIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year_Flood_Hazard_DDP.mxd




NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH.PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD DEPTH BASED ON THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

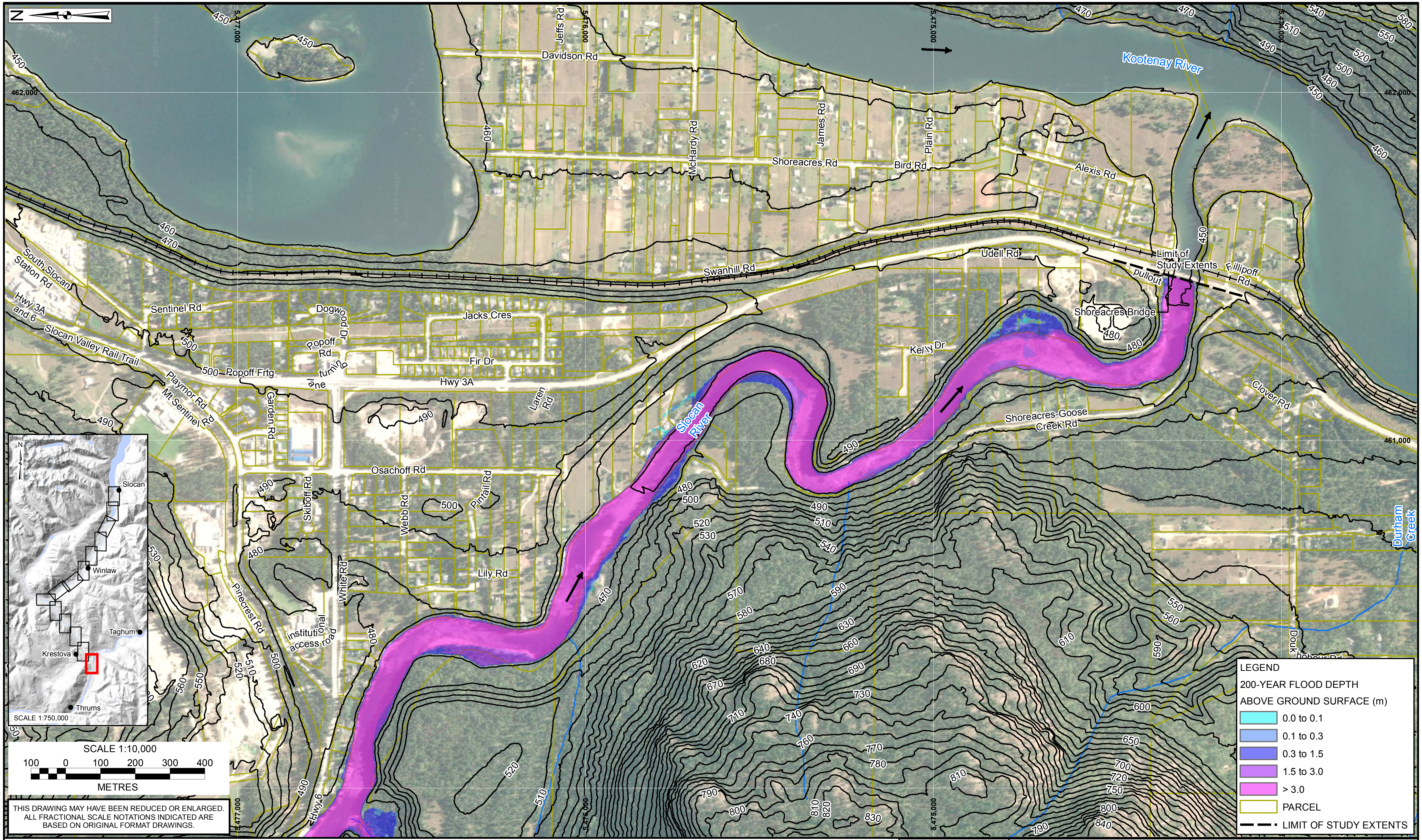
CLIENT:

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER

TITLE: 200-YEAR FLOOD HAZARD (SHEET 13 OF 14)

| PROJECT No.: | DWG No: |
|---|---|
| 0268 007 | 06 |

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year Flood_Hazard_DDP.mxd




NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH.PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD DEPTH BASED ON THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

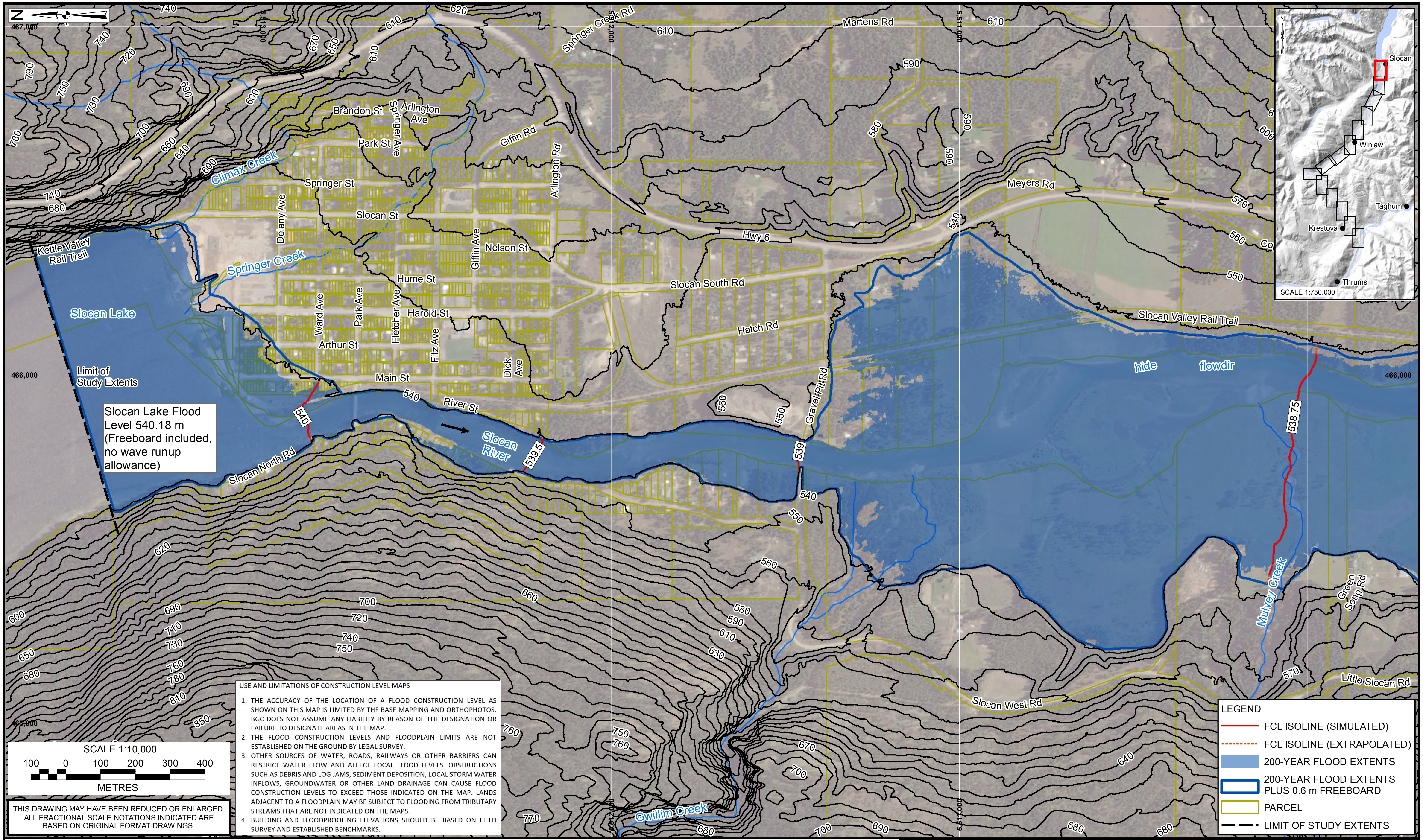
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER

TITLE: 200-YEAR FLOOD HAZARD (SHEET 14 OF 14)

| PROJECT No.: | DWG No: |
|---|---|
| 0268 007 | 06 |




THIS DRAWING MAY HAVE BEEN REDUCED OR ENLARGED. ALL FRACTIONAL SCALE NOTATIONS INDICATED ARE BASED ON ORIGINAL FORMAT DRAWINGS.

USE AND LIMITATIONS OF CONSTRUCTION LEVEL MAPS

1. THE ACCURACY OF THE LOCATION OF A FLOOD CONSTRUCTION LEVEL AS SHOWN ON THIS MAP IS LIMITED BY THE BASE MAPPING AND ORTHOPHOTOS. BGC DOES NOT ASSUME ANY LIABILITY BY REASON OF THE DESIGNATION OR FAILURE TO DESIGNATE AREAS IN THE MAP.
2. THE FLOOD CONSTRUCTION LEVELS AND FLOODPLAIN LIMITS ARE NOT ESTABLISHED ON THE GROUND BY LEGAL SURVEY.
3. OTHER SOURCES OF WATER, ROADS, RAILWAYS OR OTHER BARRIERS CAN RESTRICT WATER FLOW AND AFFECT LOCAL FLOOD LEVELS. OBSTRUCTIONS SUCH AS DEBRIS AND LOG JAMS, SEDIMENT DEPOSITION, LOCAL STORM WATER INFLOWS, GROUNDWATER OR OTHER LAND DRAINAGE CAN CAUSE FLOOD CONSTRUCTION LEVELS TO EXCEED THOSE INDICATED ON THE MAP. LANDS ADJACENT TO A FLOODPLAIN MAY BE SUBJECT TO FLOODING FROM TRIBUTARY STREAMS THAT ARE NOT INDICATED ON THE MAPS.
4. BUILDING AND FLOODPROOFING ELEVATIONS SHOULD BE BASED ON FIELD SURVEY AND ESTABLISHED BENCHMARKS.

