BGC

RDCK FLOODPLAIN AND STEEP CREEK STUDY

Eagle Creek

FINAL
March 31, 2020

BGC Project No.:
0268007

BGC Document No.:
RDCK2-SC-001F

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

TABLE OF REVISIONS

ISSUE	DATE	REV	REMARKS
DRAFT	February 10, 2020		Original issue
FINAL	March 31, 2020		Final issue

LIMITATIONS

EXECUTIVE SUMMARY

This report and its appendices provide a detailed hydrogeomorphic hazard assessment of Eagle Creek. Eagle Creek was chosen as a high priority creek amongst hundreds in the Regional District of Central Kootenays from a risk perspective because of its comparatively high hazards and consequences from debris flooding. This report provides a comprehensive geomorphological and hydrological background and details the analytical techniques applied to create scenario and composite hazard rating maps for Eagle Creek fan-delta. This work is the foundation for possible future quantitative risk assessments or conceptualization and eventual design and construction of mitigation measures.

Eagle Creek is one of ten steep creeks selected for detailed assessment, which can be grouped by hazard process as those principally dominated by floods and debris floods (Wilson, Cooper, Eagle, Kokanee, Sitkum, Harrop and Duhamel creeks); those by debris flows (Kuskonook Creek); and hybrids (Procter and Redfish creeks).

Two numerical models were employed to simulate the chosen hazard scenarios on the fan-delta. The reason for using two models was to simulate a range of results as both models have their distinct advantages and shortfalls. Multiple hazard scenarios were developed for specific event return periods. This included bulking of flow to allow for higher organic and mineral sediment concentrations. Bridge blockage scenarios were also explicitly considered.

BGC also estimated bank erosion from a physically-based model for different debris flood probabilities. Table E-1 provides key observations derived from the numerical modelling.

Table E-1. Key findings from numerical modelling of Eagle Creek debris floods.

Process	Key Observations
Clearwater inundation (HEC-RAS results for all return periods)	• Eagle Creek remains channelized for all flows except the bridge blockage scenario that was invoked for return periods of 200 and 500 years. • Bridge blockage will result in the flow avulsing from its channel towards the north where it will preferentially follow existing paleochannels
Sedimentation	• Sedimentation will likely be confined to the existing active channel floodplain and will concentrate in the fan-delta area where the lowest gradients persist, and the floodplain has little confinement.
Bank Erosion	• Bank erosion could reach up to approximately 80 m for the 500-year return period. • Bank erosion could impact the south side of Monashee Avenue if the steep banks of the creek were to undercut the road surface.
Auxiliary Hazards	• Bank erosion along the high glaciofluvial deposits south of Monashee Avenue could lead to isolated deeper seated landsliding. • Uncontrolled runoff from the uplands on which Edgewood is situated could lead to severe gullying of the escarpment to the south. • In case of a fan-delta apex avulsion and major flow redirection to the northeast down the central avulsion channel on Eagle Creek fan-delta, substantial sediment could be delivered to Inonoaklin Creek. Aggradation over the lower 300 m of Inonoaklin Creek could lead to flooding along the Inonoaklin Creek floodplain.

The multiple process numerical modelling ensemble approach demonstrates the key hazards and associated risks stem from the potential of a bridge blockage at the fan-delta apex and subsequent dike breaches and avulsions. Secondly, it highlights bank erosion hazards and possible associated slope instability along the southern fan-delta escarpment north of the active channel. Accordingly, future mitigation efforts should focus on these hazard scenarios.

Model results are cartographically expressed in two ways: The individual hazard scenarios (defined by return period and avulsion scenarios) are captured by showing the impact force which combines flow velocity, flow depth and material density. It is an index of destructiveness of an event and well suited for debris floods. The individual hazard scenario maps are useful for assessments of individual properties as well as to guide emergency response as they provide a high degree of detail.

The composite hazard rating map combines all hazard scenarios into one map and incorporates the respective debris flood frequencies. It provides a sense of the areas that could possibly be impacted by future debris floods up to the highest modeled return period. The composite hazard rating map can serve to guide subdivision and other development permit approvals. It requires discussions and regulatory decisions on which hazard zone is attributed to specific landuse prescriptions, covenants, bylaws or other limiting clauses for both existing and proposed development.

The categories range from very low to very high hazard. Very low hazard is defined as areas likely to not be affected by any of the modeled scenarios up to the 500-year return period debris floods, but which are not free of hazard. Very low hazard zones could be impacted by flows of higher return periods, or if, over time, the channel bed of Eagle Creek aggrades, or the channel or fan surface is artificially altered. All other hazard categories are classified via the impact force intensity. The composite hazard rating map shows that the majority of the Eagle Creek fan-delta are subject to very low and low hazards. Moderate and high hazards are confined to the channel of Eagle Creek as well as an avulsion channel to the north of the main channel.

While not comprehensive or quantitative, BGC provides several considerations for creek hazard management. These include (from the top of the fan delta to the bottom): Update berm upstream of Worthington Creek Forest Service Road (FSR) to prevent avulsions to the northern fan section; increase capacity of Worthington Creek FSR bridge and protect abutments from erosion; and improve existing erosion protection at the toe of steep slopes adjacent to the main channel with development at the top. In addition to physical mitigation, other measures should be considered such as development restrictions.

Some uncertainties persist in this study. As with all hazard assessments and corresponding maps, they constitute a snapshot in time. Re-assessment and/or re-modelling may be warranted due to significant alterations of the surface topography or scenario assumptions, such as future fan-delta developments, debris floods, developments of large landslides in the watershed that could impound Eagle Creek, bridge re-design or alteration to the existing dikes near the fan-delta apex. Furthermore, the assumptions made on changes in runoff due to climate change and sediment bulking, while systematic and well-reasoned, will likely need to be updated occasionally as scientific understanding evolves.

Not all hazards can be adequately modeled as each process displays some chaotic behaviour. For example, unforeseen log jams may alter flow directions and create avulsions into areas not specifically considered in the individual hazard scenarios. Substantial changes of Lower Arrow Lake levels would alter the morphodynamics of the fan-delta and the upstream channel.

Despite these limitations and uncertainties, a detailed and credible hazard assessment has been achieved on which land use decisions can be made.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF DRAWINGS

1. INTRODUCTION

1.1. Summary

The Regional District of Central Kootenay (RDCK, the District) retained BGC Engineering Inc. (BGC) to complete detailed assessments and mapping of 6 floodplains and 10 steep creeks within the District (Figure 1-1, Table 1-1). The work focuses on high priority areas identified during a 2018-2019 regional study that prioritized flood and steep creek hazard areas across the District (BGC, March 31, 2019). The March 31, 2019 assessment is referred to as the "Stream 1" study, and the work described herein as the "Stream 2 study".

This report presents the results of a detailed steep creek geohazards assessment for Eagle Creek, located approximately 61 km northwest of Castlegar, BC, in Electoral Area K. The site lies on the west side of Lower Arrow Lake in the Inonoaklin Creek Valley and flows along the community of Edgewood, BC into the lake. The study objective is to provide detailed steep creek hazard maps and information that will support community planning, bylaw enforcement, emergency response, risk control, and asset management at Eagle Creek. This assessment also provides inputs to possible future work such as:

- Risk tolerance policy development (a process to evaluate situations where geohazards pose a level of risk considered intolerable by the District)
- Quantitative geohazard risk assessments as required to support the implementation of risk tolerance policy.
- Geohazards risk reduction (mitigation) plans.

BGC is providing a summary report for the entire assessment, *RDCK Floodplain and Steep Creek Study Summary Report* (BGC, March 31 2020a) (referred to herein as the "Summary Report"). BGC is also providing a *RDCK Floodplain and Steep Creek Study Steep Creek Assessment Methodology Report* (BGC, March 31 2020b) (referred to herein as the "Methodology Report"). Readers are encouraged to read the Summary Report (BGC, March 31 2020a) to obtain context about the objectives, scope of work, deliverables, and recommendations of the larger study and to read the Methodology Report (BGC, March 31 2020b) for a description of assessment methods.

Table 1-1. List of study areas.

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

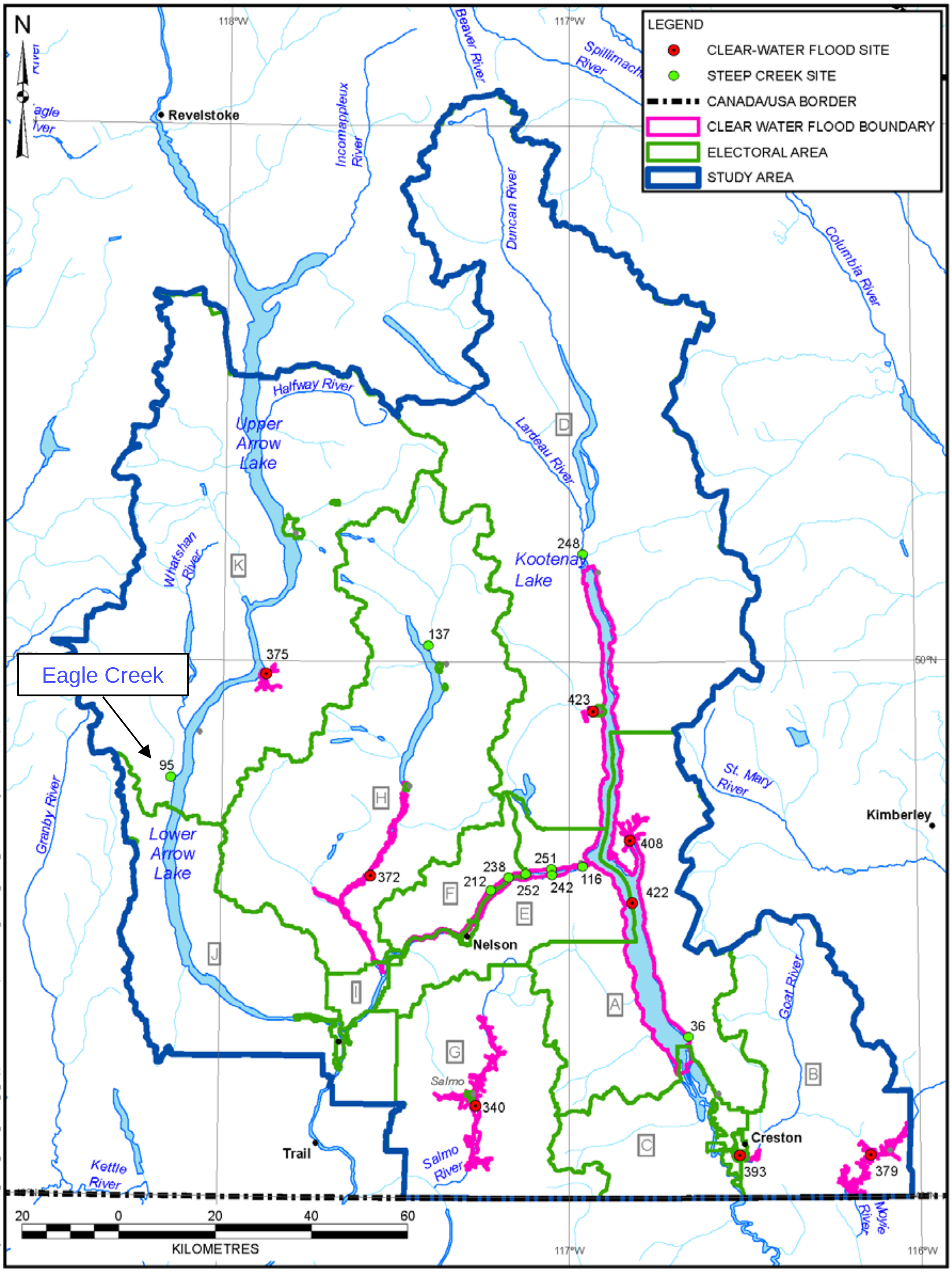


Figure 1-1. Hazard areas prioritized for detailed flood and steep creek mapping. Site labels correspond to hazard identification numbers in Cambio Communities. Eagle Creek (No. 95) is labelled on the figure.

1.2. 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). It is being carried out under the terms of contract between RDCK and BGC (June 20, 2019). The work scope was funded by Emergency Management BC (EMBC) and Public Safety Canada under Stream 2 of the Natural Disaster Mitigation Program (NDMP).

At Eagle Creek, the scope of work includes:

- Characterization of the study area including regional physiography and hydroclimate, and local geology, steep creek process, and watershed, fan-delta and creek characteristics.
- Development of a comprehensive site history of floods and mitigation activity.
- Development of frequency-magnitude (F-M) relationships (flow (discharge) and volume).
- Consideration of climate change impacts on the frequency and magnitude of steep creek flood hazard processes.
- Identification of active and inactive[1] portions of the alluvial fan-delta and areas potentially susceptible to avulsion or bank erosion.
- Mapping of inundation areas, flow velocity, and flow depth for a spectrum of return periods.
- Consideration of processes specific to fan-deltas (backwater effect during times of high lake levels and high peak discharges).
- Recommendations for hazard management on the alluvial fan-delta.

For clarity, BGC notes that the current study is a hazard assessment. No estimation of geohazard consequences or risk were completed as part of the Stream 2 scope of work.

The scope of work considers the "return period ranges" and "representative return periods" outlined in Table 1-2. The representative return periods fall close to the mean of each range[2]. Given uncertainties, they generally represent the spectrum of event magnitudes within the return period ranges.

Table 1-2. Return period classes.

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

[1] Active alluvial fan – The portion of the fan surface which may be exposed to contemporary hydrogeomorphic or avulsion hazards. Inactive alluvial fan – Portions of the fan that are removed from active hydrogeomorphic or avulsion processes by severe fan erosion, also termed fan entrenchment.

[2] The 50- and 500- year events do not precisely fall at the mean of the return period ranges shown in Table 1-2 but were chosen as round figures due to uncertainties and because these return periods have a long tradition of use in BC.

1.3. Deliverables

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

This report is best read with access to a BGC web application, Cambio^{TM}. Cambio displays the results of both the Stream 1 and Stream 2 studies. The application can be accessed at www.cambiocommunities.ca, using either Chrome or Firefox web browsers. Section 5 of the Methodology Report (BGC, March 31 2020b) 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 1-3.

- Kris Holm, M.Sc., P.Geo., Principal Geoscientist
- Sarah Kimball, M.A.Sc., P.Eng., P.Geo., Senior Geological Engineer
- Matthias Jakob, Ph.D., P.Geo., Principal Geoscientist
- Hamish Weatherly, M.Sc., P.Geo., Principal Hydrologist
- Lauren Hutchinson, M.Sc., P.Eng., Intermediate Geotechnical 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
- Jack Park, B.A.Sc., EIT, GIT, Junior Geological Engineer
- Hilary Shirra, B.A.Sc., EIT, Junior Hydrotechnical Engineer
- Phil LeSueur, M.Sc., P.Geo., Geological Engineer
- Patrick Grover, M.A.Sc., P.Eng., Senior Hydrotechnical Engineer
- Melissa Hairabedian, M.Sc., P.Geo., Senior Hydrologist
- Gemma Bullard, Ph.D., EIT, Junior Civil Engineer
- Midori Telles-Langdon, B.A.Sc., P.Eng., P.Geo., Intermediate Geological Engineer
- Sarah Davidson, Ph.D., P.Geo., Intermediate Geoscientist
- Toby Perkins, M.A.Sc., P.Eng., Senior Hydrotechnical Engineer
- Anna Akkerman, B.A.Sc., P.Eng., Senior Hydrotechnical Engineer
- Elisa Scordo, M.Sc., P.Geo., P.Ag., Senior Hydrologist
- Matthew Buchanan, B.Sc., GISP, A.D.P., GIS Analyst
- 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 1-3. Study team.