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED APRIL 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH. PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD CONSTRUCTION LEVEL BASED ON THE WATER SURFACE ELEVATION FROM THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE PLUS 0.6 m FREEBOARD
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

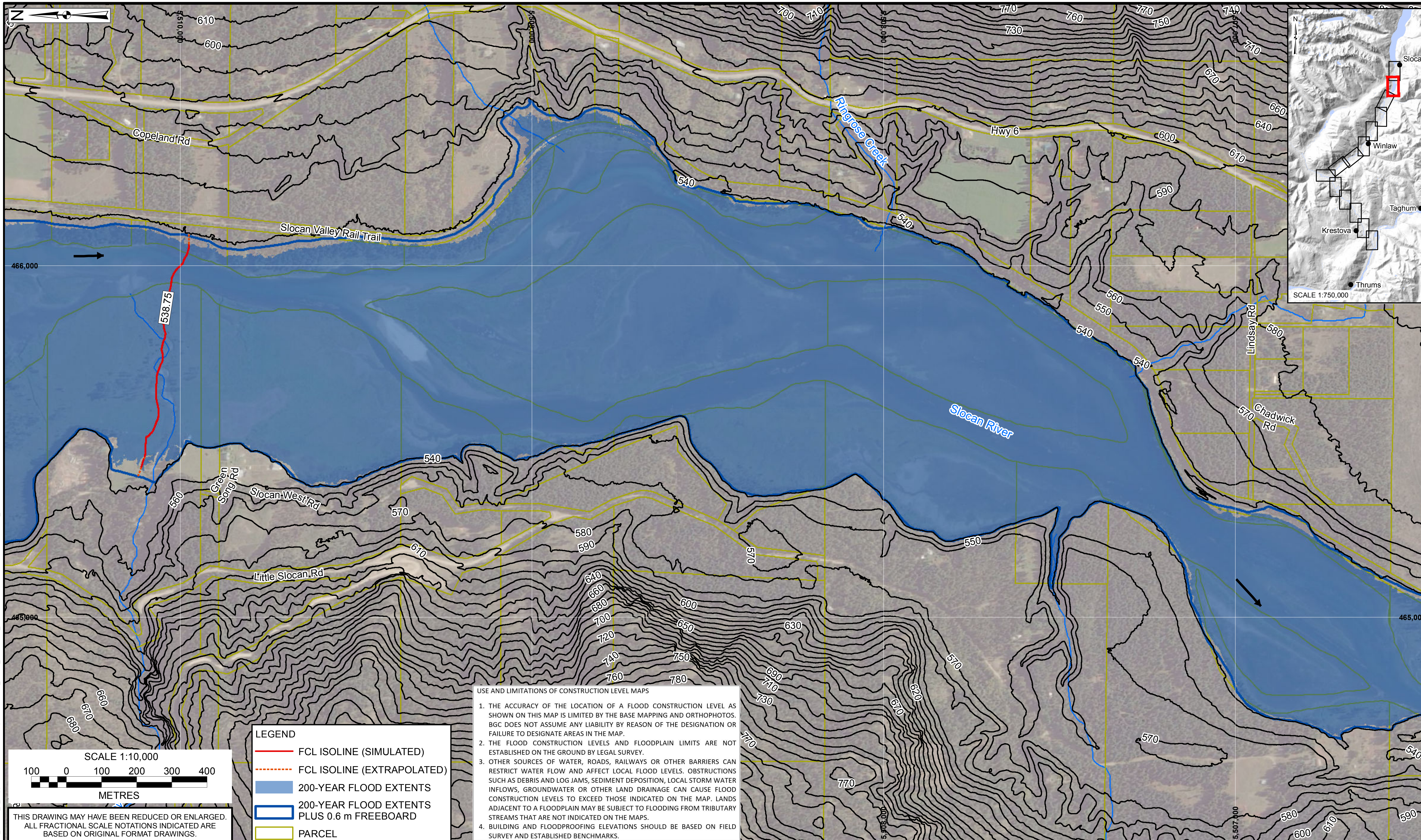
CLIENT: REGIONAL DISTRICT CENTRAL KOOTENAY

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER

TITLE: 200-YEAR FLOOD CONSTRUCTION LEVEL (SHEET 01 OF 14)

PROJECT No.: 0268 007 | DWG No: 07

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year Flood Construction Limits_DDP.mxd




LEGEND

- FCL ISOLINE (SIMULATED)
- FCL ISOLINE (EXTRAPOLATED)
- 200-YEAR FLOOD EXTENTS
- 200-YEAR FLOOD EXTENTS PLUS 0.6 m FREEBOARD
- PARCEL

SCALE 1:10,000

100 0 100 200 300 400

METRES

THIS DRAWING MAY HAVE BEEN REDUCED OR ENLARGED. ALL FRACTIONAL SCALE NOTATIONS INDICATED ARE BASED ON ORIGINAL FORMAT DRAWINGS.

USE AND LIMITATIONS OF CONSTRUCTION LEVEL MAPS

1. THE ACCURACY OF THE LOCATION OF A FLOOD CONSTRUCTION LEVEL AS SHOWN ON THIS MAP IS LIMITED BY THE BASE MAPPING AND ORTHOPHOTOS. BGC DOES NOT ASSUME ANY LIABILITY BY REASON OF THE DESIGNATION OR FAILURE TO DESIGNATE AREAS IN THE MAP.
2. THE FLOOD CONSTRUCTION LEVELS AND FLOODPLAIN LIMITS ARE NOT ESTABLISHED ON THE GROUND BY LEGAL SURVEY.
3. OTHER SOURCES OF WATER, ROADS, RAILWAYS OR OTHER BARRIERS CAN RESTRICT WATER FLOW AND AFFECT LOCAL FLOOD LEVELS. OBSTRUCTIONS SUCH AS DEBRIS AND LOG JAMS, SEDIMENT DEPOSITION, LOCAL STORM WATER INFLOWS, GROUNDWATER OR OTHER LAND DRAINAGE CAN CAUSE FLOOD CONSTRUCTION LEVELS TO EXCEED THOSE INDICATED ON THE MAP. LANDS ADJACENT TO A FLOODPLAIN MAY BE SUBJECT TO FLOODING FROM TRIBUTARY STREAMS THAT ARE NOT INDICATED ON THE MAPS.
4. BUILDING AND FLOODPROOFING ELEVATIONS SHOULD BE BASED ON FIELD SURVEY AND ESTABLISHED BENCHMARKS.

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED APRIL 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH. PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD CONSTRUCTION LEVEL BASED ON THE WATER SURFACE ELEVATION FROM THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE PLUS 0.6 m FREEBOARD
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

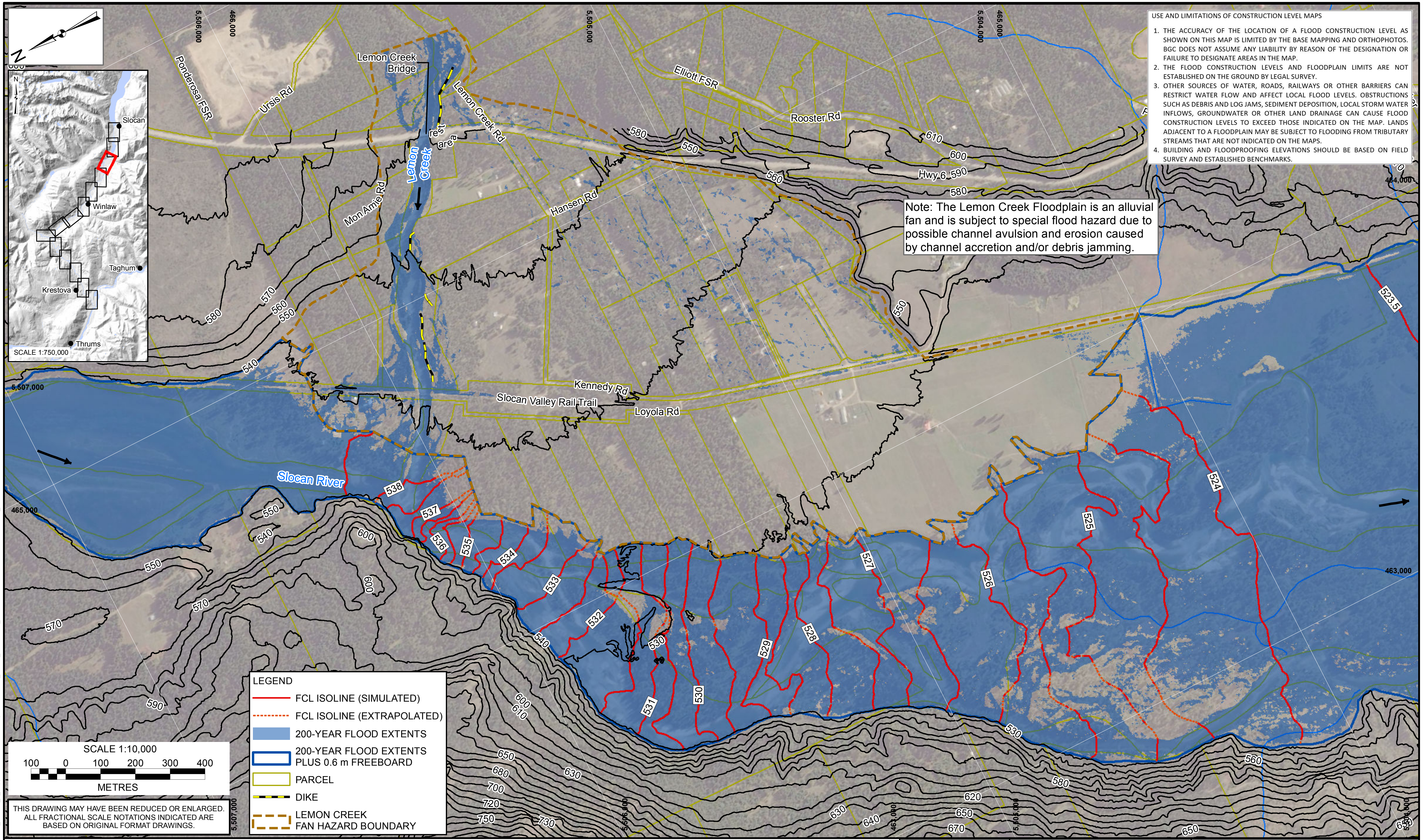
CLIENT:

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY
SLOCAN RIVER

TITLE:
200-YEAR FLOOD CONSTRUCTION LEVEL
(SHEET 02 OF 14)

| PROJECT No.: | DWG No: |
|---|---|
| 0268 007 | 07 |

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year Flood Construction Limits_DDP.mxd




USE AND LIMITATIONS OF CONSTRUCTION LEVEL MAPS

1. THE ACCURACY OF THE LOCATION OF A FLOOD CONSTRUCTION LEVEL AS SHOWN ON THIS MAP IS LIMITED BY THE BASE MAPPING AND ORTHOPHOTOS. BGC DOES NOT ASSUME ANY LIABILITY BY REASON OF THE DESIGNATION OR FAILURE TO DESIGNATE AREAS IN THE MAP.
2. THE FLOOD CONSTRUCTION LEVELS AND FLOODPLAIN LIMITS ARE NOT ESTABLISHED ON THE GROUND BY LEGAL SURVEY.
3. OTHER SOURCES OF WATER, ROADS, RAILWAYS OR OTHER BARRIERS CAN RESTRICT WATER FLOW AND AFFECT LOCAL FLOOD LEVELS. OBSTRUCTIONS SUCH AS DEBRIS AND LOG JAMS, SEDIMENT DEPOSITION, LOCAL STORM WATER INFLOWS, GROUNDWATER OR OTHER LAND DRAINAGE CAN CAUSE FLOOD CONSTRUCTION LEVELS TO EXCEED THOSE INDICATED ON THE MAP. LANDS ADJACENT TO A FLOODPLAIN MAY BE SUBJECT TO FLOODING FROM TRIBUTARY STREAMS THAT ARE NOT INDICATED ON THE MAPS.
4. BUILDING AND FLOODPROOFING ELEVATIONS SHOULD BE BASED ON FIELD SURVEY AND ESTABLISHED BENCHMARKS.

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED APRIL 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH. PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD CONSTRUCTION LEVEL BASED ON THE WATER SURFACE ELEVATION FROM THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE PLUS 0.6 m FREEBOARD
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

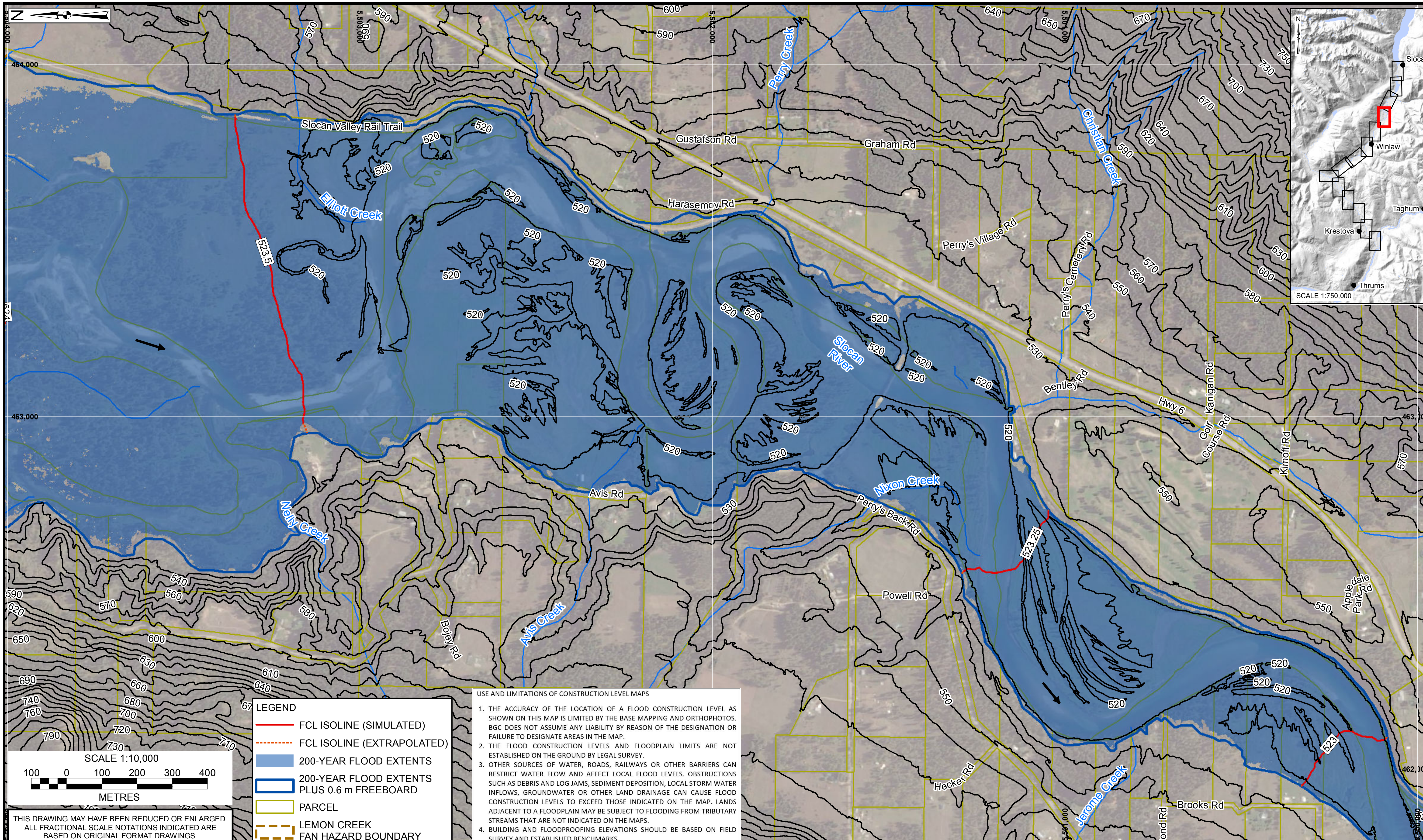
PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER

TITLE: 200-YEAR FLOOD CONSTRUCTION LEVEL (SHEET 03 OF 14)

PROJECT No.: 0268 007

DWG No: 07

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year Flood Construction Limits_DDP.mxd




THIS DRAWING MAY HAVE BEEN REDUCED OR ENLARGED. ALL FRACTIONAL SCALE NOTATIONS INDICATED ARE BASED ON ORIGINAL FORMAT DRAWINGS.

LEGEND

- FCL ISOLINE (SIMULATED)
- FCL ISOLINE (EXTRAPOLATED)
- 200-YEAR FLOOD EXTENTS
- 200-YEAR FLOOD EXTENTS PLUS 0.6 m FREEBOARD
- PARCEL
- LEMON CREEK FAN HAZARD BOUNDARY

USE AND LIMITATIONS OF CONSTRUCTION LEVEL MAPS

1. THE ACCURACY OF THE LOCATION OF A FLOOD CONSTRUCTION LEVEL AS SHOWN ON THIS MAP IS LIMITED BY THE BASE MAPPING AND ORTHOPHOTOS. BGC DOES NOT ASSUME ANY LIABILITY BY REASON OF THE DESIGNATION OR FAILURE TO DESIGNATE AREAS IN THE MAP.
2. THE FLOOD CONSTRUCTION LEVELS AND FLOODPLAIN LIMITS ARE NOT ESTABLISHED ON THE GROUND BY LEGAL SURVEY.
3. OTHER SOURCES OF WATER, ROADS, RAILWAYS OR OTHER BARRIERS CAN RESTRICT WATER FLOW AND AFFECT LOCAL FLOOD LEVELS. OBSTRUCTIONS SUCH AS DEBRIS AND LOG JAMS, SEDIMENT DEPOSITION, LOCAL STORM WATER INFLOWS, GROUNDWATER OR OTHER LAND DRAINAGE CAN CAUSE FLOOD CONSTRUCTION LEVELS TO EXCEED THOSE INDICATED ON THE MAP. LANDS ADJACENT TO A FLOODPLAIN MAY BE SUBJECT TO FLOODING FROM TRIBUTARY STREAMS THAT ARE NOT INDICATED ON THE MAPS.
4. BUILDING AND FLOODPROOFING ELEVATIONS SHOULD BE BASED ON FIELD SURVEY AND ESTABLISHED BENCHMARKS.

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED APRIL 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH. PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD CONSTRUCTION LEVEL BASED ON THE WATER SURFACE ELEVATION FROM THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE PLUS 0.6 m FREEBOARD
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

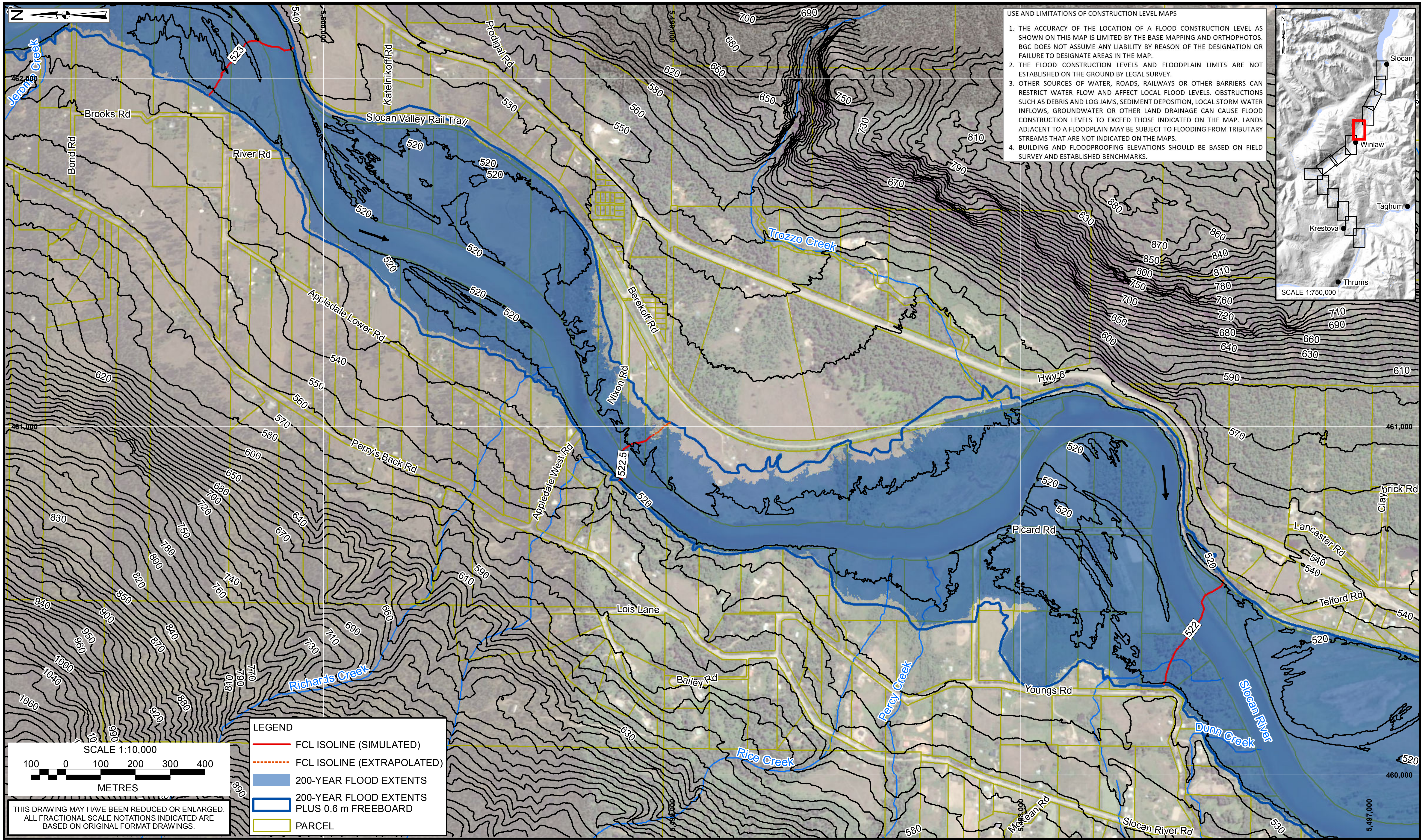
PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER

TITLE: 200-YEAR FLOOD CONSTRUCTION LEVEL (SHEET 04 OF 14)

PROJECT No.: 0268 007

DWG No: 07

X:\Projects\0268007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year Flood Construction Limits_DDP.mxd




NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED APRIL 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH. PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD CONSTRUCTION LEVEL BASED ON THE WATER SURFACE ELEVATION FROM THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE PLUS 0.6 m FREEBOARD
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