Project Director	Kris Holm	
Project Manager	Sarah Kimball	
Overall Technical Reviewer(s)	Matthias Jakob Hamish Weatherly	
Section	**Primary Author(s)**	**Peer Reviewer(s)**
1	Lauren Hutchinson	Sarah Kimball; Kris Holm
2	Beatrice Collier-Pandya	Matthias Busslinger; Lauren Hutchinson
3	Beatrice Collier-Pandya	Lauren Hutchinson; Carie-Ann Lau; Matthias Busslinger
4	Jack Park	Carie-Ann Lau; Matthias Busslinger
5.1	Beatrice Collier-Pandya	Lauren Hutchinson; Matthias Jakob
5.2	Patrick Grover	Melissa Hairabedian
5.3	Matthias Busslinger; Matthias Jakob	Beatrice Collier-Pandya; Lauren Hutchinson
5.4	Beatrice Collier-Pandya; Gemma Bullard	Lauren Hutchinson Anna Akkerman
5.5	Gemma Bullard; Midori Telles-Langdon	Sarah Davidson
5.6	Matthias Jakob	Lauren Hutchinson
6.1 – 6.2	Beatrice Collier-Pandya; Jack Park	Lauren Hutchinson
6.3	Patrick Grover	Melissa Hairabedian; Toby Perkins
6.4	Matthias Jakob	Lauren Hutchinson
6.5	Gemma Bullard; Beatrice Collier-Pandya	Lauren Hutchinson Anna Akkerman
6.6	Gemma Bullard; Midori Telles-Langdon,	Sarah Davidson
6.7	Beatrice Collier-Pandya; Gemma Bullard	Lauren Hutchinson
7	Matthias Jakob	Lauren Hutchinson

2. STEEP CREEK HAZARDS

2.1. Introduction

Steep creek or hydrogeomorphic hazards are natural hazards that involve a mixture of water ("hydro") and debris or sediment ("geo"). These hazards typically occur on creeks and steep rivers with small watersheds (usually less than 100 km^2) in mountainous terrain, usually after intense or long rainfall events, sometimes aided by snowmelt and worsened by forest fires.

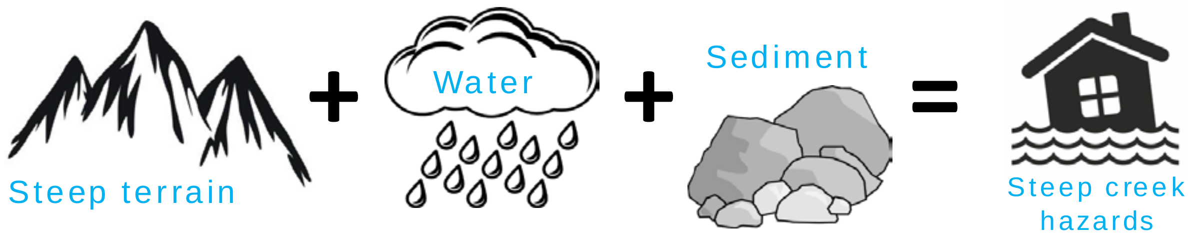


Figure 2-1. Illustration of steep creek hazards.

Steep creek hazards span a continuum of processes from clearwater flood to debris flows (Figure 2-2). Debris flow is by definition a landslide process. This section introduces these hazards; more details are provided in Section 1 of the Methodology Report (BGC, March 31 2020b). Definitions of specific hazard terminology used in this report are provided in Appendix A.

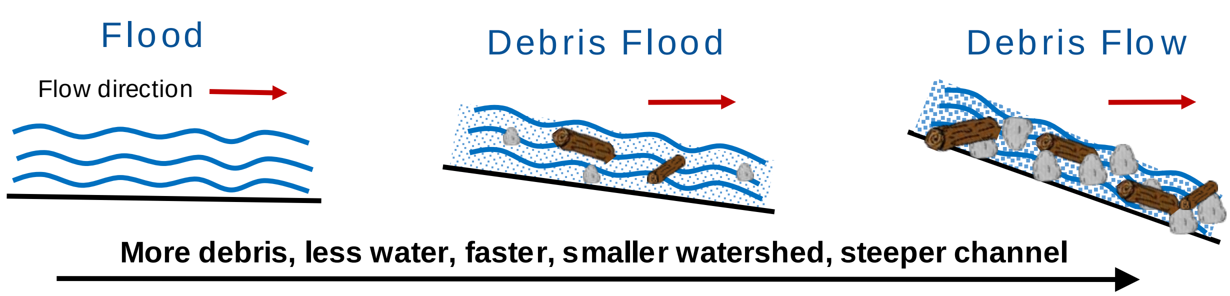


Figure 2-2. Continuum of steep creek hazards.

2.2. Clearwater Floods and Debris Floods

Clearwater floods occur due to rainfall, or when snow melts. Recent major clearwater floods occurred in the RDCK on the Salmo and Slocan Rivers in May 2018.

Debris floods occur when large volumes of water in a creek or river entrain the gravel, cobbles and boulders on the channel bed; this is known as "full bed mobilization". Debris floods can occur from different mechanisms. BGC has adopted the definitions of three different sub-types of debris floods per Church and Jakob (2020):

- Type 1 – Debris floods that are generated from rainfall or snowmelt runoff resulting in sufficient water depth to result in full bed mobilization.
- Type 2 – Debris floods that are generated from diluted debris flows (e.g., a debris flow that runs into a main channel in the upper watershed).

- Type 3 – Debris floods that are generated from natural (e.g., landslide dam) or artificial dam breaches.

The process of sediment and woody debris getting entrained in the water of a flood leads to an increase in the volume of organic and mineral debris flowing down a channel with a commensurate increase in peak discharge. This is referred to as flow bulking. Imagine a bucket of water filled with water. Then it is spilled down a children's slide. That's a clearwater flood. Refilling the bucket to 10 litres and taking a shovel of sand and perhaps some twigs and put it into the bucket. Now the water-sediment mixture occupies 12 litres worth of volume. It has bulked by a factor of 1.2. If one mixes it a bit and then spill it down the slide, one has a bulked debris flood with some 20% sediment concentration by volume. The experiment can be repeated with increasing volumes of sediment until it becomes a debris flow (see Section 2.3).

The effects of debris floods can range from relatively harmless to catastrophic depending on their magnitude and duration. Debris floods can be relatively harmless if of short duration and low magnitude. In contrast, they can be damaging when they cause bank erosion and channel change but do not jeopardize major infrastructure or threaten lives. A catastrophic level is reached when major infrastructure damage occurs in the form of riprap erosion, bridge foundation collapse of isolation, culverts becoming blocked or bypassed and road surfaces being eroded. Furthermore, homes are impacted beyond repair, and injuries and/or fatalities occur.

Within the RDCK, recent debris floods occurred on Fletcher Creek and Hamill Creek in June 2013 (Figure 2-3). The June 2013 events were damaging at both creeks, with multiple homes being flooded and a home being eroded at its foundation (Nelson Star, 2013). Another damaging debris flood occurred at Schroeder Creek on June 19, 2013 where coarse woody debris partially blocked the Highway 31 culvert, excess flow flooded the road surface, dispersed flow ran through the Schroeder Creek Resort campground, and the lower reach of Schroeder Creek (below the highway culvert) experienced significant channel scouring and stream bank erosion (Perdue, 2015). On August 11, 2019, a damaging post-wildfire debris flood occurred on Morley Creek; where a road culvert was blocked, a water intake was destroyed, and several houses were damaged by muddy water (MFLNRORD S. Crookshanks, personal communication, August 20, 2019).

2.3. Debris Flows

Debris flows have higher sediment concentrations than debris floods and can approach consistencies similar to wet concrete. Using the example of a bucket again, if one adds sand to fill the bucket to the top, so that the fluid is half sand, half water, it is bulked by 100%, so a bulking factor of 2. Spilling it down the slide one now has a debris flow that behaves more like liquid concrete than a fluid.

Debris flows are typically faster than debris floods and have substantially higher peak discharges and impact forces. They are particularly threatening to life and properties due to these characteristics. Recent debris flows occurred in the RDCK on Gar Creek, impacting Johnson's Landing, in July 2012, and on Kuskonook Creek in 2004.

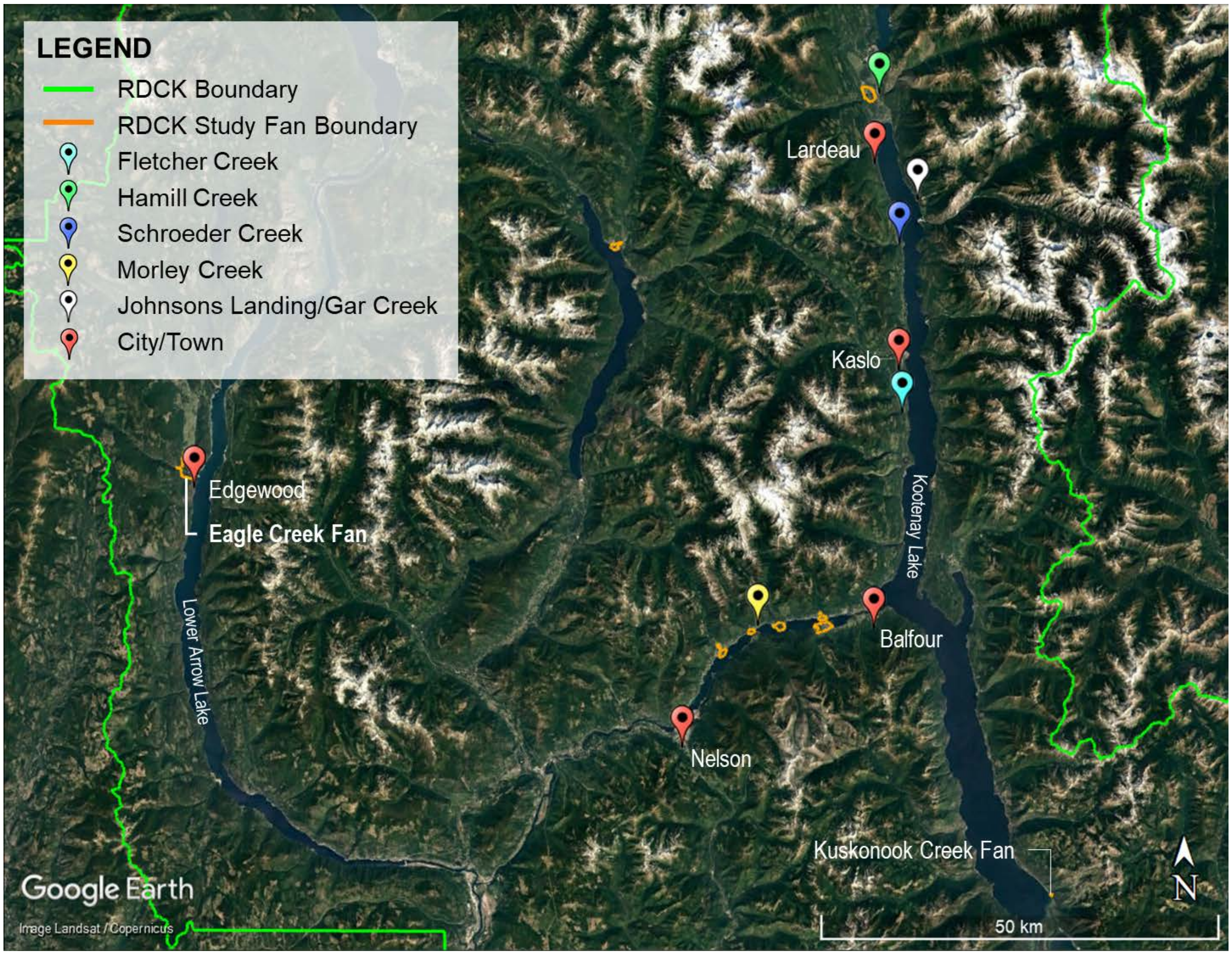


Figure 2-3. Locations of RDCK fan-deltas and recent clearwater floods, debris flows, and debris floods (Google Earth Pro, 2016).

2.4. Contextualizing Steep Creek Processes

Individual steep creeks can be subject to a range of process types and experience different peak discharges depending on the process even within the same return period class. For example, a steep creek may experience a "200-year flood" (with a return period of 200 years or a 0.5% chance of occurrence in any given year) with an observed discharge of 20 m^3/s. A 200-year flood would almost certainly be a Type 1 debris flood (after Church and Jakob, 2020) as it would result in the mobilization of the largest grains in the stream bed. In this study a Type 2 debris flood was estimated to have peak discharges 1.05 to 1.5 times higher than the clearwater flood. Type 3 debris floods were simulated on several creeks but only one (Sitkum Creek) exceeded the largest modeled Type 2 discharge at the fan-delta apex. If the creek is subject to debris flows, the peak discharge may be 1 to 2 orders of magnitude higher than a 200-year flood (Jakob, 2005). Figure 2-4 demonstrates this concept with an example cross-section of a steep creek, including representative flood depths for the peak discharge of the following processes:

- Q_2; Clearwater flow with 2-year return period
- Q_{200}; Clearwater flow with 200-year return period (i.e., a clearwater flood)

- $Q_{max\ debris\ flood\ (full\ bed\ mobilization)}$; Type 1 debris flood generated by full bed mobilization
- $Q_{max\ debris\ flood\ (outburst\ flood)}$; Type 2 debris flood generated by an outburst flood
- $Q_{max\ debris\ flow}$; Debris flow.

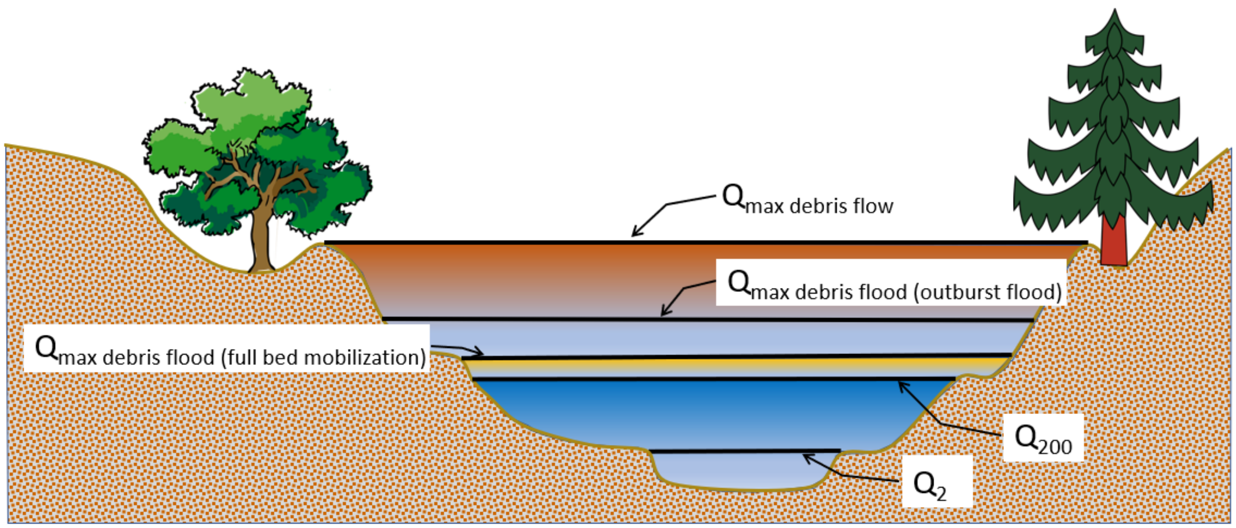


Figure 2-4. Conceptual steep creek channel cross-section showing peak discharge levels for different events. Note that for some outburst floods or debris flows the discharge may well exceed what is shown here.

This difference in peak discharge is one of the reasons that process-type identification is critical for steep creeks. For example, if a bridge is designed to accommodate a 200-year flood, but the creek experiences a debris flow with a much larger peak discharge, the bridge would likely be damaged or destroyed. For clearwater floods, a longer duration is more likely to saturate protective dikes, increasing the likelihood for piping and dike failure prior to, or instead of, the structure being overtopped. For debris floods, the duration of the event will also affect the total volume of sediment transported and the amount of bank erosion occurring.

2.5. Avulsions

An avulsion occurs when a watercourse jumps out of its main channel into a new course across its fan or floodplain (Appendix A). This can happen because the main channel cannot convey the flood discharge and simply overflows, or it occurs because the momentum of a flow allows overtopping on the outside of a channel bend. Finally, an avulsion can occur because a log jam or collapsed/blocked bridge redirects flow away from the present channel. The channel an avulsion flow travels down is referred to as an avulsion channel. An avulsion channel can be a new flow path that forms during a flooding event or a channel that was previously occupied either as the main channel or in a previous avulsion.

In Figure 2-5, a schematic of a steep creek and fan is shown where the creek avulses on either side of the main channel. The avulsion channels are shown as dashed blue lines as avulsions only occur during severe floods (i.e., rarely). On high resolution topographic maps generated from lidar, avulsion channels are generally visible and are tell-tale signs of past and future avulsions.

Also shown on Figure 2-5 is the fan apex, which is the uppermost point of the fan, where net deposition of sediment from the creek begins. It coincides with a change in slope and confinement where the creek debouches from the mountainous upstream portion of the watershed. The hillsides flanking the fan apex are also preferential locations for remnants of paleofans. These represent remaining portions of an ancient (early Holocene or some 10,000 years ago) fan that developed during a different climate, sediment transport regime or base level. Paleofan surfaces will not be inundated by contemporary debris flows, debris floods, or clearwater floods as they are well above the maximum flow depths achieved by such modern-day processes. For this reason, they are often suitable for development from a geohazard point of view.

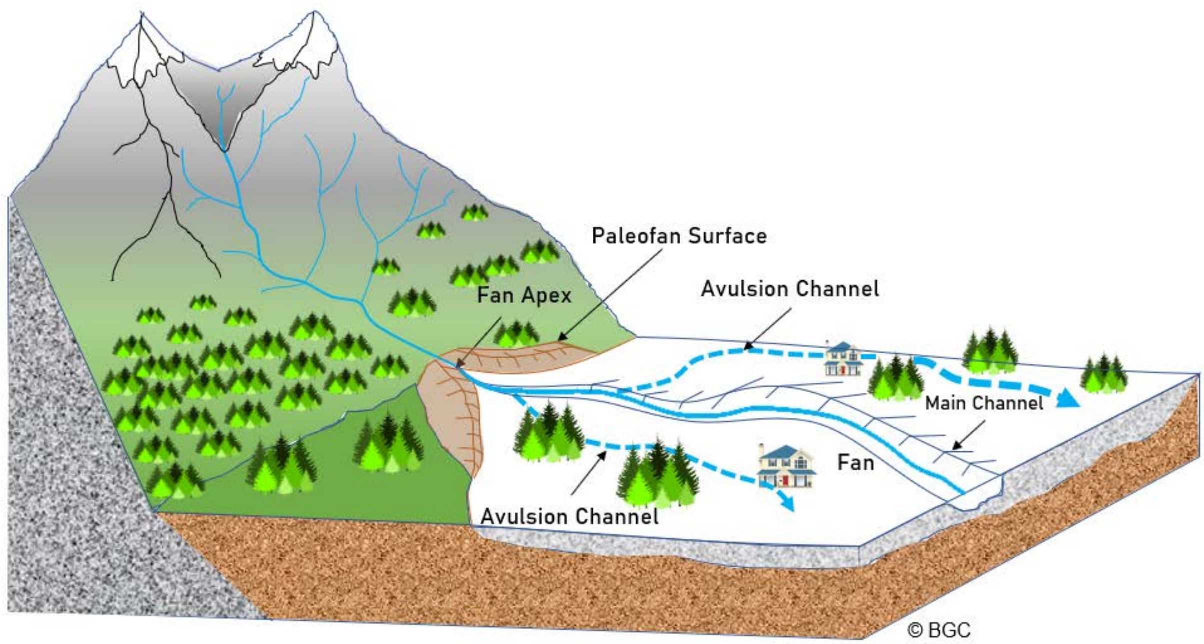


Figure 2-5. Schematic of a steep creek channel with avulsions downstream of the fan apex. Artwork by BGC.

2.6. Steep Creek Process

BGC assessed the potential steep creek process types and hazards on Eagle Creek based on the Melton Ratio and historical and field evidence. In comparison with a large dataset of steep creeks in B.C. and Alberta, Eagle Creek plots in the zone of floods to debris floods (Figure 2-6). The points shown on the plot are subject to some error and watersheds can be subject to multiple processes at different timescales; for this reason, it is important to consider additional evidence to supplement the assessment of process type.

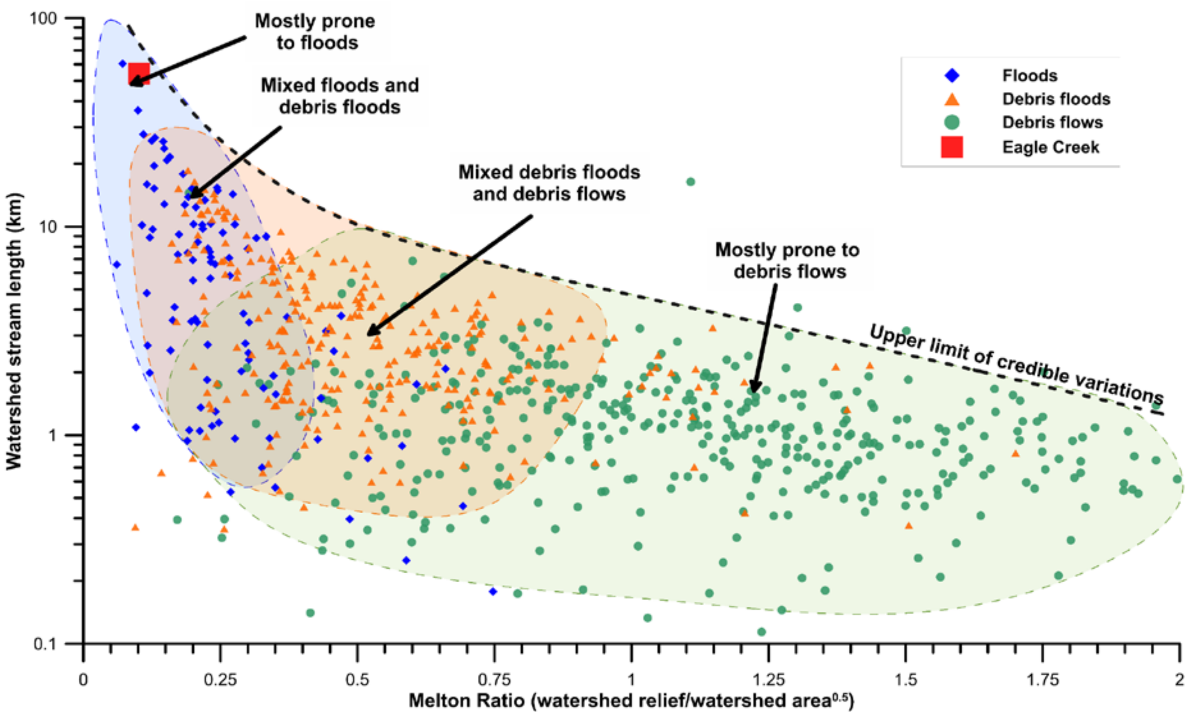


Figure 2-6. Tendency of creeks to produce floods, debris floods and debris flows, as a function of Melton Ratio and stream length (data from Holm et al., 2016 and Lau, 2017). See Section 3.2 for Eagle Creek watershed data.

Debris floods can be subdivided into three types, those triggered by the exceedance of a critical bed shear stress threshold (Type 1), those through transitions from debris flows (Type 2), and those triggered from outbreak floods (Type 3) (Section 1 of Methodology Report (BGC, March 31 2020b)). This differentiation is not included in the above plot as such nuances are unknown for the data included above; however, it is included in this detailed assessment. In this assessment only Type 1 debris floods are considered.

BGC interprets Type 1 debris floods to be the dominant hydrogeomorphic process at Eagle Creek (for more detail see Section 6.3.3). Type 2 and 3 debris floods may occur, but with fan-delta discharges exceeding those of Type 1 debris flows at return period exceeding 500 years. Should there be a large stand-replacing high intensity fire in an area subject to tributary debris flows, a Type 3 debris flood may ensue which ought to be considered in the context of a post-fire hazard assessment.

3. STUDY AREA CHARACTERIZATION

The following section provides a characterization of the study area including physiography, hydroclimatic conditions and projected impacts of climate change, glacial history and surficial geology, as well as a description of the Eagle Creek watershed (Drawing 01) and existing development on the fan-delta (Drawings 02A, 02B).

3.1. Site Visit

Fieldwork on Eagle Creek was conducted from July 22 to 25, 2019 and on November 18, 2019 by the following BGC personnel: Carie-Ann Lau, P.Geo., Beatrice Collier-Pandya, EIT, and Hilary Shirra, EIT. Field work included channel hikes to look for evidence of high-water marks, measurement of grain size diameters (Wolman sampling) at the fan-delta apex and the channel mouth, measurement of cross-sections at bridge and other infrastructure crossing locations, collection of tree core samples for dendrogeomorphic analysis, and excavation of test pits to develop stratigraphic profiles supplemented by radiocarbon dating of samples (Drawings 02A, 02B). The watershed was also flown by helicopter and numerous photographs were taken for later analysis of major sediment sources to the channel.

3.2. Physiography and Geomorphology

Eagle Creek lies on the west side of Lower Arrow Lake in the Inonoaklin Creek Valley and flows along the south side of the community of Edgewood, BC into the lake. Drawings 01, 02A, and 02B show the watershed and fan-delta boundaries on a shaded, bare earth digital elevation model (DEM) of the watershed, fan-delta, and surrounding terrain created from LiDAR data. Drawing 03 shows a profile along the creek mainstem and main tributaries. Representative photographs of the watershed and fan-delta are provided in Appendix B.

Eagle Creek is in the southern portion of the Monashee Mountains, which are a subgroup of the Columbia Mountains in southeastern BC. The watershed falls within the Selkirk Foothills ecosection of the Selkirk-Bitterroot Foothills ecoregion and is bounded by the Okanagan Highlands to the north and west, and by the Selkirk Mountains to the east (Demarchi, 2011). The ecosection is characterized by rounded mountains and wide valleys filled with vast quantities of glacial sediment deposited by the Pleistocene Ice Sheet (Holland, 1976). Considerable moisture is provided to the area from northwesterly Pacific storms traveling across the Columbia Plateau. It also experiences warm summer temperatures (20-25°C, Figure 3-9) due to its proximity to the Columbia Basin to the south (Demarchi, 2011). In the Eagle Creek area, typical vegetation includes moist forests composed of Engelmann Spruce and Subalpine Fir.

Geomorphological analysis of Eagle Creek included characterization of the watershed and fan-delta using historical airphotos (Drawings 04A and 04B) and LiDAR supplemented by literature on the regional geology, geologic history and physiography and supplemented by a field visit.

The headwaters of Eagle Creek are the mountainous slopes of Mount Scaia (approximate elevation 2255 m) and Gunwad Mountain (approximate elevation 2080 m) at the western edge of the watershed. The upper portion of the watershed below these slopes is characterized by a gentle to moderately dipping plateau created by glaciation, into which Eagle Creek has incised.

The plateau generally consists of glacial material (till) deposited as glaciers overrode this area. Small lakes (e.g., York Lake, Lindsay Lake) are present on the flatter portions of the plateau. The slopes and plateaus are forested, and 23% of the watershed area has been logged since 1966, predominantly in the 1990's as shown in Drawing 05. Upstream of the fan-delta apex, the watershed is characterized by steep bedrock-controlled slopes of the incised river valley. The northern slopes in the incised reach are sparsely vegetated and display abundant bedrock outcrops, whereas the southern slopes are more evenly vegetated. Several landslides and a debris flow were identified along the northern side of the incised channel in the upper watershed. Several tributaries may be subject to debris flows, especially if disturbed by logging or wildfires. Drawing 05 shows a geomorphic map of the study area, including specific landforms and sediment sources in the watershed.

Table 3-1 summarizes relevant geomorphic characteristics of the Eagle Creek watershed. These characteristics are indicators of the process type and anticipated behaviour of the watershed in response to rainfall events. The Melton Ratio (watershed relief divided by square root of watershed area) and channel gradient both assist in determining if a creek is susceptible to flood, debris flood, or debris-flow processes (Section 2.6). The channel gradient above the fan-delta apex provides an indication of whether transportation of sediment is likely, and the fan-delta gradient approximates the angle where sediment deposition of larger flows from the watershed generally ensues.

Table 3-1. Watershed characteristics of Eagle Creek.

Characteristic	Value
Watershed area (km^2)	99
Fan-delta are (km^2)	4.6
Active fan-delta area (km^2)[1]	4.7
Maximum watershed elevation (m)	2,255
Minimum watershed elevation (m)	534
Watershed relief (m)	1,721
Melton Ratio (km/km)[2]	0.17
Average channel gradient of mainstem above fan-delta apex (%)	12
Average channel gradient on fan-delta (%)	3.9
Average fan-delta gradient (%)	9.0

Notes:
1. Active fan-delta area includes the eastern delineations of the paleofan and a 10% increase to the area mapped from lidar to account for the submerged portion of the fan-delta.
2. Melton ratio is an indicator of the relative susceptibility of a watershed to debris flows, debris floods or floods.

Eagle Creek exits the confined reach of the watershed at the fan-delta apex, located approximately 150 m upstream of the Worthington Creek Forest Service Road bridge (Drawings 02A, 02B). The creek has deposited a broadly shaped fan-delta to the west of Inonoaklin Creek indicating that Eagle Creek has experienced significant lateral migration in the past leading to deposition across the entire fan-delta and that future avulsion and lateral migration across the fan-delta surface is possible.

3.3. Geology and Glacial History

3.3.1. Bedrock Geology

The Eagle Creek watershed is underlain by gneissic rocks, of the Monashee Complex (Cui et al., 2015). Igneous intrusions cover the majority of the watershed area. The Granby River Fault is located approximately 5 km from Eagle Creek, though there are no faults mapped within the watershed that would suggest localized fault-related instability (Cui et al., 2015). Bedrock geology often controls large features, such as valley orientations. In the Eagle Creek watershed there is no dominant orientation within the watershed area implying that major rock slope failures are unlikely (Tempelman-Kluit, 1989). This also implies that landslide damming events from bedrock failures along Eagle Creek are considered unlikely.

Bedrock weathering is believed to contribute relatively little sediment compared to glacial sediments that are still abundant in the watershed. Therefore, the engineering geology and lithology of bedrock in the Eagle Creek watershed are believed to be of minor importance.

3.3.2. Surficial Geology

Surficial geology controls the sediment available to be transported in hydrogeomorphic events. Figure 3-1 shows the surficial geology of the Eagle Creek watershed. This surficial geology was generated during the Fraser glaciation that began approximately 30,000 years ago and lasted until approximately 10,000 years ago (Fulton & Smith, 1978). At this time, glaciers flowed from high mountains, down tributary streams, and ultimately into deep valleys such as the Columbia River Valley, creating an ice sheet that dominantly flowed south. After reaching its maximum extent approximately 18,000 years ago, ice began to retreat, mainly from south to north. As the ice retreated, it formed glacial lakes at the front of the receding ice and in tributary valleys where their mouths were still blocked by ice in the main valley (Fulton et al., 1989). Blue-grey silty clays from one of these glacial lakes have been observed near Fauquier, approximately 10 km north of Edgewood (Fulton et al., 1989) and in residential wells located in the Inonoaklin Creek Valley (Ministry of Environment and Climate Change Strategy, n.d.). The glacial lake sediments at Fauquier are overlain by sands and gravels created by a post-glacial lake, indicating that Lower Arrow Lake was once approximately 25 m higher than present (Fulton et al., 1989).

BGC has interpreted a glacial and post-glacial history for the Eagle Creek alluvial fan-delta, based on the regional glacial history, field observations, and well records, as shown in Figure 3-2.