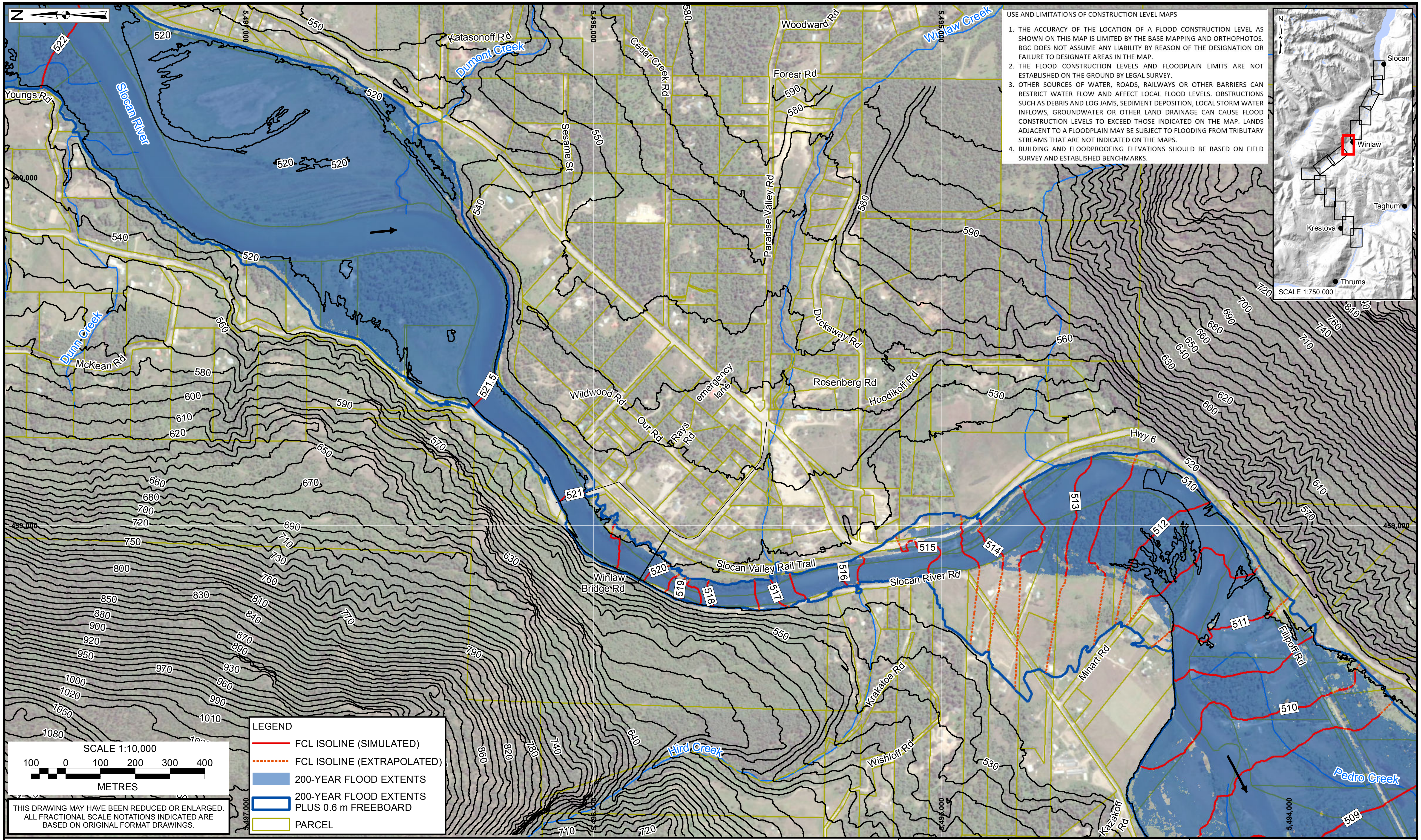
CLIENT:

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY
SLOCAN RIVER

TITLE:
200-YEAR FLOOD CONSTRUCTION LEVEL
(SHEET 05 OF 14)

| PROJECT No.: | DWG No: |
|---|---|
| 0268 007 | 07 |

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year Flood Construction Limits_DDP.mxd




USE AND LIMITATIONS OF CONSTRUCTION LEVEL MAPS

1. THE ACCURACY OF THE LOCATION OF A FLOOD CONSTRUCTION LEVEL AS SHOWN ON THIS MAP IS LIMITED BY THE BASE MAPPING AND ORTHOPHOTOS. BGC DOES NOT ASSUME ANY LIABILITY BY REASON OF THE DESIGNATION OR FAILURE TO DESIGNATE AREAS IN THE MAP.
2. THE FLOOD CONSTRUCTION LEVELS AND FLOODPLAIN LIMITS ARE NOT ESTABLISHED ON THE GROUND BY LEGAL SURVEY.
3. OTHER SOURCES OF WATER, ROADS, RAILWAYS OR OTHER BARRIERS CAN RESTRICT WATER FLOW AND AFFECT LOCAL FLOOD LEVELS. OBSTRUCTIONS SUCH AS DEBRIS AND LOG JAMS, SEDIMENT DEPOSITION, LOCAL STORM WATER INFLOWS, GROUNDWATER OR OTHER LAND DRAINAGE CAN CAUSE FLOOD CONSTRUCTION LEVELS TO EXCEED THOSE INDICATED ON THE MAP. LANDS ADJACENT TO A FLOODPLAIN MAY BE SUBJECT TO FLOODING FROM TRIBUTARY STREAMS THAT ARE NOT INDICATED ON THE MAPS.
4. BUILDING AND FLOODPROOFING ELEVATIONS SHOULD BE BASED ON FIELD SURVEY AND ESTABLISHED BENCHMARKS.

THIS DRAWING MAY HAVE BEEN REDUCED OR ENLARGED. ALL FRACTIONAL SCALE NOTATIONS INDICATED ARE BASED ON ORIGINAL FORMAT DRAWINGS.

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED APRIL 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH. PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD CONSTRUCTION LEVEL BASED ON THE WATER SURFACE ELEVATION FROM THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE PLUS 0.6 m FREEBOARD
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

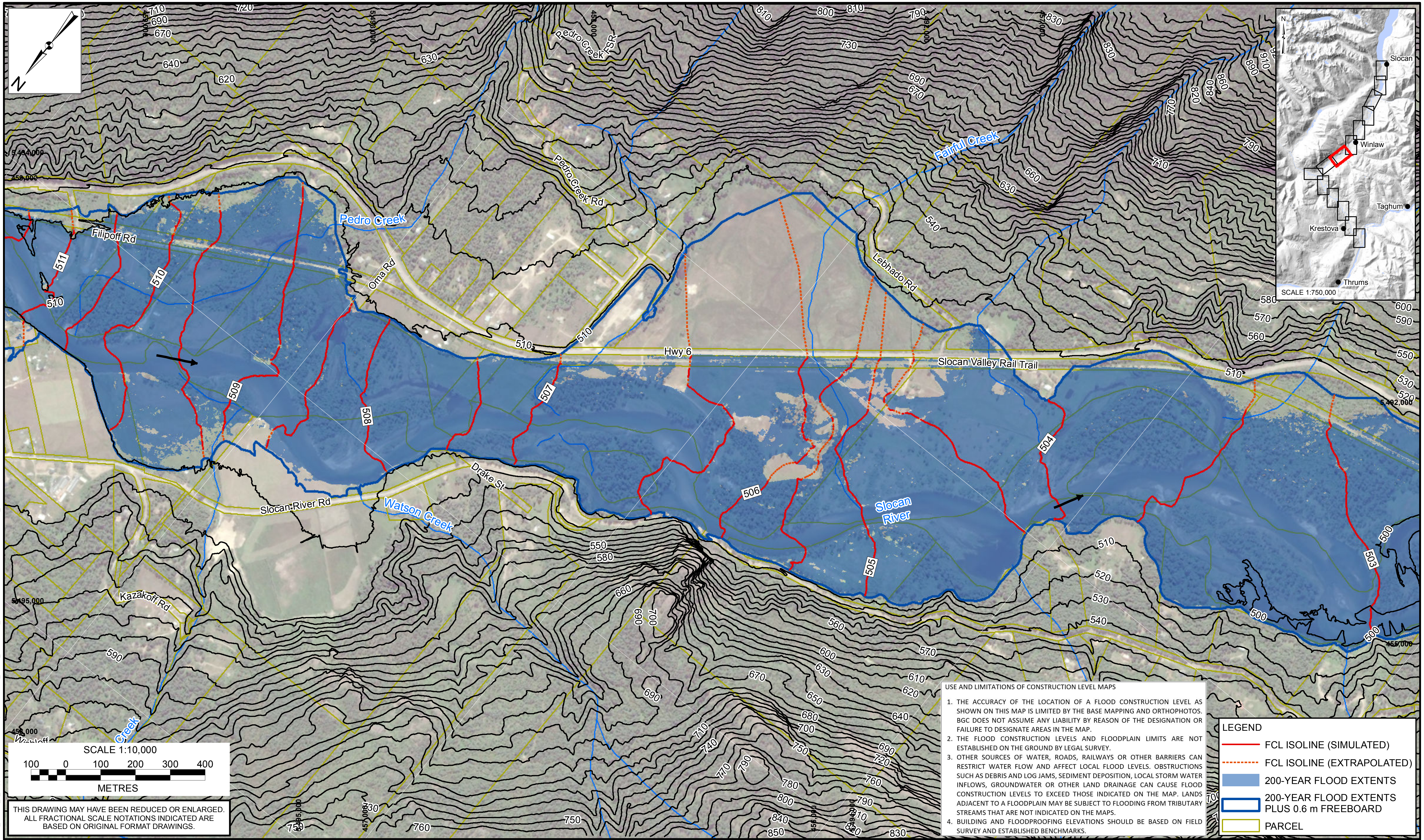
CLIENT:

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY
SLOCAN RIVER

TITLE:
200-YEAR FLOOD CONSTRUCTION LEVEL
(SHEET 06 OF 14)

| PROJECT No.: | DWG No: |
|---|---|
| 0268 007 | 07 |

X:\Projects\0268007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year Flood Construction Limits_DDP.mxd




USE AND LIMITATIONS OF CONSTRUCTION LEVEL MAPS

1. THE ACCURACY OF THE LOCATION OF A FLOOD CONSTRUCTION LEVEL AS SHOWN ON THIS MAP IS LIMITED BY THE BASE MAPPING AND ORTHOPHOTOS. BGC DOES NOT ASSUME ANY LIABILITY BY REASON OF THE DESIGNATION OR FAILURE TO DESIGNATE AREAS IN THE MAP.
2. THE FLOOD CONSTRUCTION LEVELS AND FLOODPLAIN LIMITS ARE NOT ESTABLISHED ON THE GROUND BY LEGAL SURVEY.
3. OTHER SOURCES OF WATER, ROADS, RAILWAYS OR OTHER BARRIERS CAN RESTRICT WATER FLOW AND AFFECT LOCAL FLOOD LEVELS. OBSTRUCTIONS SUCH AS DEBRIS AND LOG JAMS, SEDIMENT DEPOSITION, LOCAL STORM WATER INFLOWS, GROUNDWATER OR OTHER LAND DRAINAGE CAN CAUSE FLOOD CONSTRUCTION LEVELS TO EXCEED THOSE INDICATED ON THE MAP. LANDS ADJACENT TO A FLOODPLAIN MAY BE SUBJECT TO FLOODING FROM TRIBUTARY STREAMS THAT ARE NOT INDICATED ON THE MAPS.
4. BUILDING AND FLOODPROOFING ELEVATIONS SHOULD BE BASED ON FIELD SURVEY AND ESTABLISHED BENCHMARKS.