Upstream of the fan-delta, the surficial geology within the watershed differs between the upper and lower halves of the watershed, as shown in Figure 3-1. The upper portion of the watershed is characterized by till and glaciofluvial deposits blanketing bedrock (Ministry of Environment and Climate Change Strategy, 2016). The lower portion of the watershed, just upstream of the fan-delta apex, is characterized by steep and hummocky bedrock covered by veneers of colluvium and till. The abundant colluvium and till in the watershed indicate that the watershed contains a quasi-unlimited amount of sediment available to be mobilized during debris floods. Tributary debris flows or landslides sourced within till deposits are expected to contain a higher proportion of fine-grained sediment (fine sands, silts, and clays). All other factors being equal, these types of debris flows or landslides can flow further than those sourced from coarser-grained colluvial, fluvial, and glaciofluvial materials and contribute towards increased sediment availability in the stream.

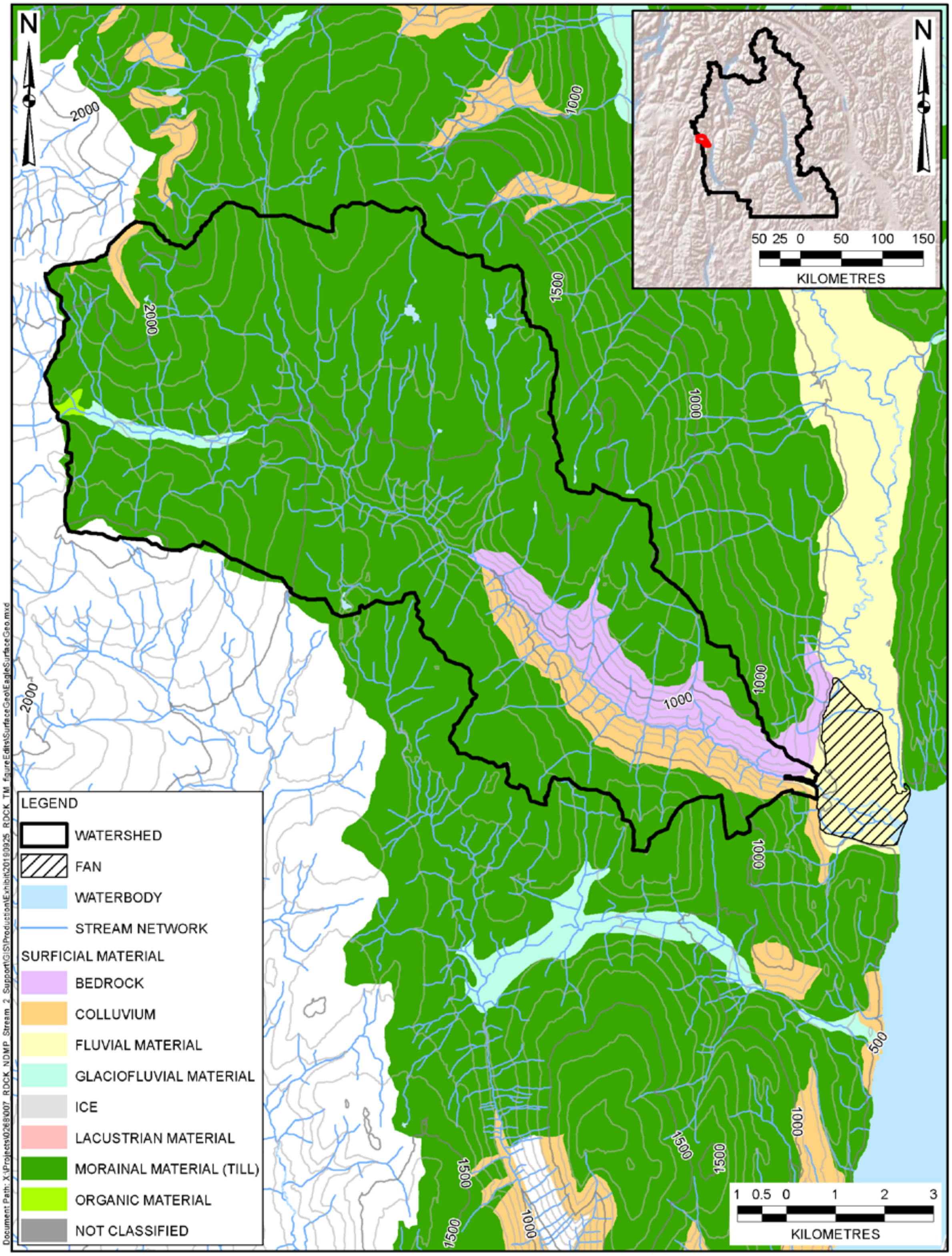


Figure 3-1. Surficial geology of the Eagle Creek watershed (adapted from Ministry of Environment and Climate Change Strategy, 2016).

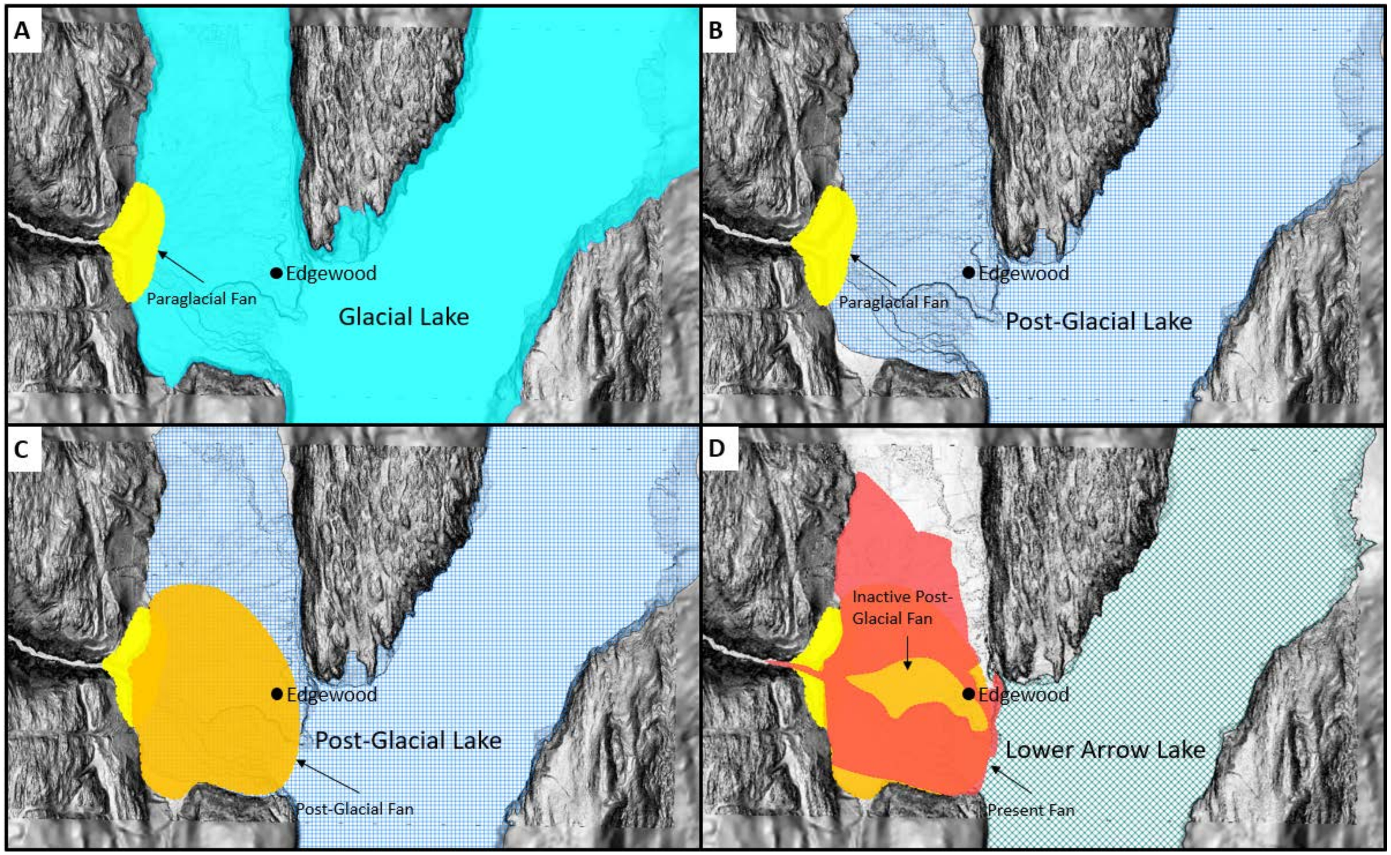


Figure 3-2. BGC's interpretation of the glacial and post-glacial history of the Eagle Creek fan-delta, overlain on a shaded, bare earth[3] DEM of the area. A) During the Late Wisconsin (25,000 to 10,000 years ago) glacial retreat, a glacial lake covered the Inonoaklin Creek Valley and the entire Eagle Creek fan-delta. A paraglacial fan-delta formed at the mouth of Eagle Creek, as evidenced by the high terraces currently present at the fan-delta apex. B) Lake levels receded following deglaciation (approximately 10,000 years ago), but the post-glacial lake levels were higher than current Lower Arrow Lake levels (Fulton et al., 1989). C) The post-glacial Eagle Creek eroded through the paraglacial fan-delta and deposited a post-glacial fan-delta that projected into Lower Arrow Lake. D) As the lake levels receded to present levels, Eagle Creek incised into the post-glacial fan-delta, pushed the fan-delta further into the lake and created an inactive post-glacial surface upon which most of Edgewood is situated on.

[3] Vegetation and buildings removed.

3.4. Eagle Creek Fan-Delta

An overview of the Eagle Creek watershed and fan-delta are shown in Drawings 01, 02A, and 02B. Drawing 06 shows geomorphic fan-delta features. Locations referred to in the text below are labelled on these drawings. The fan-delta areas delineated in the drawings have been interpreted by BGC based on LiDAR and field data; however, the extents of the fan-delta beyond the LiDAR data limits at Lower Arrow Lake are difficult to define due to changing lake levels.

BGC has divided the fan-delta into active and inactive fan-delta surfaces based on geomorphic interpretations and historical information. Inactive fans are those that may still be affected by contemporary geomorphic processes. Paleofans are those that were created at a time where climate, sediment available and/or base level were substantially different, and the reactivation of the fan surface is considered extremely unlikely.

There are seven distinct geomorphic surfaces on the fan-delta (annotated in Figure 3-4 and shown on Drawing 06):

- An active fan surface in the middle of the overall fan-delta landform (Surface A).
- An active fan surface stretching from the fan apex in a north-east direction toward the Inonoaklin Valley (Surface B).
- A paleofan surface which is presently shrinking due to erosion (Surface C).
- A paleofan terrace on the southern margin of the fan (Surface D).
- Paleofan surfaces flanking the fan apex (Surface E and F).
- The submerged fan-delta beyond the channel outlet at Lower Arrow Lake (Surface G).

Figure 3-3 shows a cross-fan profile that illustrates the different surfaces.

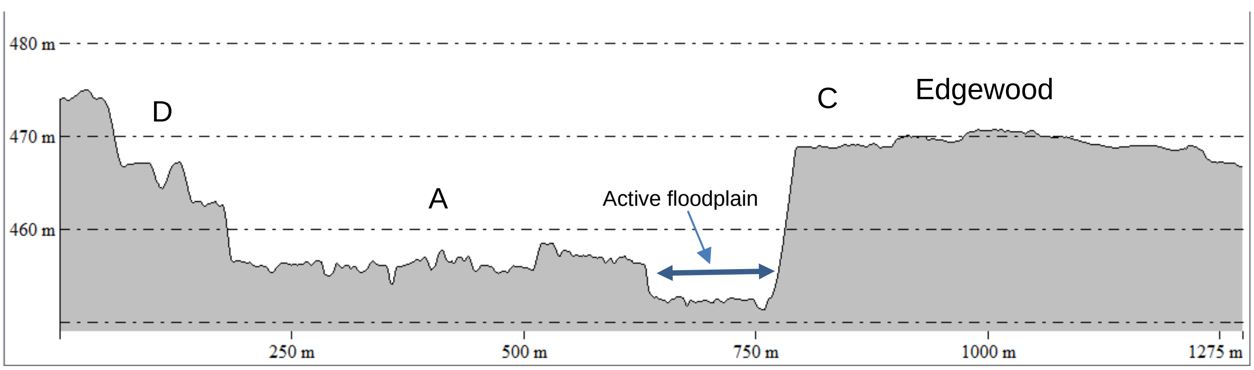


Figure 3-3. Cross-fan profile at Section A-A' (see Figure 3-4) showing the different fan surfaces.

Figure 3-4. Oblique view of the Eagle Creek fan-delta looking west. Edgewood is located on the mid to distal end of the fan-delta. Areas A through G refer to geomorphic surfaces described in text. Photo: Google Earth (2019). The cross-section A-A' related to Figure 3-3.

The average current bankfull width of Eagle Creek is 40 m. The active floodplain of Eagle Creek is approximately 50 to 75 m wide with the active channel width ranging from 10 to 40 m in Area A. The creek has a braided morphology on the fan-delta. The average channel gradient decreases from approximately 3° (~5%) at the fan-delta apex to approximately 1.5° (~ 3%) near the channel outlet at Lower Arrow Lake. Historically, the channel migrated and avulsed into new locations within this reach. The active channel appears to be actively aggrading and depositing large gravel bars, which contribute to the large width and activity in this area. Bank erosion has also occurred on the left (north) bank, below the town site. The actively aggrading channel indicates that the channel depth relative to the adjacent fan-delta surfaces is shallow and thus the potential for avulsion is greater within active braiding portions of the fan-delta. Sediment sizes on the fan-delta range from <2 mm to 230 mm in diameter (Table 3-5, Appendix C). A description of sediment size sampling procedure is included in the Methodology Report (BGC, March 31 2020b).

Table 3-2. Eagle Creek sediment distribution from Wolman Count Data. Locations of samples outlined in Appendix C.

Grain Size	Eagle 1	Eagle 2
Location	Downstream of fan-delta apex	Confluence with Lower Arrow Lake
Number of stones measured	98	138
D95 (mm)	233	176
D84 (mm)	188	126
D50 (mm)	66	34
D15 (mm)	18	<2
D5 (mm)	<2	<2

In 1968, the lake level in Lower Arrow Lake was raised 12 m as a result of the construction of the Keenleyside dam (Figure 4-1, Section 4). The mouth of the active channel of Eagle Creek at Lower Arrow Lake has been modified by the rise of the lake level. The lower portions of the fan-delta east of the current channel mouth, visible in historical aerial photographs, were flooded by the lake level raise. At present, Eagle Creek flows into Lower Arrow Lake in an approximately 450 m wide bay.

The second active fan-delta surface (Surface B in Figure 3-4) is defined as the portion of the fan-delta extending from the fan-delta apex towards the northeast, approximately paralleling the Worthington Creek Forest Service Road. Boyer (1988) reported that a historical channel survey in 1903 showed Eagle Creek flowing northeast from the fan-delta apex, across this portion of the fan-delta, and entering Inonoaklin Creek north of Edgewood. Between 1903 and 1907, the main channel was re-routed into its present configuration. A historical map from 1912 shows a similar configuration for a secondary channel of Eagle Creek (Figure 3-7).

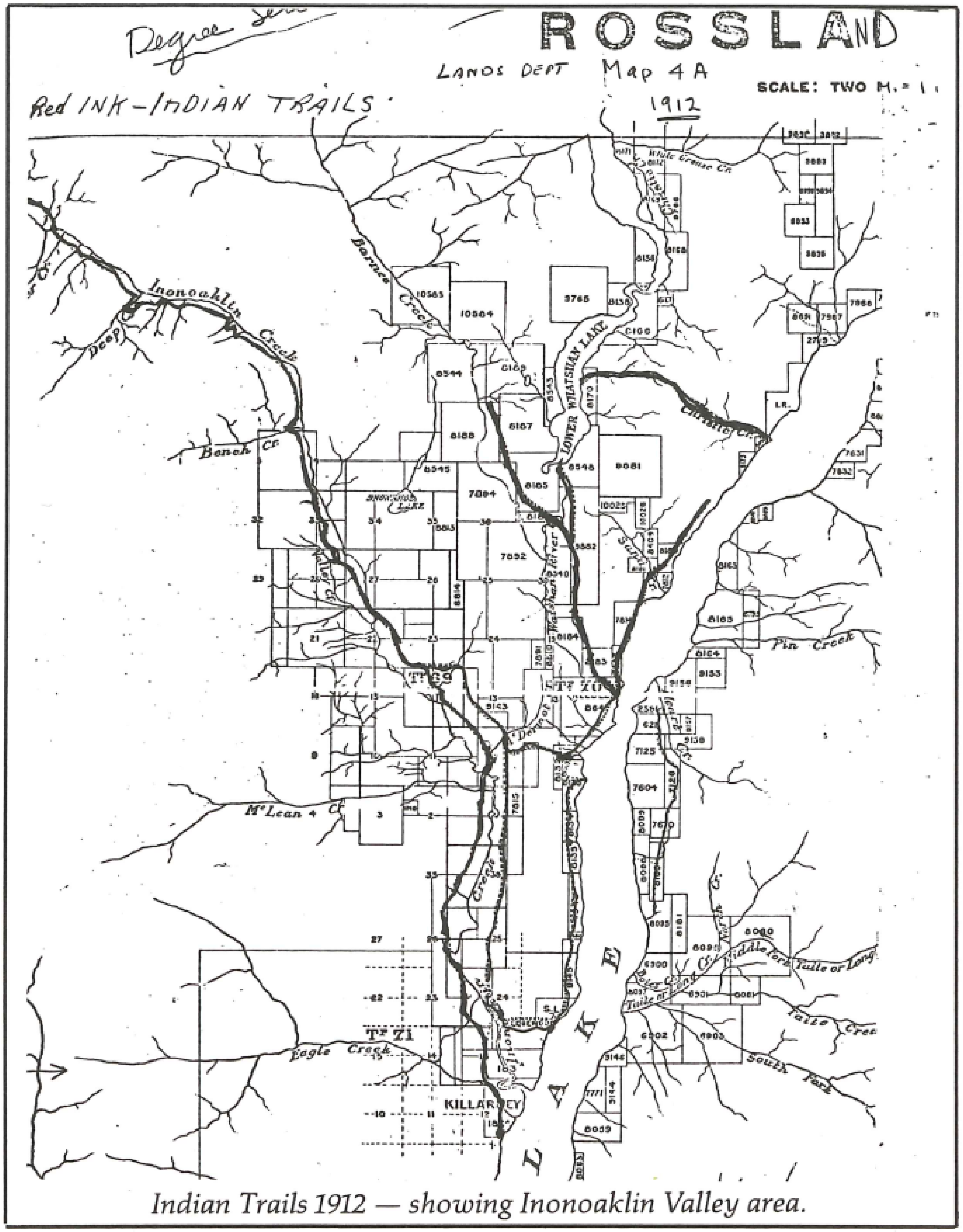


Figure 3-5. Map of Inonoaklin Valley area from 1912. Eagle Creek is shown in the bottom left (Rossland Lands Department, 1912).

Local resident Rob Murray indicated that a small ephemeral channel of Eagle Creek flowed through the northern portion of the fan-delta in the 1940s to 1950s and disappeared into the floodplain upstream of the outlet to Inonoaklin Creek. This ephemeral channel has not been active for several decades. BGC mapped a significant number of long, incised avulsion channels across this surface (Drawing 06). Based on these observations, BGC interprets that Area B is potentially active and could be exposed to channel hazards. For this reason, this area was considered in the hazard analysis (Section 0). The overall gradient of this surface is approximately 2° (~ 4%) near the fan-delta apex and decreases to approximately 1° (~ 2%) as it approaches the Inonoaklin Creek floodplain, which means that coarser bedload sediment will largely deposit prior to Inonoaklin Creek.

BGC interprets Surfaces C and D to be fan-delta surfaces of Eagle Creek that have been inactive for thousands of years (see Section 6.2.2) but which are presently being eroded by Eagle Creek. Therefore, the majority of these surfaces (barring their edges) are presently not subject to debris flood hazards. Surface C forms a narrow triangle that radiates in approximately the center of the fan-delta from the fan-delta apex towards Lower Arrow Lake. Surface D forms the southern margin of the Eagle Creek fan-delta. The extents of Surfaces C and D have been differentiated from Surfaces A and B based on the absence of avulsion channels on LiDAR imagery, and on the height above the current channel elevation (approximately 5 to 10 m above the active channel elevation) (see Figure 3-3).

Surfaces E and F are paraglacial paleofans above the fan-delta apex, as discussed in Section 3.3.2. Surface G was mapped from the historical aerial photographs prior the raising of the Lower Arrow Lake reservoir and is now submerged.

3.5. Existing Development

Development on the Eagle Creek fan-delta comprises the community of Edgewood (on the north side of the Creek) and the Inonoaklin Provincial Park and Arrow Lakes Provincial Park and campground on the distal portions of the fan-delta (Drawings 02A, 02B). The active fan-delta area on the south side of Eagle Creek (Surface A) is unpopulated and the waterfront is part of Arrow Lakes Provincial Park. The original Edgewood townsite was located further east on the shore of Lower Arrow Lake. In the late 1960s, the town was relocated to its current position due to construction of the Hugh Keenleyside Dam and subsequent raise of Lower Arrow Lake (Nelson Star, 2014).

Development in Edgewood includes residential homes, a general store, gas station, post office, credit union and Legion Hall. Recreational visitors can access Inonoaklin and Arrow Lakes Provincial Parks and campground on the waterfront, fish, visit Inonoaklin Falls and use the network of logging roads as trails (Nakusp & District Chamber of Commerce, 2020). According to the 2016 census, the population of Edgewood is approximately 250 people (Statistics Canada, 2016). Edgewood Elementary School is located mid-fan-delta on the north side of Eagle Creek within Surface C. The Edgewood water system sources water from two wells located off Monashee Road on the Eagle Creek fan-delta (RDCK, 2019). The estimated total improvement value of parcels intersecting the Eagle Creek fan-delta based on the 2018 BC Assessment Data is $13,544,300 (BGC, March 31, 2019).

3.5.1. Bridges

The Worthington Creek Forest Service Road crosses Eagle Creek approximately 150 m downstream of the fan-delta apex (Drawings 02A, 02B). The bridge is approximately 5 m wide and spans 14 m. The bridge location is shown in Drawings 02A, 02B, and 06, and bridge dimensions are provided in Table 3-3.

Both the left and right abutments are supported by large angular riprap at the base of a retaining wall (Figure 3-6). The Eagle Creek channel gradient is approximately 4% from the fan apex to farther downstream when the creek becomes a braided channel and decreases in gradient to 2% (approximately 500 m from the outlet).

Table 3-3. Estimated dimensions of bridge crossings on Duhamel Creek fan-delta, heading downstream by creek channel.

Bridge	Span (m)	Height Above Channel Center (m)	Notes
Worthington Creek Forest Service Road Bridge	14.2	4.1	Near fan-delta apex.

Note: The bridge dimensions were either obtained in the field or estimated from site photographs from typical dimensions for the size of road.

A) EGL-BR-1. Looking downstream towards bridge approximately 150 m downstream of the fan apex.

B) EGL-BR-1. Standing on right bank looking at left bank retaining wall and rip rap.

Figure 3-6. Photos of Worthington Creek Forest Service Road Bridge (Photo by BGC July 23, 2019).

3.5.2. Flood Protection Structures

Almost directly upstream of the bridge on the left bank is a two-tiered, dike delineated in Drawings 02A, 02B as EGL-FP-01. Photos of EGL-FP-01 are shown in Figure 3-5. This dike was built in the mid 1900's, though there are conflicting accounts of the construction date; BC Hydro claims it was built in the 1970s while Edgewood residents say it was built in the 1940s. The dike does not appear to be maintained as recent floods have deposited sand over the first tier and vegetation is growing out of it. The dike appears to have been constructed out of smooth, rounded river rock. The Government of British Columbia's (2020) list of dikes by river/watercourse states "no local authority" as Owner/Administrator of EGL-FP-01, rendering it an orphan dike, i.e., a flood protection structure which is not maintained by a diking authority[4]. Attributes of EGL-FP-01 from the BC Flood Protection Works Database are listed in Table 3-4.

Table 3-4. Flood protection structure attributes along Eagle Creek.

Attribute	Flood Protection Structure	
BGC ID	EGL-FP-01 (Eagle Creek Dike)	EGL-FP-02
Source[1]	iMapBC	BGC Field Observation
Type	Protection	Dike
Orphan (Y/N)[2]	Y	-
Comments	Pushed up river rock	
Survey Year(s)	2003	-
Erosion Protection Side	Left	Left
Length (m)	101	652

Notes:
1. iMapBC data downloaded from Flood Protection Structural Works layer on February 7, 2020.
2. Only the structure within iMapBC data was classified as an orphan structure.

[4] The Government of British Columbia (2020) states the following with respect to Orphan Dikes: "There are over 100 flood protection works in B.C. which are not maintained by a diking authority. As many of these works were constructed under emergency conditions, they generally lack adequate planning and engineering design. Local emergency plans should address any specific risks that may be associated with these works."

Figure 3-7. Photos of Eagle Creek Dike (EGL-FP-01) near fan-delta apex. A) Looking upstream (north) from Worthington Creek Forest Service Road Bridge at EGL-FP-01 (Photo by BGC July 23, 2019). B) looking south at material of EGL-FP-01 approximately 120 m upstream of the bridge, note the rounded clasts of the dike behind field staff (Photo by BGC July 23, 2019).

In the lower reaches of Eagle Creek, where it passes by Edgewood, riprap was installed along the toe of the steep, left banks (EGL-FP-02). This riprap was installed by BC Hydro in 1986, after a storm in 1985 caused significant bank erosion damage and led to channel encroachment on the Edgewood pump station. The riprap is constructed of angular material and appears to be in different states of repair along the bank as shown in Figure 3-6. BGC has deemed this flood protection to be orphaned as it is not known to be regularly repaired or inspected. Erosion and breach of this dike could lead to avulsions on the northern and central portions of Eagle Creek fan-delta. This possibility was numerically modeled (see Section 5.4).

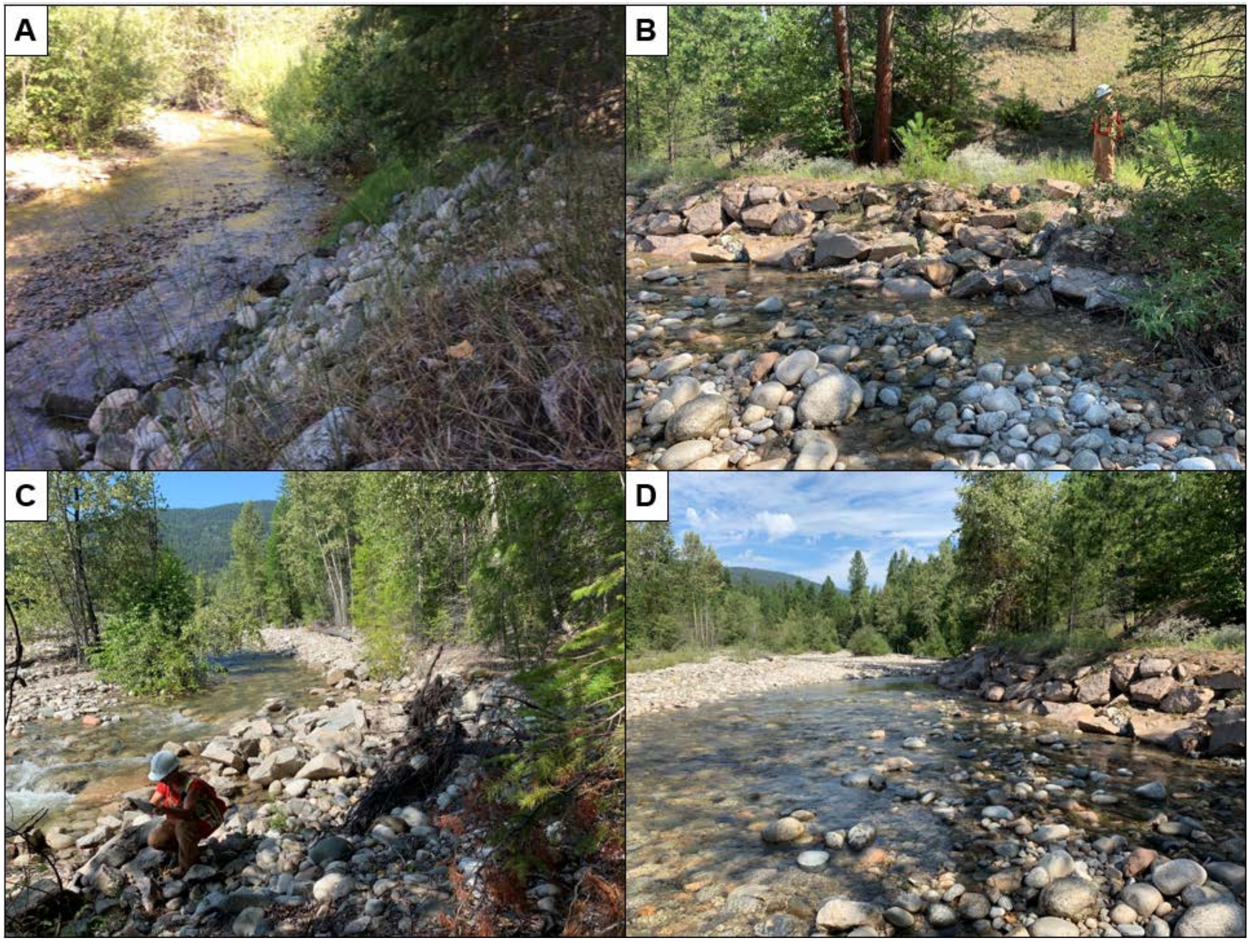


Figure 3-8. Photos of riprap on lower left bank (EGL-FP-02) on Eagle Creek as delineated in Drawings 02A, 02B. A) Section of riprap where river cobbles are covering angular riprap, looking upstream. B) Typical section of riprap, looking north towards left bank. C) Section of riprap that had failed into creek, looking upstream. D) Along typical section of riprap, looking upstream. All photos taken by BGC in July 2019.

3.6. Hydroclimatic Conditions

Climate normal[5] data were obtained from Environment and Climate Change Canada's (ECCC) Fauquier station (El. 490 m), located approximately 10 km northeast of the Eagle Creek outlet (El. 530 m).

Figure 3-9 shows the average monthly temperature and precipitation for the Fauquier station based on the 1981 to 2010 climate normals. Total annual precipitation (rain and snow) is 791 mm as summarized in Table 3-5. Monthly precipitation peaks in June with an average of 90 mm. A rainfall intensity-duration-frequency (IDF) curve for the Fauquier station is shown in Figure 3-10.

The measured precipitation at the Fauquier weather station is lower than the actual precipitation in the Eagle Creek watershed, where the mountaintops extend more than 1800 m above Lower Arrow Lake. This difference in precipitation is due to orographic effects, which occur when an air

[5] Climate normal are long-term (typically 30 years) averages used to summarize average climate conditions at a particular location.

mass is forced up over rising terrain from lower elevations. As the air mass gains altitude, it quickly cools down and the water vapour condenses forming clouds resulting in precipitation. Hence interpretation of precipitation data from central valley locations, such as the Fauquier station, require caution when used to predict precipitation events in the Eagle Creek watershed.