LEGEND
- FCL ISOLINE (SIMULATED)
- FCL ISOLINE (EXTRAPOLATED)
- 200-YEAR FLOOD EXTENTS
- 200-YEAR FLOOD EXTENTS PLUS 0.6 m FREEBOARD
- PARCEL

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED APRIL 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH. PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD CONSTRUCTION LEVEL BASED ON THE WATER SURFACE ELEVATION FROM THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE PLUS 0.6 m FREEBOARD
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

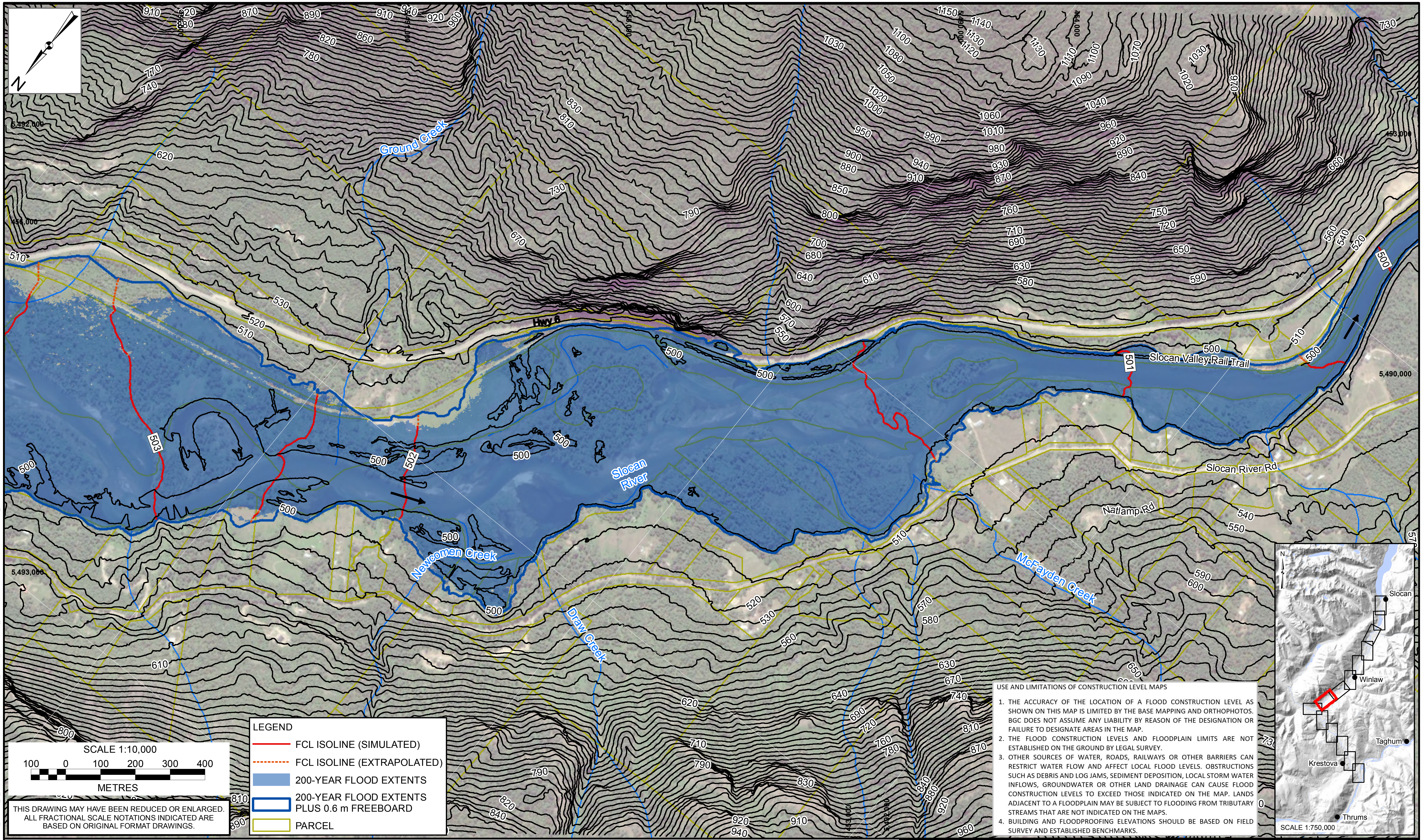
CLIENT:

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER

TITLE: 200-YEAR FLOOD CONSTRUCTION LEVEL (SHEET 07 OF 14)

| PROJECT No.: | DWG No: |
|---|---|
| 0268 007 | 07 |

X:\Projects\0268007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year Flood Construction Limits_DDP.mxd




SCALE 1:10,000

100 0 100 200 300 400

METRES

THIS DRAWING MAY HAVE BEEN REDUCED OR ENLARGED. ALL FRACTIONAL SCALE NOTATIONS INDICATED ARE BASED ON ORIGINAL FORMAT DRAWINGS.

LEGEND

- FCL ISOLINE (SIMULATED)
- FCL ISOLINE (EXTRAPOLATED)
- 200-YEAR FLOOD EXTENTS
- 200-YEAR FLOOD EXTENTS PLUS 0.6 m FREEBOARD
- PARCEL

USE AND LIMITATIONS OF CONSTRUCTION LEVEL MAPS

1. THE ACCURACY OF THE LOCATION OF A FLOOD CONSTRUCTION LEVEL AS SHOWN ON THIS MAP IS LIMITED BY THE BASE MAPPING AND ORTHOPHOTOS. BGC DOES NOT ASSUME ANY LIABILITY BY REASON OF THE DESIGNATION OR FAILURE TO DESIGNATE AREAS IN THE MAP.
2. THE FLOOD CONSTRUCTION LEVELS AND FLOODPLAIN LIMITS ARE NOT ESTABLISHED ON THE GROUND BY LEGAL SURVEY.
3. OTHER SOURCES OF WATER, ROADS, RAILWAYS OR OTHER BARRIERS CAN RESTRICT WATER FLOW AND AFFECT LOCAL FLOOD LEVELS. OBSTRUCTIONS SUCH AS DEBRIS AND LOG JAMS, SEDIMENT DEPOSITION, LOCAL STORM WATER INFLOWS, GROUNDWATER OR OTHER LAND DRAINAGE CAN CAUSE FLOOD CONSTRUCTION LEVELS TO EXCEED THOSE INDICATED ON THE MAP. LANDS ADJACENT TO A FLOODPLAIN MAY BE SUBJECT TO FLOODING FROM TRIBUTARY STREAMS THAT ARE NOT INDICATED ON THE MAPS.
4. BUILDING AND FLOODPROOFING ELEVATIONS SHOULD BE BASED ON FIELD SURVEY AND ESTABLISHED BENCHMARKS.

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED APRIL 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH. PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD CONSTRUCTION LEVEL BASED ON THE WATER SURFACE ELEVATION FROM THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE PLUS 0.6 m FREEBOARD
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: REGIONAL DISTRICT CENTRAL KOOTENAY

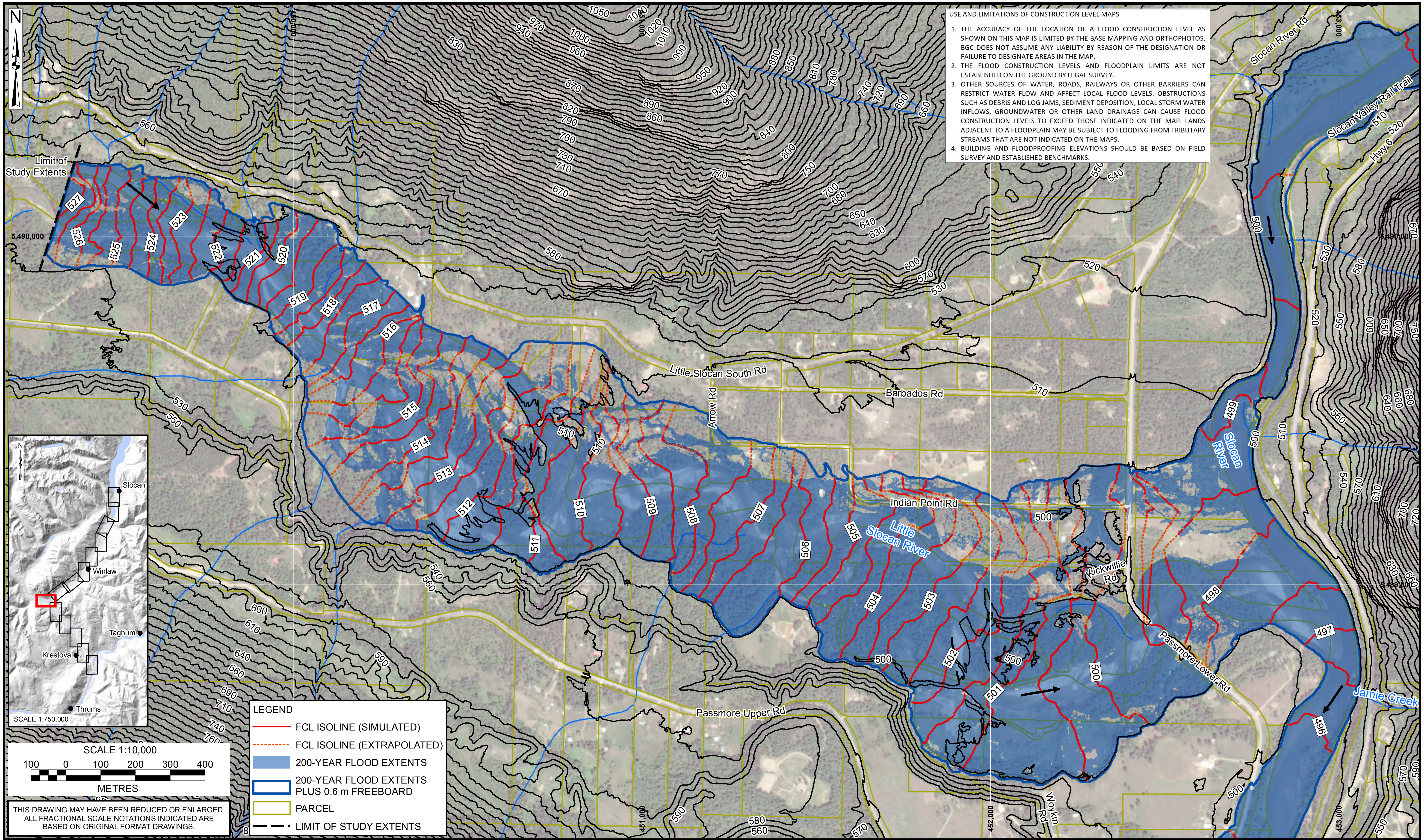
PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER

TITLE: 200-YEAR FLOOD CONSTRUCTION LEVEL (SHEET 08 OF 14)

PROJECT No.: 0268 007

DWG No: 07

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year Flood Construction Limits_DDP.mxd




NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED APRIL 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH. PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD CONSTRUCTION LEVEL BASED ON THE WATER SURFACE ELEVATION FROM THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE PLUS 0.6 m FREEBOARD
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

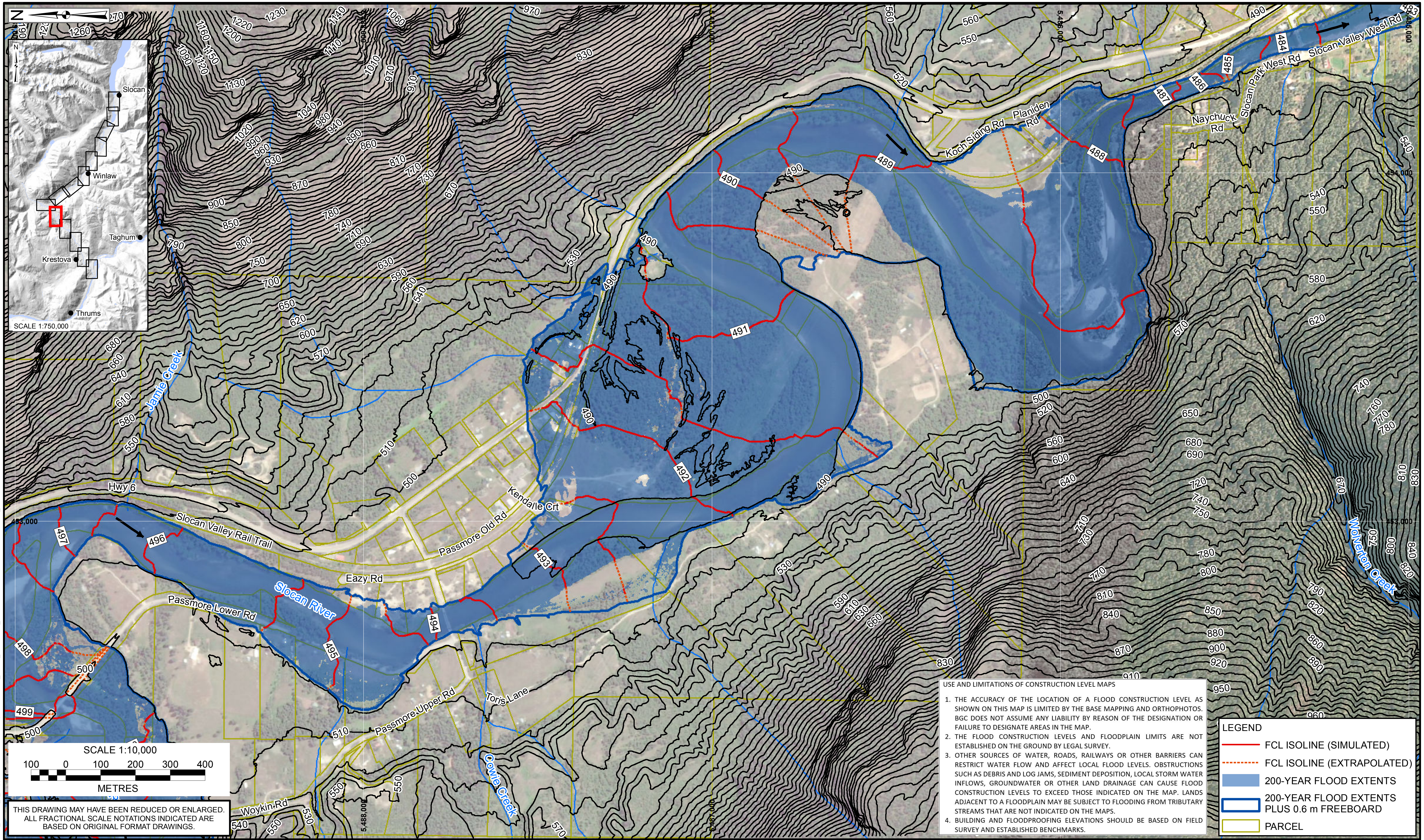
CLIENT:

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY
SLOCAN RIVER

TITLE: 200-YEAR FLOOD CONSTRUCTION LEVEL
(SHEET 09 OF 14)

| PROJECT No.: | DWG No: |
|---|---|
| 0268 007 | 07 |

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year Flood Construction Limits_DDP.mxd




THIS DRAWING MAY HAVE BEEN REDUCED OR ENLARGED. ALL FRACTIONAL SCALE NOTATIONS INDICATED ARE BASED ON ORIGINAL FORMAT DRAWINGS.

USE AND LIMITATIONS OF CONSTRUCTION LEVEL MAPS

1. THE ACCURACY OF THE LOCATION OF A FLOOD CONSTRUCTION LEVEL AS SHOWN ON THIS MAP IS LIMITED BY THE BASE MAPPING AND ORTHOPHOTOS. BGC DOES NOT ASSUME ANY LIABILITY BY REASON OF THE DESIGNATION OR FAILURE TO DESIGNATE AREAS IN THE MAP.
2. THE FLOOD CONSTRUCTION LEVELS AND FLOODPLAIN LIMITS ARE NOT ESTABLISHED ON THE GROUND BY LEGAL SURVEY.
3. OTHER SOURCES OF WATER, ROADS, RAILWAYS OR OTHER BARRIERS CAN RESTRICT WATER FLOW AND AFFECT LOCAL FLOOD LEVELS. OBSTRUCTIONS SUCH AS DEBRIS AND LOG JAMS, SEDIMENT DEPOSITION, LOCAL STORM WATER INFLOWS, GROUNDWATER OR OTHER LAND DRAINAGE CAN CAUSE FLOOD CONSTRUCTION LEVELS TO EXCEED THOSE INDICATED ON THE MAP. LANDS ADJACENT TO A FLOODPLAIN MAY BE SUBJECT TO FLOODING FROM TRIBUTARY STREAMS THAT ARE NOT INDICATED ON THE MAPS.
4. BUILDING AND FLOODPROOFING ELEVATIONS SHOULD BE BASED ON FIELD SURVEY AND ESTABLISHED BENCHMARKS.

LEGEND

- FCL ISOLINE (SIMULATED)
- FCL ISOLINE (EXTRAPOLATED)
- 200-YEAR FLOOD EXTENTS
- 200-YEAR FLOOD EXTENTS PLUS 0.6 m FREEBOARD
- PARCEL

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED APRIL 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH. PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD CONSTRUCTION LEVEL BASED ON THE WATER SURFACE ELEVATION FROM THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE PLUS 0.6 m FREEBOARD
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

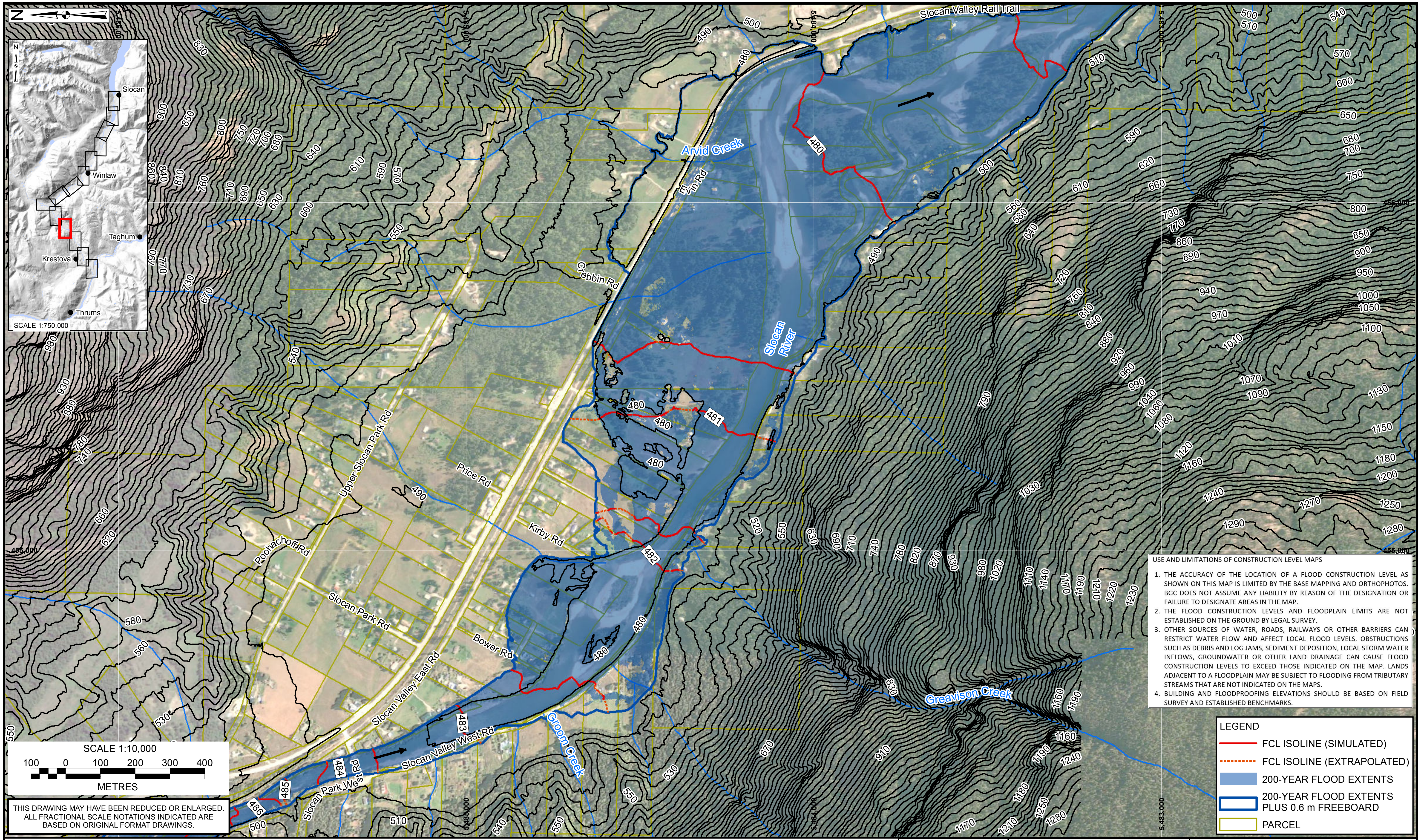
CLIENT:

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER

TITLE: 200-YEAR FLOOD CONSTRUCTION LEVEL (SHEET 10 OF 14)

| PROJECT No.: | DWG No: |
|---|---|
| 0268 007 | 07 |

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year Flood Construction Limits_DDP.mxd




THIS DRAWING MAY HAVE BEEN REDUCED OR ENLARGED. ALL FRACTIONAL SCALE NOTATIONS INDICATED ARE BASED ON ORIGINAL FORMAT DRAWINGS.