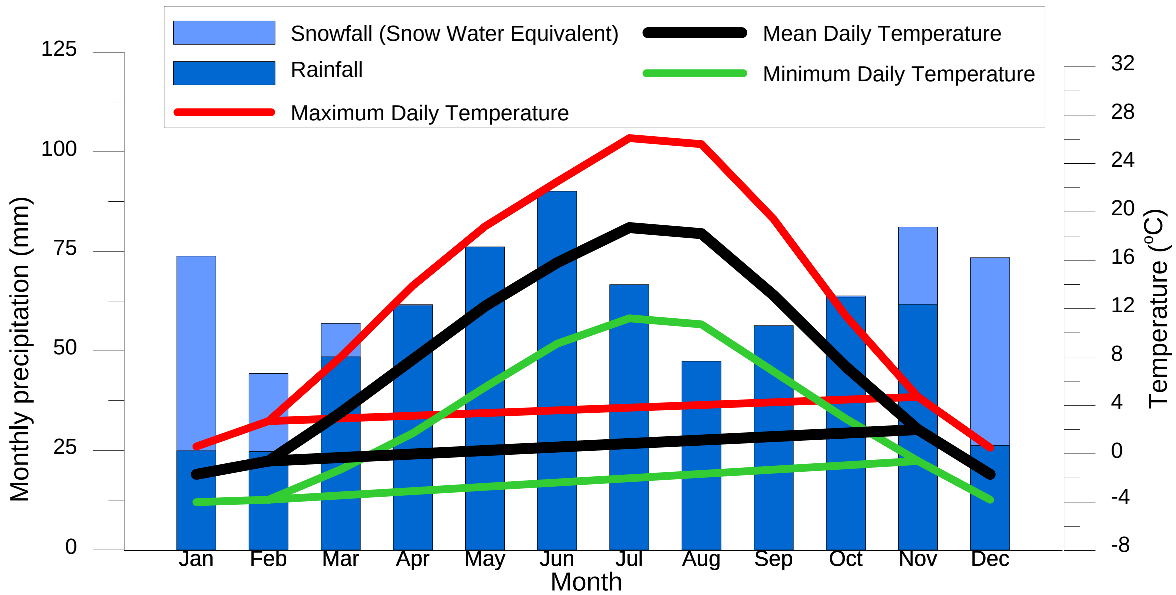


Figure 3-9. Climate normal data for Fauquier station (ID 1142820; UTM Zone 11, 423110.40 m E, 5524725.84 m) from 1981 to 2010.

Table 3-5. Annual total of climate normal data for Fauquier station (ID 1142820) from 1981 to 2010.

Variable	Annual Total	Percent of total annual precipitation (%)
Rainfall (mm)	647	82
Snowfall (cm)	144	18
Precipitation (mm)	791	100

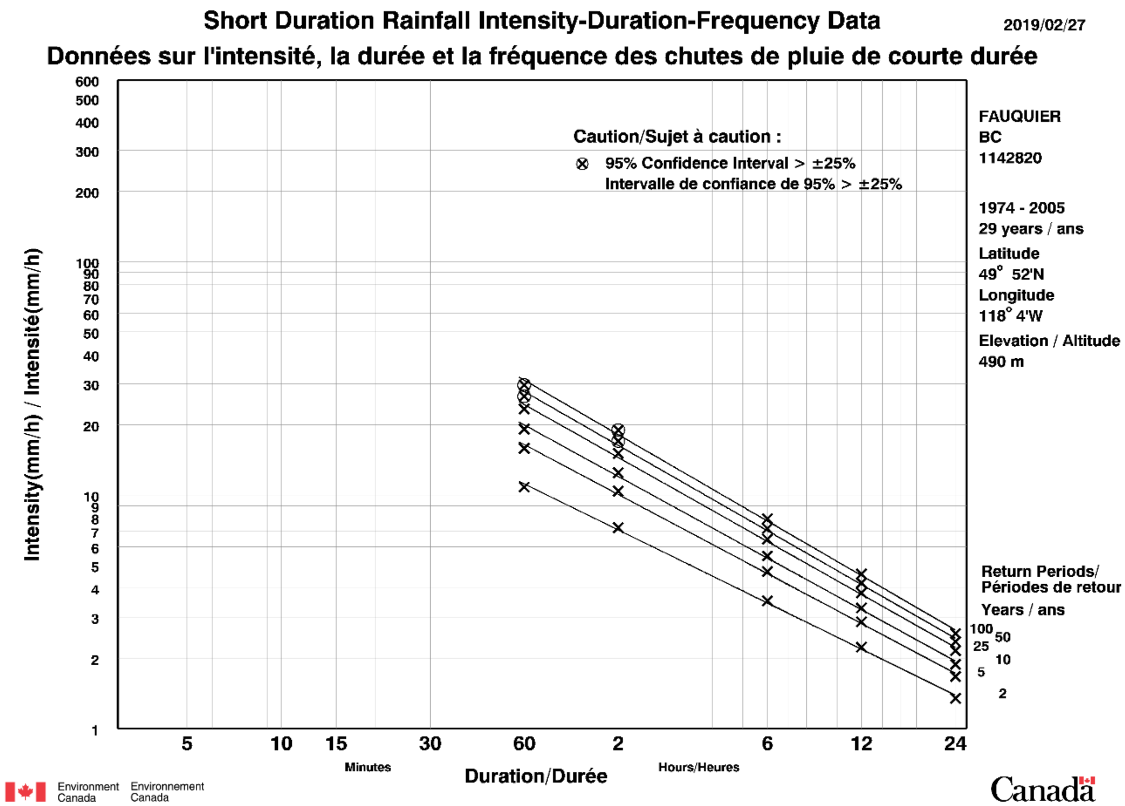


Figure 3-10. Short Duration Rainfall Intensity-Duration-Frequency Curves for Fauquier Station (ID 1142820).

To understand the regional distribution of precipitation and snowfall patterns and supplement the data from the Fauquier station, BGC obtained climate normal data based on the CRU-TS 3.22 dataset (Mitchell & Jones, 2005) for the period 1961-1990. This dataset was generated with the ClimateNA v5.10 software package, available at *http://tinyurl.com/ClimateNA*, based on methodologies described by Wang et al. (2016). The historical Mean Annual Precipitation (MAP) over the region is shown in Figure 3-11. The MAP average over the watershed is 946 mm, varying as a function of elevation. The Fauquier Station located near the bottom of the valley accumulates less precipitation than the Eagle Creek watershed which extends up into higher elevations. The same trend is evident in the mean annual Precipitation as Snow (PAS) shown in Figure 3-12. The PAS average over the watershed is 469 mm. The PAS increases at the higher elevations, therefore Eagle Creek experiences greater precipitation falling as snow over the entire watershed compared to Fauquier Station, particularly at higher elevations.

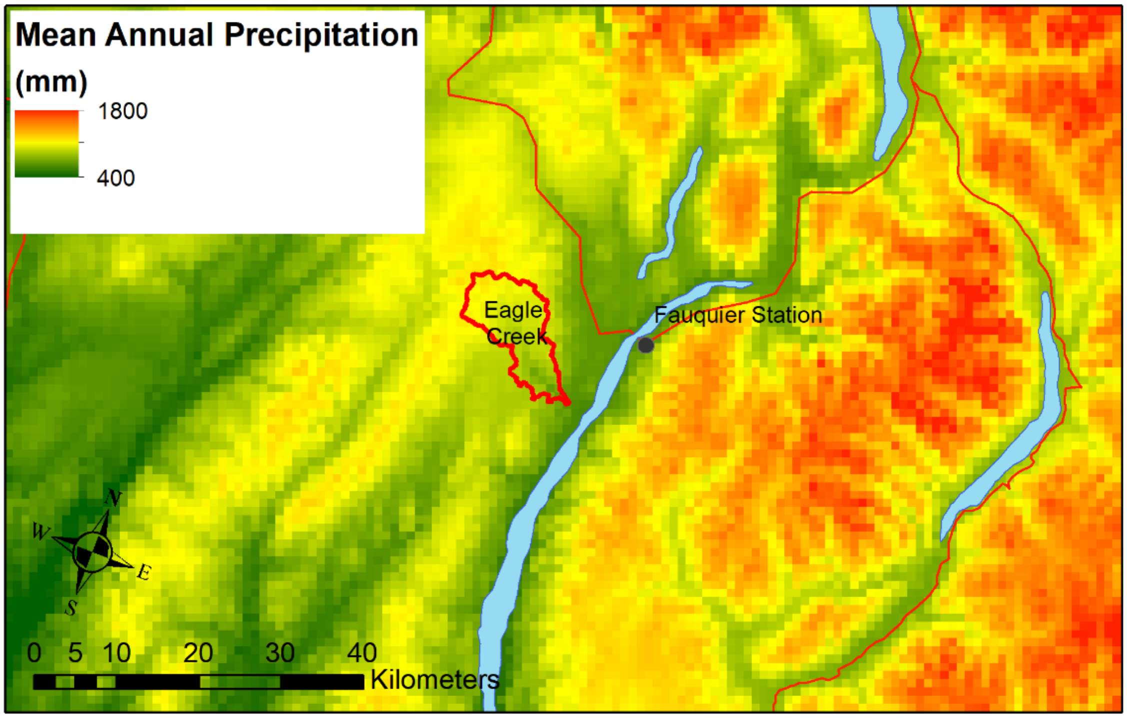


Figure 3-11. Regional distribution of Mean Annual Precipitation for Eagle Creek watershed (thick red line) and the Fauquier Station (1961-1990 normal period) based on (Mitchell & Jones, 2005).

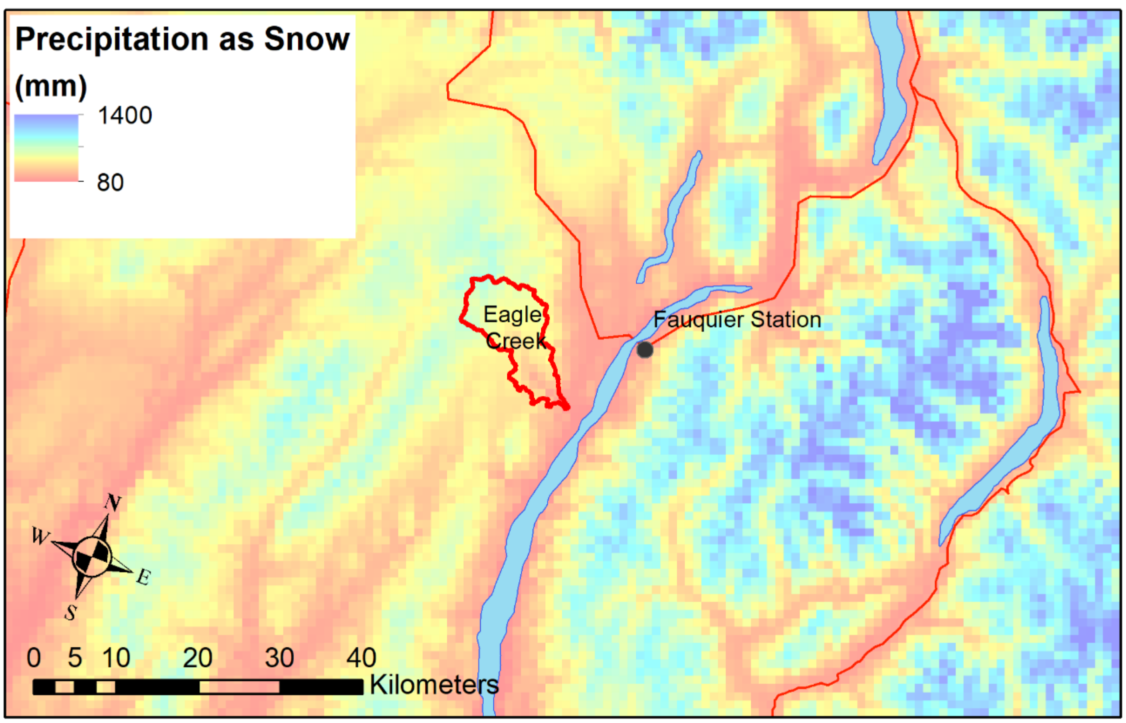


Figure 3-12. Regional distribution of Precipitation as Snow for Eagle Creek watershed (thick red line) and the Fauquier Station (1961-1990 normal period) based on (Mitchell & Jones, 2005).

3.7. Climate Change Impacts

The watershed is located in the Selkirk-Bitterroot Foothills ecoregion and spreads across a portion of the Selkirk Foothills ecosection. Extreme flood events in this region 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 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 & Quirk., 1999; Schnorbus et al., 2014).

The Climate NA model provides downscaled climate projections for future conditions (Wang et al., 2016). The projections based on the Representative Carbon Pathway (RCP) 8.5 indicate that the mean annual temperature in the Eagle Creek watershed is projected to increase from 2.8ºC (average between 1961 to 1990) to 6.3ºC by 2050 (average between 2041 to 2070). The mean annual precipitation is projected to increase from 946 mm to 993 mm while precipitation as snow is projected to decrease from 469 mm to 303 mm by 2050 in the Eagle Creek watershed. Projected change in climate variables from historical conditions for the Eagle Creek watershed (Wang et al., 2016) are presented in Table 3-6.

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 discharge timing is expected in many rivers (Schnorbus et al., 2014; Farjan et al., 2016). Peak discharges may increase or decrease depending on the watershed characteristics and the balance of temperature and precipitation changes in the future.

Table 3-6. Projected change (RCP 8.5, 2050) from historical (1961 to 1990) conditions for the Eagle Creek watershed (Wang et. al, 2016).

Climate Variable	Projected Change
Mean Annual Temperature (MAT)	+3.5 ºC
Mean Annual Precipitation (MAP)	+47 mm
Precipitation as Snow (PAS)	-166 mm

4. SITE HISTORY

4.1. Introduction

The village of Edgewood lies on the Eagle Creek fan-delta. Historically, this village was located on the shores of Lower Arrow Lake, east of its current location. The village was moved prior to the raising of the Lower Arrow Lake reservoir in the late 1960s. BGC notes historical documents refer to the town site as “Killarney Landing”, and the Inonoaklin Creek Valley as the “Fire Valley”.

4.2. Document Review

In developing a flood, mitigation, and development history for Eagle Creek, BGC reviewed several documents, including:

- Archival records from the BC Archives, Nelson Touchstone Museum, and the Arrow Lakes Historical Society.
- Reports provided to BGC by RDCK (Table 4-1), including:
    - Precondition applications (building permit, subdivision, and site-specific exemptions, etc.).
    - Hazard assessments (flooding, post-fire, etc.).
- Reports provided to BGC by Ministry of Forests, Lands, Natural Resource Operations and Rural Development (MFLNRORD) (Table 4-1).
- Historical flood and landslide events from the following sources:
    - Social media and online media reports.
    - Septer (2007).
    - DriveBC historical events (2009 to 2017) (MoTI, 2019).
    - Canadian Disaster Database (Public Safety Canada, n.d.).
    - MFLNRORD Complaints Database.
    - “Just Where is Edgewood?” book (Edgewood History Book Committee, 1991).
    - Accounts from Edgewood residents.
- Historical wildfire perimeters (MFLNRORD, n.d.).
- Cutblock perimeters (MFLNRORD, n.d.).

BGC’s review of the above work is not aimed as a critique but rather a brief summary of the findings of each report. Each scientific or engineering/geoscientific study builds on the preceding one benefitting from the added knowledge. By summarizing aspects of the studies listed below, BGC is neither endorsing nor rejecting the findings of those studies, as this was not the scope of the present study.

Table 4-1. Previous reports and documents on Eagle Creek.

Year	Month/Day	Source	Purpose
1986	March	A. Salway, Kokanee Hydrological Serv.	Water quality monitoring
1988	September	D. Boyer, Water Management Branch	Preliminary flood hazard assessment
1994	September. 22	BC Ministry of Environment	Site inspection memo
1996	January	D. Barlow, Water Management Branch	Correspondence with D. Boyer.
1997	May 30	S.W. Rilkoff	Precondition for building permit
1998	February 23	Klohn Crippen Consultants Ltd.	Alluvial and debris torrent fan-delta inventory
2000	October 3	Woods Associates Engineering	Landslide assessment
2005	April 18	Horizon Geotechnical Ltd.	Precondition for building permit
2008	Aug. 11	Perdue Geotechnical Services Ltd.	Precondition for building permit
2010	August. 18	Horizon Geotechnical Services Ltd.	Precondition for building permit
2010	October 23	Perdue Geotechnical Services Ltd.	Precondition for building permit
2017	April	Okanagan Nation Alliance	Feasibility assessment
2017	November 21	WD Modern Dimensions Design Inc.	Precondition for building permit

4.2.1. Boyer (1988)

A preliminary assessment of flood hazard on the upper Eagle Creek fan was completed by Boyer (1988). Boyer observed that Eagle Creek is well incised on the north bank from the apex to Lower Arrow Lake excepting for a 200 m length of channel between the fan apex and the Worthington FSR bridge. Boyer concluded that based on the anticipated flows during an extreme event and the low confinement in this area that this is a probable location for an avulsion. At the time, there was a proposed subdivision in the area northeast of this location that was recommended to be moved to an alternate location (Boyer, 1988).