USE AND LIMITATIONS OF CONSTRUCTION LEVEL MAPS

1. THE ACCURACY OF THE LOCATION OF A FLOOD CONSTRUCTION LEVEL AS SHOWN ON THIS MAP IS LIMITED BY THE BASE MAPPING AND ORTHOPHOTOS. BGC DOES NOT ASSUME ANY LIABILITY BY REASON OF THE DESIGNATION OR FAILURE TO DESIGNATE AREAS IN THE MAP.
2. THE FLOOD CONSTRUCTION LEVELS AND FLOODPLAIN LIMITS ARE NOT ESTABLISHED ON THE GROUND BY LEGAL SURVEY.
3. OTHER SOURCES OF WATER, ROADS, RAILWAYS OR OTHER BARRIERS CAN RESTRICT WATER FLOW AND AFFECT LOCAL FLOOD LEVELS. OBSTRUCTIONS SUCH AS DEBRIS AND LOG JAMS, SEDIMENT DEPOSITION, LOCAL STORM WATER INFLOWS, GROUNDWATER OR OTHER LAND DRAINAGE CAN CAUSE FLOOD CONSTRUCTION LEVELS TO EXCEED THOSE INDICATED ON THE MAP. LANDS ADJACENT TO A FLOODPLAIN MAY BE SUBJECT TO FLOODING FROM TRIBUTARY STREAMS THAT ARE NOT INDICATED ON THE MAPS.
4. BUILDING AND FLOODPROOFING ELEVATIONS SHOULD BE BASED ON FIELD SURVEY AND ESTABLISHED BENCHMARKS.

LEGEND

- FCL ISOLINE (SIMULATED)
- FCL ISOLINE (EXTRAPOLATED)
- 200-YEAR FLOOD EXTENTS
- 200-YEAR FLOOD EXTENTS PLUS 0.6 m FREEBOARD
- PARCEL

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED APRIL 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH. PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD CONSTRUCTION LEVEL BASED ON THE WATER SURFACE ELEVATION FROM THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE PLUS 0.6 m FREEBOARD
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

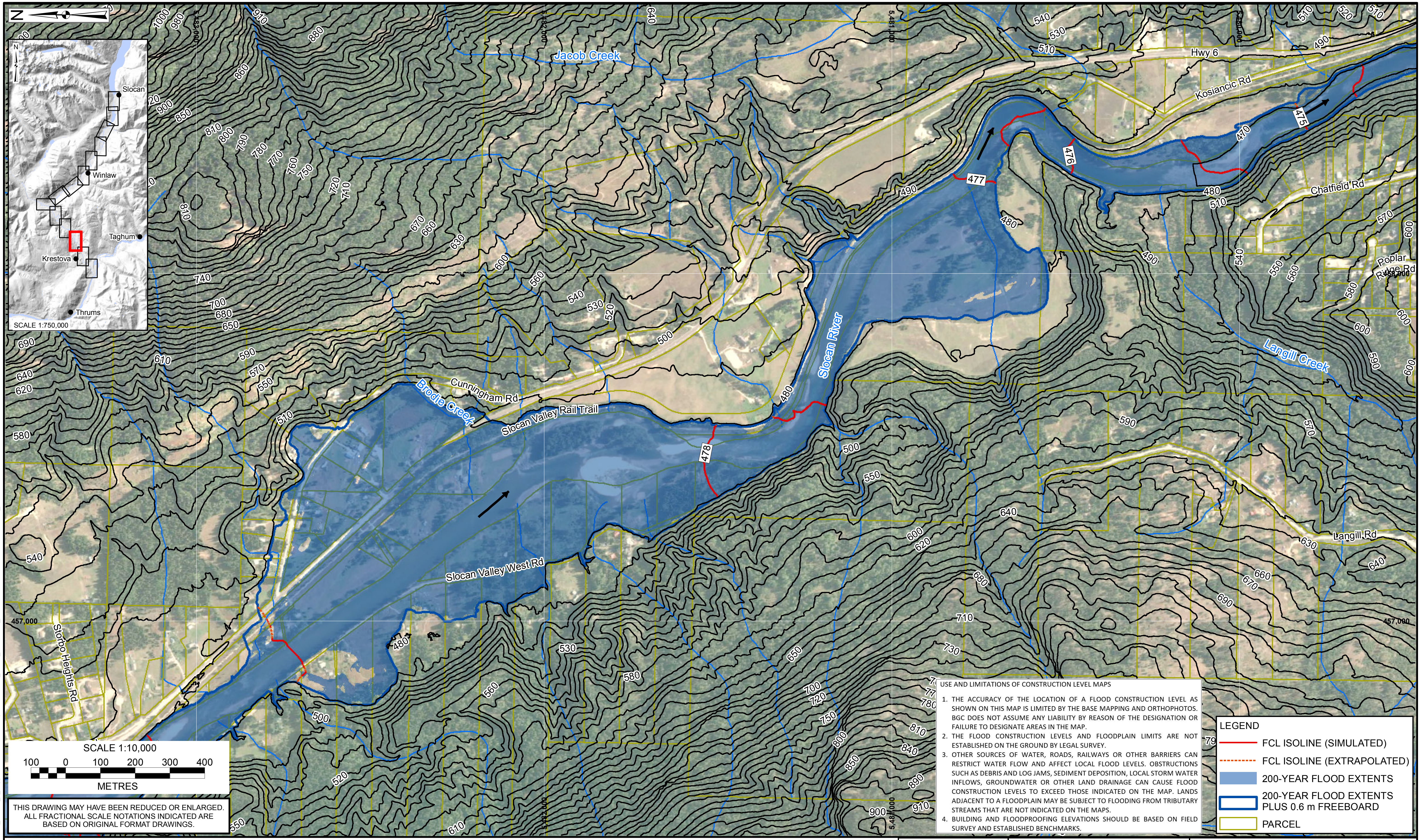
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER

TITLE: 200-YEAR FLOOD CONSTRUCTION LEVEL (SHEET 11 OF 14)

| PROJECT No.: | DWG No: |
|---|---|
| 0268 007 | 07 |




USE AND LIMITATIONS OF CONSTRUCTION LEVEL MAPS

1. THE ACCURACY OF THE LOCATION OF A FLOOD CONSTRUCTION LEVEL AS SHOWN ON THIS MAP IS LIMITED BY THE BASE MAPPING AND ORTHOPHOTOS. BGC DOES NOT ASSUME ANY LIABILITY BY REASON OF THE DESIGNATION OR FAILURE TO DESIGNATE AREAS IN THE MAP.
2. THE FLOOD CONSTRUCTION LEVELS AND FLOODPLAIN LIMITS ARE NOT ESTABLISHED ON THE GROUND BY LEGAL SURVEY.
3. OTHER SOURCES OF WATER, ROADS, RAILWAYS OR OTHER BARRIERS CAN RESTRICT WATER FLOW AND AFFECT LOCAL FLOOD LEVELS. OBSTRUCTIONS SUCH AS DEBRIS AND LOG JAMS, SEDIMENT DEPOSITION, LOCAL STORM WATER INFLOWS, GROUNDWATER OR OTHER LAND DRAINAGE CAN CAUSE FLOOD CONSTRUCTION LEVELS TO EXCEED THOSE INDICATED ON THE MAP. LANDS ADJACENT TO A FLOODPLAIN MAY BE SUBJECT TO FLOODING FROM TRIBUTARY STREAMS THAT ARE NOT INDICATED ON THE MAPS.
4. BUILDING AND FLOODPROOFING ELEVATIONS SHOULD BE BASED ON FIELD SURVEY AND ESTABLISHED BENCHMARKS.

THIS DRAWING MAY HAVE BEEN REDUCED OR ENLARGED. ALL FRACTIONAL SCALE NOTATIONS INDICATED ARE BASED ON ORIGINAL FORMAT DRAWINGS.

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED APRIL 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH. PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD CONSTRUCTION LEVEL BASED ON THE WATER SURFACE ELEVATION FROM THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE PLUS 0.6 m FREEBOARD
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: REGIONAL DISTRICT CENTRAL KOOTENAY

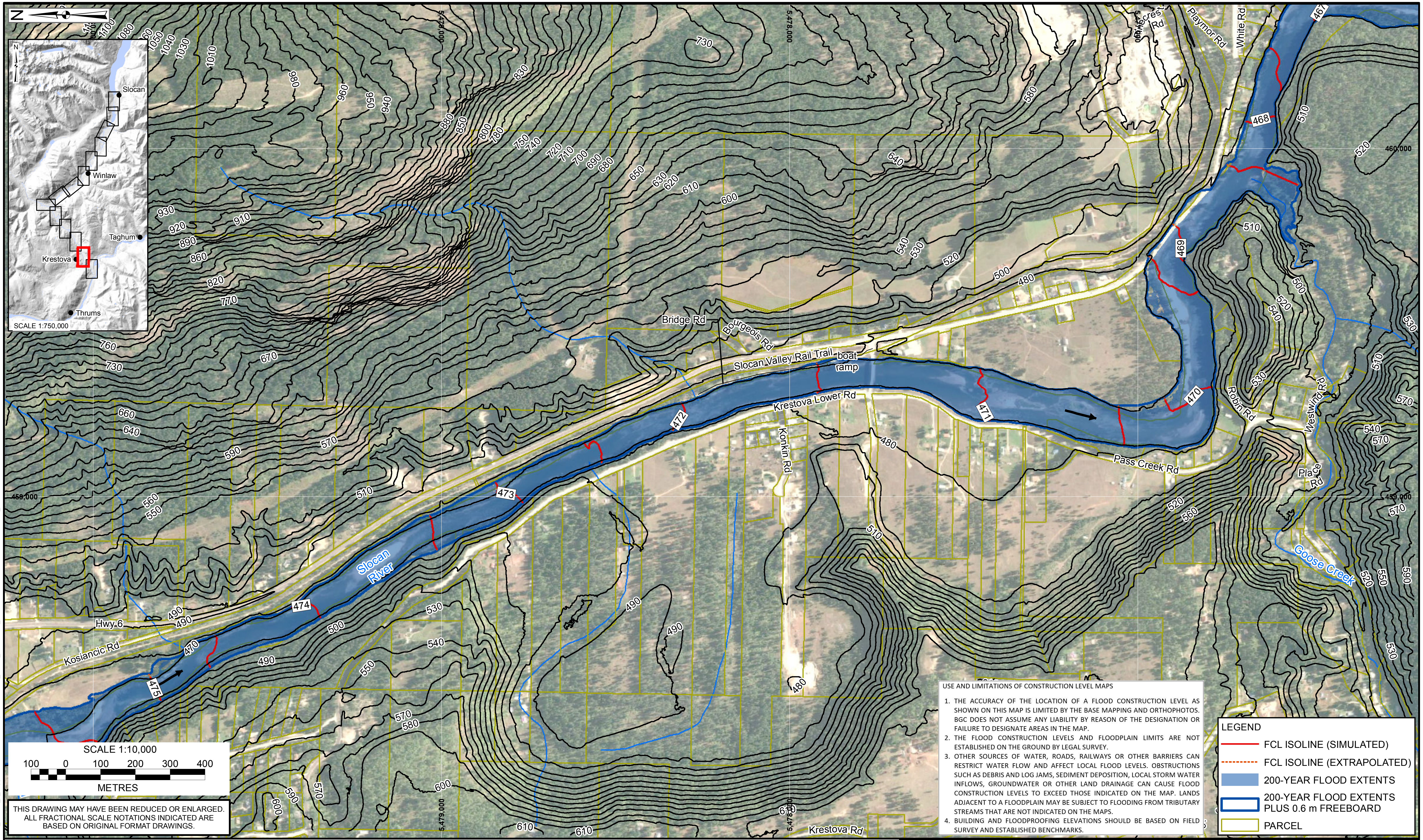
PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER

TITLE: 200-YEAR FLOOD CONSTRUCTION LEVEL (SHEET 12 OF 14)

PROJECT No.: 0268 007

DWG No: 07

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year Flood Construction Limits_DDP.mxd




SCALE 1:10,000

100 0 100 200 300 400

METRES

THIS DRAWING MAY HAVE BEEN REDUCED OR ENLARGED. ALL FRACTIONAL SCALE NOTATIONS INDICATED ARE BASED ON ORIGINAL FORMAT DRAWINGS.

USE AND LIMITATIONS OF CONSTRUCTION LEVEL MAPS

1. THE ACCURACY OF THE LOCATION OF A FLOOD CONSTRUCTION LEVEL AS SHOWN ON THIS MAP IS LIMITED BY THE BASE MAPPING AND ORTHOPHOTOS. BGC DOES NOT ASSUME ANY LIABILITY BY REASON OF THE DESIGNATION OR FAILURE TO DESIGNATE AREAS IN THE MAP.
2. THE FLOOD CONSTRUCTION LEVELS AND FLOODPLAIN LIMITS ARE NOT ESTABLISHED ON THE GROUND BY LEGAL SURVEY.
3. OTHER SOURCES OF WATER, ROADS, RAILWAYS OR OTHER BARRIERS CAN RESTRICT WATER FLOW AND AFFECT LOCAL FLOOD LEVELS. OBSTRUCTIONS SUCH AS DEBRIS AND LOG JAMS, SEDIMENT DEPOSITION, LOCAL STORM WATER INFLOWS, GROUNDWATER OR OTHER LAND DRAINAGE CAN CAUSE FLOOD CONSTRUCTION LEVELS TO EXCEED THOSE INDICATED ON THE MAP. LANDS ADJACENT TO A FLOODPLAIN MAY BE SUBJECT TO FLOODING FROM TRIBUTARY STREAMS THAT ARE NOT INDICATED ON THE MAPS.
4. BUILDING AND FLOODPROOFING ELEVATIONS SHOULD BE BASED ON FIELD SURVEY AND ESTABLISHED BENCHMARKS.

LEGEND

- FCL ISOLINE (SIMULATED)
- FCL ISOLINE (EXTRAPOLATED)
- 200-YEAR FLOOD EXTENTS
- 200-YEAR FLOOD EXTENTS PLUS 0.6 m FREEBOARD
- PARCEL

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED APRIL 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH. PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD CONSTRUCTION LEVEL BASED ON THE WATER SURFACE ELEVATION FROM THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE PLUS 0.6 m FREEBOARD
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

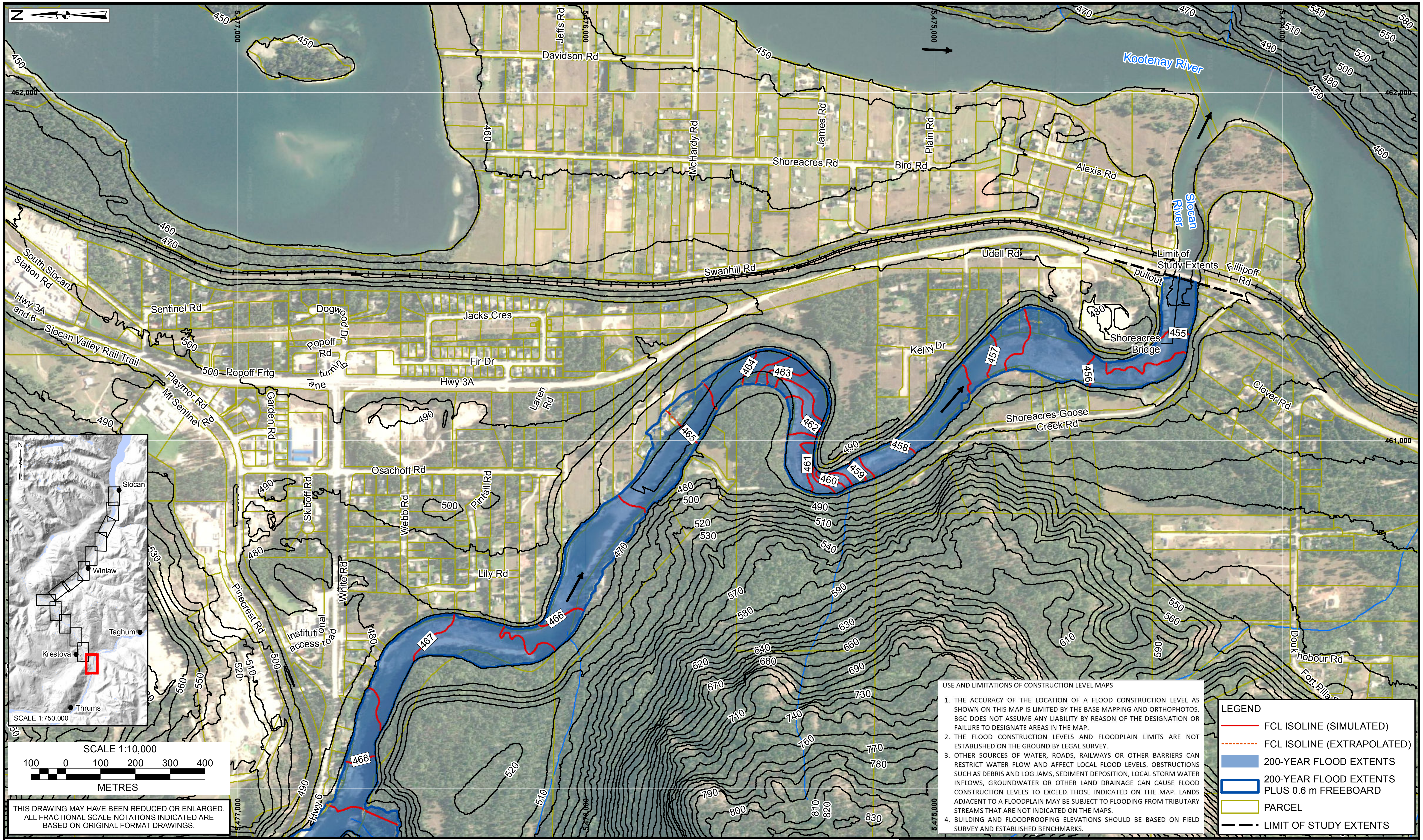
CLIENT:

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER

TITLE: 200-YEAR FLOOD CONSTRUCTION LEVEL (SHEET 13 OF 14)

| PROJECT No.: | DWG No: |
|---|---|
| 0268 007 | 07 |

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year Flood Construction Limits_DDP.mxd




USE AND LIMITATIONS OF CONSTRUCTION LEVEL MAPS

1. THE ACCURACY OF THE LOCATION OF A FLOOD CONSTRUCTION LEVEL AS SHOWN ON THIS MAP IS LIMITED BY THE BASE MAPPING AND ORTHOPHOTOS. BGC DOES NOT ASSUME ANY LIABILITY BY REASON OF THE DESIGNATION OR FAILURE TO DESIGNATE AREAS IN THE MAP.
2. THE FLOOD CONSTRUCTION LEVELS AND FLOODPLAIN LIMITS ARE NOT ESTABLISHED ON THE GROUND BY LEGAL SURVEY.
3. OTHER SOURCES OF WATER, ROADS, RAILWAYS OR OTHER BARRIERS CAN RESTRICT WATER FLOW AND AFFECT LOCAL FLOOD LEVELS. OBSTRUCTIONS SUCH AS DEBRIS AND LOG JAMS, SEDIMENT DEPOSITION, LOCAL STORM WATER INFLOWS, GROUNDWATER OR OTHER LAND DRAINAGE CAN CAUSE FLOOD CONSTRUCTION LEVELS TO EXCEED THOSE INDICATED ON THE MAP. LANDS ADJACENT TO A FLOODPLAIN MAY BE SUBJECT TO FLOODING FROM TRIBUTARY STREAMS THAT ARE NOT INDICATED ON THE MAPS.
4. BUILDING AND FLOODPROOFING ELEVATIONS SHOULD BE BASED ON FIELD SURVEY AND ESTABLISHED BENCHMARKS.

LEGEND

- FCL ISOLINE (SIMULATED)
- FCL ISOLINE (EXTRAPOLATED)
- 200-YEAR FLOOD EXTENTS
- 200-YEAR FLOOD EXTENTS PLUS 0.6 m FREEBOARD
- PARCEL
- LIMIT OF STUDY EXTENTS

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER", AND DATED APRIL 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017 AND 2018. CONTOUR INTERVAL IS 10 m. IMAGERY FROM GOOGLE EARTH. PARCEL DATA FROM PARCELMAP BC. DIKE DATA FROM DATA BC. FLOOD CONSTRUCTION LEVEL BASED ON THE WATER SURFACE ELEVATION FROM THE 200-YEAR FLOOD USING THE INSTANTANEOUS PEAK DISCHARGE ADJUSTED FOR CLIMATE CHANGE PLUS 0.6 m FREEBOARD
4. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS CGVD2013.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

| | |
|---|---|
| SCALE: | 1:10,000 |
| DATE: | MAR 2020 |
| DRAWN: | LL |
| CHECKED: | PG, MOT |
| APPROVED: | RM |

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY SLOCAN RIVER

TITLE: 200-YEAR FLOOD CONSTRUCTION LEVEL (SHEET 14 OF 14)

| PROJECT No.: | DWG No: |
|---|---|
| 0268 007 | 07 |

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191218_RDCK_Clearwater_FCL\200-Year Flood Construction Limits_DDP.mxd