4.2.2. Barlow (1996)

In 1996, Barlow inspected the Eagle Creek Dike at the Worthington FSR. Barlow references the 1988 hazard assessment (Boyer, 1988) and indicates that since writing, the FSR bridge had been rebuilt. Based on site observations, Barlow concluded that the Eagle Creek Dike, constructed in the early 1970s, did not meet Ministry standards for a dike that was intended to protect property. Barlow provides a series of potential courses of action to reduce risk to a proposed subdivision northeast of the FSR bridge and recommended that the dike be upgraded to Ministry dike standards.

4.2.3. Perdue Geotechnical Services (2008)

In 2008, Perdue Geotechnical Services (Perdue) completed a hazard assessment for a property located at the corner of Monashee Ave and Eagle Cres north of Eagle Creek as a precondition for a building permit. Perdue assessed Eagle Creek to have a moderate likelihood of channel avulsion at the fan apex (no description of this qualitative rating was provided). Perdue assessed that Eagle Creek Dike was not of sufficient height above expected seasonal high water levels to contain extreme peak flows. Given the elevation of the lot in question, Perdue concluded that it was not at risk from flooding and erosion from high velocity flows, avulsion, debris flows or bank instability (Perdue, 2008).

4.3. Historic Timeline

Figure 4-1 summarizes the flood and mitigation history for Eagle Creek. For location references, refer to Drawings 01, 02A, and 02B. The historical event inventory is likely incomplete, but the information contained within it can be used to identify the location of past geohazards events and associated consequences of these events. From this information, the following can be concluded:

- At least five notable hydrogeomorphic events have occurred since 1894. BGC interprets that all the noted events are likely debris flood events due to their extensive erosion, avulsions and observed movement of sediment in air photos.
- Debris floods have caused bank erosion on the left (north) bank of Eagle Creek threatening structures on the top of the bank. BGC interprets that these events are Type 1 debris floods due to the mobilization of sediment required for significant bank erosion.
- Eagle Creek avulsed near the fan-delta apex, possibly during the 1894 flood event. The main channel was re-routed into its present location in the early 1900s.
- Water levels at the toe of the fan-delta are influenced by the reservoir levels on Lower Arrow Lake.

Specific flood protection structures installed at Eagle Creek include:

- BC Hydro installed flood protection measures (berm) in the 1980s at the base of the large bank slope below the town site. The berm is constructed of rip rap and shown in Drawings 02A, 02B. It was repaired in 2007.
- Eagle Creek Dike (EGL-FP-01) (Figure 3-7 and Drawings 02A, 02B) was constructed near the fan-delta apex upstream of the Worthington Creek Forest Service Road bridge in the 1940s or 1970s (residential recollections and reports differ). Photos of Eagle Creek Dike (EGL-FP-01) are shown in Figure 3-7 and Drawings 02A, 02B shows its location. Eagle Creek Dike (EGL-FP-01) was built using in channel material (i.e., rounded channel clasts). The design and intention for this structure is uncertain, but it was likely constructed to prevent avulsions to the northern and central portions of Eagle Creek fan-delta.

Geohazard History

Flood event, looking downstream from forestry road bridge, 1997 (Sharon Baker)

August 2018 - Edgewood put on evacuation notice due to Mount O'Leary wildfire approximately 6 km south of town site

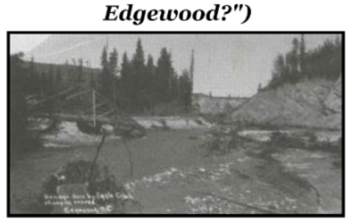
2013 - Residents recorded flooding event on creek
Assumed to be 2013 (coincident with flood) - Landslides in upper watershed along incised reach approximately 10 and 15 km upstream of fan apex

2000 - Human-caused wildfire burned approximately 15 ha of Eagle Creek watershed in the mid-reaches
1997 - Residents recorded flooding event on creek

1985 - Complaints about bank erosion at toe of slope below town
Early 1970s - Residents accounted that a large flood event eroded the top edge of the bank approximately 15 to 30 m in one night. One house was threatened by the erosion, but was not damaged (this event could be a duplicate of the 1968 record below, or could be from 1972 when a flood event was observed on Inonoaklin Creek)
1972 - Maximum daily flow on the Inonoaklin doubled from May 30th to 31st. The same flows could have been expected on Eagle Creek
1971 - Lightning-caused wildfire burned approximately 60 ha of north eastern Eagle Creek watershed
1968 - Bank erosion on bank below town site and water pumphouse below Monashee Ave.

Flood damage, 1894 (Edgewood History Book Committee "Just Where is Edgewood?")

June 1948 - The creek flooded and washed out the road into Edgewood. The townsite was isolated except for boat access. The dock floated off its moorings; the bakery and cheese factory were flooded



Flood damage to Eagle Creek Bridge, 1894 (Edgewood History Book Committee "Just Where is Edgewood?")

1929 - Human-caused wildfire burned approximately 165 ha of southern Eagle Creek watershed in the mid-reaches.
July 1925 - Lightning-caused wildfire burned approximately 20,000 ha of Inonoaklin Creek watershed near Needles
1924 - Lightning-caused wildfire burned approximately 160 ha of northeastern Eagle Creek watershed
1922 - Human-caused wildfire burned approximately 8,600 ha of Eagle Creek and Inonoaklin Creek watersheds
1920 - Lightning-caused wildfire burned approximately 116 ha of mid reaches of Eagle Creek watershed
1917 - A forest fire broke out and local men were conscripted to fight the fires

1912 - "Indian Trails" map shows a secondary channel of Eagle Creek flowing northeast from the fan apex and discharging into Inonoaklin Creek north of its current position

1903 - Survey shows channel flowing from the fan apex to the northeast, with the creek discharging into Inonoaklin Creek upstream of the present town site

June 1894 - Eagle Creek changed its course completely by turning northeast from the fan apex and entering the Inonoaklin River in at least three channels. The roads, bridges, and wharf were all destroyed

Wildfire
Flood
Landslide
Debris flow or debris flood
Channel location
Mitigation
Development event

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

Mitigation

May 2007 - BC Hydro repaired berm at base of eroding slope below community water well and pump

1993 - The forestry road bridge was replaced

1986 - BC Hydro installed berm at base of eroding slope below Edgewood to protect community well and pump

Unknown date (residents account - 1940s, BC Hydro accounts - 1970s) - Dike constructed on left bank near fan apex (upstream of present forestry road bridge). Dike was constructed of in-stream channel material (rounded boulders and cobbles)

Approx. 1914 - Jack Harris and Harold Calcutt report having to control Eagle Creek from eroding north onto their property (near the creek outlet at the lake)

1903 to 1907 - Eagle Creek channel re-routed back into its present configuration

Development

2018 - New community fire hall constructed
2017 to Present - Construction of new water system west of town site

2001 - Edgewood water system upgraded

Late 1980s to Present - Logging in upper watershed

1970 - Sports ground constructed in Edgewood
October 1968 - The Keenleyside Dam is declared operational. Lower Arrow Lake water levels are raised 12 m
1966 - Edgewood water system constructed
Late 1960s - The town site is relocated from the lower alluvial fan to its present location in preparation for the Lower Arrow Lake reservoir raise

1926 - The valley name was changed from "Fire Valley" to "Inonoaklin Valley"

August 1915 - Internment camp opened in Edgewood

1909 - Edgewood's first school opened
1908 - Edgewood boat landing constructed at town site and Killarney wharf abandoned
1902 - Edgewood Post Office opens
1897 - Road constructed between Fire Valley and the lakeshore
1893 - Government wharf constructed at Killarney Landing
1891 - Surveyors and early settlers arrive in the valley

Figure 4-1. Summary of recorded geohazard, mitigation, and development history at Eagle Creek.

5. METHODS

The overall assessment methodology applied to the nine flood and debris flood prone steep creeks in the RDCK is summarized in the Methodology Report (BGC, March 31 2020b). This section summarizes the overall workflow as well as any specific deviations from the steep creek methodology applied at Eagle Creek. Figure 5-1 shows the workflow to develop frequency-magnitude (F-M) relationships for Eagle Creek and other flood and debris flood prone creeks in the RDCK.

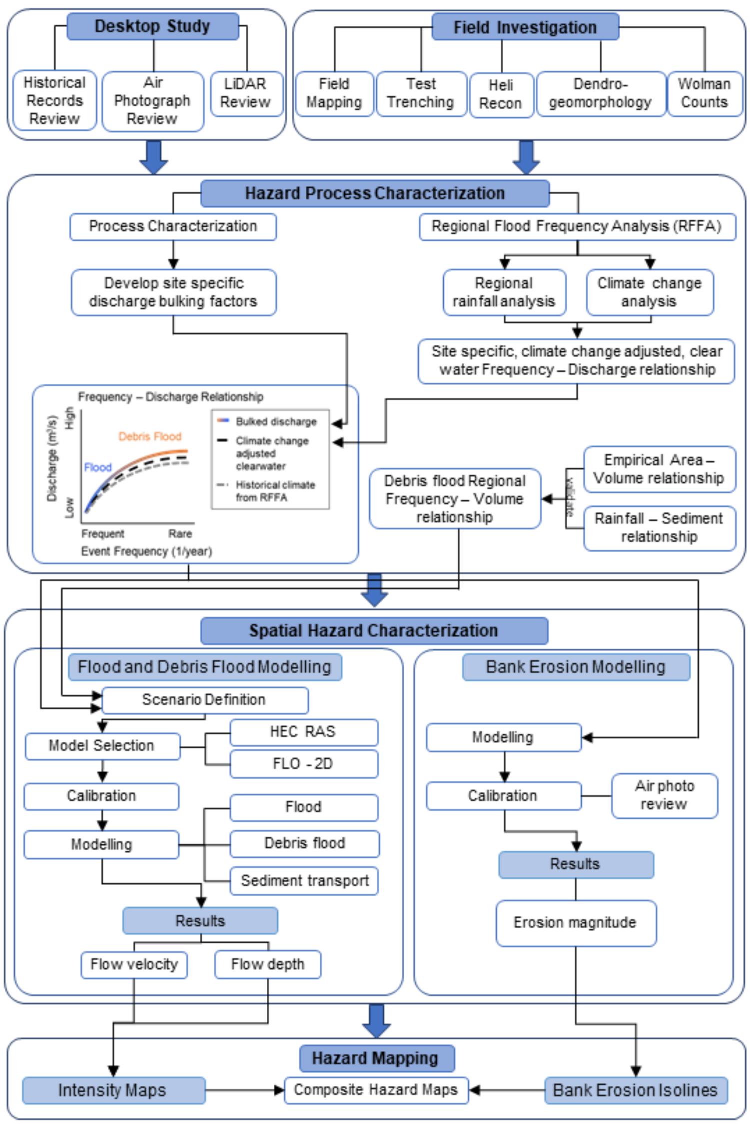


Figure 5-1. Flood and debris flood prone steep creeks workflow used for developing frequency-magnitude relationships, modelling, and preparing hazard maps.

5.1. Debris Flood Frequency Assessment

This section combines the methods established to estimate debris flood frequencies from remote sensing and field methods on Eagle Creek. They entail air photograph interpretation, dendrogeomorphological assessment, and test pitting.

5.1.1. Air Photo Interpretation

Air photos dated between 1939 and 2014 were examined for evidence of past sediment transport events on Eagle Creek. A complete list of the air photos reviewed is included in Appendix D. Events were identified from the appearance of bright areas and disturbed vegetation relative to previous air photos. Smaller events that did not deposit sediment outside the channel or significantly change the course of the channel are not captured in this analysis. Similarly, events that occurred during large gaps between air photos or successive events that overlap may not be captured. Air photo interpretation was supplemented by historical records of past events (Figure 4-1).

5.1.2. Dendrogeomorphology

Eleven tree core samples were collected for dendrogeomorphological analysis from Eagle Creek (Drawings 02A, 02B). Characteristics of the samples including the tree type, minimum establishment date[6], and features that indicate physical damage to the tree are presented in the results section (Table 6-2). The presence of features indicating a tree sustained damage in a given year can supplement the historical records, air photo interpretation, and evidence from test pits in the development of a record of historical events, as well as the extents of such events.

5.1.3. Test Pitting

Five test pits were excavated on the Eagle Creek fan-delta (Drawings 02A, 02B). During field work a trench was also open in Area C due to waterline works, which BGC traversed and logged intermittently (TP-BGC19-EGL-Waterline-06 to -08). All the test pits are located north of the active channel of Eagle Creek. The waterline trench was immediately north of the channel west of Monashee Ave. One pit was dug just north of Worthington Creek FSR. Two pits are between Granby Drive and Worthington Creek FSR and the final two pits are north of Worthington Creek FSR near Townsite Road on the distal fan-delta.

Test pit logs and photographs are included in Appendix E.

5.2. Peak Discharge Estimates

5.2.1. Clearwater Peak Discharge Estimation

Peak discharge (flood quantile) estimates were calculated using a regional flood frequency analysis (Regional FFA) because there are no hydrometric stations on Eagle Creek. The regionalization of floods procedure was completed using the index-flood method. For this project,

[6] The minimum establishment date refers to oldest tree ring identified in the sample. The samples do not always hit the earliest tree rings so this year is taken as the minimum date the tree could have established itself.

the mean annual flood was selected as the index-flood and dimensionless regional growth curves were developed from Water Survey of Canada (WSC) data to scale the mean annual flood to other return periods. The index-flood for each creek is determined from watershed characteristics. The index-flood was estimated using a regional and provincially based ensemble of multiple regression models. The Eagle Creek watershed was assigned to the 4 East hydrologic region for watersheds less than 500 km^2 based on its watershed characteristics. Details of the Regional FFA are presented in Section 3 of the Methodology Report (BGC, March 31, 2020b).

5.2.2. Climate-Change Adjusted Peak Discharges

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). The impacts of climate change on peak discharge estimates in Eagle Creek were assessed using statistical and processed-based methods as per Section 4 of the Methodology Report (BGC, March 31, 2020b). 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).

The results of the statistical and process-based methods were found to be inconsistent across the RDCK by 2050 (average from 2041 to 2070). 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 Section 4 of the Methodology Report (BGC, March 31, 2020b).

5.2.3. Sediment Concentration Adjusted Peak Discharges

BGC accounted for expected flow bulking from organic and mineral sediment by multiplying the climate adjusted clearwater discharge with a bulking factor specific to each return period as outlined in Section 2 of the Methodology Report (BGC, March 31, 2020b).

5.3. Frequency-Magnitude Relationships

An F-M relationship answers the question “how often (frequency) and how big (magnitude) can steep creek hazards events become?”. The ultimate objective of an F-M analysis is to develop a graph that relates the frequency of the hazard to its magnitude. For this assessment frequency is expressed using return periods[7], and discharge is used as the measure of magnitude. For more background on F-M the reader is referred to the Methodology Report (BGC, March 31, 2020b).

[7] Except for periods of T<1, the return period (T) is the inverse number of frequency F (i.e., T=1/F).

BGC assessed Eagle Creek for the 20-, 50-, 200-, and 500-year return periods. At these return periods, the hydrogeomorphic process was identified as debris flood based on climate adjusted peak discharges and stream morphometrics. Because the debris flood events will carry sediment and woody debris, the climate adjusted clearwater discharge needs to be bulked accordingly. To produce a bulked frequency-discharge relationship, a bulking factor was applied to the peak discharge for each return period, based on sediment availability and debris flood process type. The bulked frequency-discharge relationship was then used in numerical modelling.

Another measure for magnitude is sediment volume. While sediment volume is less useful as input to numerical modelling, it is helpful to verify sediment deposition predicted by the model. Therefore, a regional frequency-volume relationship was created to compare to numerical modelling results. A detailed discussion of the methodology is provided in Section 2 of the Methodology Report (BGC, March 31, 2020b).

5.4. Numerical Debris Flood Modelling

Numerical modelling of Eagle Creek was completed for 20-, 50-, 200- and 500-year return periods. Details of the numerical modelling techniques are summarized in Section 2 of the Methodology Report (BGC, March 31, 2020b). Two numerical models were used, HEC-RAS 2D (Version 5.0.7) and FLO-2D (Version 19.07.21). HEC-RAS is a public domain hydraulic modelling program developed and supported by the United States Army Corps of Engineers (Brunner & CEIWR-HEC, 2016). It was used to model clearwater floods with climate-change adjusted and bulked flows.

FLO-2D is a two-dimensional, volume conservation hydrodynamic model that supports sediment transport and mudflow processes (FLO-2D Software Inc., 2017). It is a Federal Emergency Management Agency (FEMA) approved model that has shown reasonable results when compared to other debris flow models (Cesca & D'Agostino, 2008). It was used to model sediment transport when a return period event had a predicted sediment concentration of 10% to 25% by volume. Debris flood events with a sediment concentration of 30% or greater were modelled with rheological parameters to represent mudflow.

Table 5-1 summarizes the key numerical modelling inputs selected for the HEC-RAS and FLO-2D models. Further details on modelling methods are presented in Section 2 of the Methodology Report (BGC, March 31, 2020b).

Table 5-1. Summary of numerical modelling inputs.

Variable	HEC-RAS	FLO-2D
Topographic Input	LiDAR (2018)	LiDAR (2018)
Grid cells	Variable (2- 30 m)	10 m
Manning' n	0.06 (channel), 0.02 (main roads), 0.1 (fan-delta)	
Upstream boundary condition	Steady Flow (Q_{20}, Q_{50} and Q_{200})	Steady Flow (Q_{500})
Downstream boundary condition	Steady stage at Arrow Lake (440.7 m)	

Note: The downstream boundary condition is BC Hydro's maximum flood scenario for Keenlyside Dam operation (BC Hydro, pers. comm.).

A series of modelling scenarios were developed for Eagle Creek as presented in Appendix F. Modelling scenarios include different return periods (principal scenario), different bulking scenarios, and assumed bridge blockage scenarios (sub-scenarios). The latter were based on comparisons between the bridge conveyance and the bulked and climate-change adjusted peak discharges.

Dikes were removed from topography when the bank erosion was predicted to reach the dike footprint and the critical shear stress to shear stress ratio reached or exceeded two ($\tau/\tau_c \geq 2$). For Eagle Creek, the flood protection structure EGL_1 Berm was assumed eroded away for all modelled return periods.

As the objective of this study was a hazard assessment, BGC did not attempt to assign conditional probabilities to each hazard scenario or sub-scenario. Those would need to be estimated for a quantitative risk assessment which would support the choice and scale of mitigation measures, if required.

5.5. Bank Erosion Assessment

A bank erosion assessment was conducted using a physically based model calibrated to the erosion observed in historical air photos, as calculated at nine creek cross-sections between the fan-delta apex and the mouth of the creek. The assessment methods are outlined in Section 2 of the Methodology Report (BGC, March 31, 2020b). Sediment size sample results used as inputs to the modelling are included in Appendix C. The location of each bank erosion cross-section is delineated on Drawings 02A, 02B. Refer to Appendix D for the full list of air photos consulted during the calibration process.

5.6. Hazard Mapping

BGC prepared hazard maps based on the combined results from the numerical debris flood modelling and bank erosion assessment. Specifically, BGC prepared two types of steep creek hazard maps for Eagle Creek: hazard scenario maps and a composite hazard rating map. The scenario maps support emergency planning and risk analyses, and the composite hazard rating map supports communication and policy implementation, as described further below.

5.6.1. Hazard Scenario Maps

Hazard scenario maps display the following, for each scenario considered:

1. The hazard intensity and extent of inundated areas
2. Areas of sediment deposition
3. Potential bank erosion extents.

FLO-2D and HEC-RAS 2D model outputs include grid cells showing the velocity, depth, and extent of debris flood inundation. These variables describe the intensity of an event. Hazard quantification needs to combine the intensity of potential events and their respective frequency. Sites with a low probability of being impacted and low intensities (for example, slow flowing ankle-deep muddy water) need to be designated very differently from sites that are impacted frequently and at high intensities (such as water and rocks flowing at running speed). For the latter, the resulting geohazard risk is substantially higher and development must be more restrictive than the former. The hazard maps are provided as a geospatial data package and displayed on Cambio Communities. A representative example of a hazard scenario for the 200-year return period is included as a static map (Drawing 07).

5.6.2. Composite Hazard Rating Map

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

Given their application in policy, the composite map provided with this assessment is subject to further review and discussion with RDCK. Even where the underlying hazard scenarios do not change, cartographic choices (i.e., map colours and categories) can influence interpretation of the maps. BGC anticipates that discussions about hazard map application in policy will extend beyond final report delivery, and that these discussions may lead to further modifications of the composite hazard rating maps.

The composite hazard rating map is based on an impact intensity frequency (IIF) geohazard mapping procedure that consists of two principal components: the intensity expressed by an impact force and the frequency of the respective events. The underlying equation is:

$$IIF = v^2 \times \rho_f \times d_f \times P(H) \qquad \text{[Eq. 5-7]}$$

where v is flow velocity (m/s), d_f is the fluid's flow depth (m), ρ_f is the fluid density (kg/m^3) to obtain a unit of force per metre flow width for the three left terms in Equation C-9 and $P(H)$ is the annual probability of the geohazard. The unit of IIF is then Newton or kilo Newton per metre per year (kN/m per yr).

Equation 6-7 can be translated into a matrix in which the impact force (*IF*) is on one axis and the return period (annual probability or *P(H)*) on the other. The matrix is then colour-coded to indicate the total hazard from yellow (low hazard) to dark red (extreme hazard) (Figure 5-2).

A further area designated a "very low" hazard, is also presented as areas likely to not be affected by any of the modeled scenarios up to the 500-year return period debris floods, but which are not free of hazard. Very low hazard zones could be impacted by flows of higher return periods, or if, over time, the channel bed aggrades, or the channel or fan surface is artificially altered. This designation is not classified using impact force and frequency. These fan surfaces are designated as 'inactive' which is distinct from 'paleosurfaces'.

Paleosurfaces within the approximate fan area are interpreted as not being affected by contemporary hazardous geomorphic processes considered in this study (e.g., debris floods, debris flows, bank erosion) and have no hazard rating on the composite hazard rating map. Surface flow on paleo surfaces has not been assessed in this study. Over steepened banks along paleofan surfaces can be subject to landsliding especially when undercut by streamflow. This process has been highlighted on the fan-delta geomorphology map (Drawing 06).

Figure 5-2 displays a wider range of return periods and intensities than are relevant to debris flood hazard on Eagle Creek. The intention is to provide a range that can be consistently applied to a broad spectrum of hazards, including landslides, as part of a long-term geohazard risk management program.

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

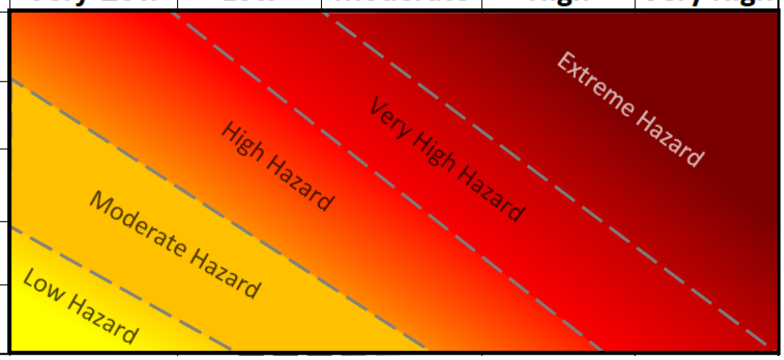


Figure 5-2. Simplified geohazard impact intensity frequency matrix.

The advantage of this mapping type is that a single map immediately codifies which areas are exposed to what hazard. Given that impact force is a surrogate for the destructiveness of a geohazard, *IIF* maps are relative proxies for risk assuming elements at risk are present in the specific hazard zones. For clarity, the values do not represent an absolute level of risk, which also depends on their vulnerability and their being present in the hazard area at the time of impact.

Interpreted hazard maps showing *IFF* values were developed for each return period class at all locations within the study area. For the individual hazard scenario maps that are added to the Cambio web application, the raw (no interpretation nor zone homogenization) impact force modelling results are presented. For the composite hazard rating map, the different intensities were interpreted by BGC to homogenize zones into easily identifiable polygons that are likely to fall into the range of intensity bins reported above. In some cases, individual properties may have been artificially raised and are thus less prone to flood or debris flood impact. Such properties would need to be identified at a site-specific level of detail, for example, if the owner wishes to subdivide or renovate and ask for an exemption to existing bylaws.

6. RESULTS

6.1. Overview

Results of the debris flood F-M assessment are presented in this section. Based on historical accounts, field evidence, and analysis of remote sensing data, Eagle Creek is believed to be subject to supply-unlimited Type 1 debris floods for the spectrum of return periods assessed. No evidence was found during remote sensing and helicopter flights for the potential formation of landslide dams in the mainstem channel or for diluted debris flows reaching the fan-delta apex. Above the fan-delta apex, Eagle Creek has a typical channel gradient of approximately 10º (Drawing 03), which is too low for debris flow transport.

6.2. Debris Flood Frequency Assessment

6.2.1. Air Photo Interpretation

At least five notable hydrogeomorphic events have occurred since 1894 as identified from the air photo interpretation. Four of these events involved avulsions. Drawings 04A and 04B show air photos with events delineated. The interpreted deposition area and characteristics of the sediment transport events are described in Table 6-1. BGC interprets that all the noted events are likely Type 1 debris flood events due to their extensive erosion, avulsions and observed movement of sediment in air photos.

Table 6-1. Summary of Eagle Creek sediment transport events in air photo record (1939-2014).

Event Year[1]	Air Photo Year	Deposition Area (m^2)	Event Characteristics
1894	1939	45,200	Avulsion at fan-delta apex (upstream of Worthington Creek FSR) to the north towards Inonoaklin Creek
1948	1952	175,500	Sediment deposit in main channel, small avulsions to south
1968	1969	236,800	Sediment deposit in main channel, avulsion to south channel
1997	2001	109,500	Sediment deposit in main channel, avulsion to south channel
2013	2014	131,200	Sediment deposit in main channel, no avulsions

Event year interpreted from air photo dates and historical records.

The deposition areas delineated from the air photos where combined with evidence from the test pits to estimate event volumes (Section 6.2.3).

6.2.2. Dendrogeomorphology

A summary of the dendrogeomorphic analysis is provided in Table 6-2.

Table 6-2. Summary of Eagle Creek dendrogeomorphology sample features.

Sample[1]	Tree type	Minimum establishment date (first ring) [2]	Features[3]
EGL-01	Lodgepole Pine	1965	Moderate traumatic resin ducts (TRD) in 2003
EGL-02	Lodgepole Pine	1963	Moderate to strong TRDs in 1981 and 1998
EGL-03	Lodgepole Pine	1919	Faint TRDs
EGL-04	Lodgepole Pine	1927	Strong TRDs in 1948, sustained growth reduction in 2006
EGL-05	Lodgepole Pine	1925	Moderate TRDs in 1937 and 1999
EGL-06a	Lodgepole Pine	1889	Scar in 1905, strong TRDs in 2012
EGL-06b	Lodgepole Pine	1907	Moderate to strong TRDs in 1907, 1910, 1912, 1927 and 2011
EGL-06c	Lodgepole Pine	1872	Strong TRDs in 2007
EGL-07	Lodgepole Pine	1936	Sustained growth reduction in 1985
EGL-08	Lodgepole Pine	1876	Faint TRDs
EGL-09	Lodgepole Pine	1877	Moderate to strong TRDs in 1908, 1910, 1911 and 1971, sustained growth reduction in 1893 and 1899

Notes:

1. Sample locations are shown on Drawings 02A, 02B.
2. Minimum establishment date refers to the oldest tree ring identified in the sample. The samples do not always hit the earliest tree rings so this year is taken as the minimum date the tree could have established itself.
3. Traumatic resin ducts (TRDs) are small circles that appear within the wood, which indicate that the tree sustained physical damage during that year (similar to scar tissue).

With no trees sampled older than 1870, the data suggest a stand replacing event some time before that (possibly a wildfire). The scar on sample EGL-06a in 1905 also aligns with moderate to strong TRDs in EGL-06b and -09 in the early 1900's (1907 and 1908), suggesting an event around 1905. These potential event dates have been used to corroborate events from other methods but were not directly used to develop the F-M relationship.

6.2.3. Test Pitting

Radiocarbon sample dates and test pits logs were used to estimate minimum return periods and event deposit thicknesses (Table 6-3). The radiocarbon results showed a minimum event return period of 300 years for those areas in which test pits were dug. This number should be viewed as a minimum due to the limited number of test pits and the fact that not everywhere organic materials are found to associate a reconstructed event with a date. No events could be delineated from the radiocarbon sample results as dates did not agree between test pit locations and an insufficient number of test pits were conducted due to budget limitations. Detailed results of the radiocarbon dating are provided in Appendix G.

Table 6-3. Sediment volumes estimated from radiocarbon dates and test pit logging.

Event Date (years BP[1])	Sample	Depth (m)	# of units above	Minimum event return period (years)
600	TP-EGL-02, G1	0.6	2	300
3000	TP-EGL-03, G1	1.3	2	1500
7600	TP-EGL-04, G1	1.2	1	7600
4300	TP-EGL-04, G3	0.8	1	4300
4700	EGL-Waterline-08	0.9	1	4700

Note:

1. Radiocarbon results are expressed in years before present (BP), where present is taken to be the year 1950.

Soil logging of the test pits identified event thicknesses ranging from 0.3 to 1.6 m, with a median thickness of 0.4 m (Appendix E). Given the size of Eagle Creek fan-delta, it was impractical to dig enough trenches to allow a seamless extrapolation of deposits across the fan-delta assuming that all deposits would have been datable. Instead, the median thickness of the deposits encountered in the test pits was used to compare numerical modelling results with magnitude estimates from the air photo interpretation and historical records (Table 6-4).

Table 6-4. Estimated deposition volume of Eagle Creek debris floods from the air photograph record (1939-2014).

Event Year	Air Photo Year	Deposition Area (m^2)	Estimated Deposition Volume using median thickness (m^3)[1]
1894	1939	45,000	18,000
1948	1952	176,000	70,000
1968	1969	237,00	95,000
1997	2001	110,000	44,000
2013	2014	131,000	53,000

Note:

1. The deposition volume is estimated based on the median thickness (0.4 m) observed in test pits on the fan-delta.

These observations are not suitable to derive an F-M relationship because the air photograph record does not entail all events that occurred, nor can deposition areas be attributed, without doubt, to a single event. Hence, the results are used as an independent check of the overall fan-delta activity. Section 6.4 discusses the sediment volume F-M relationship further.

6.3. Peak Discharge Estimates

Peak discharges for different return periods were estimated to serve as input to the numerical modelling. The workflow entailed an estimate of clearwater peak discharges, followed by a climate-change adjustment, and finally an adjustment for sediment bulking.

6.3.1. Clearwater Peak Discharges

Peak discharge (flood quantile) estimates were calculated using a regional flood frequency analysis (Regional FFA) because there are no hydrometric stations on Eagle Creek. These are summarized in Figure 6-1.

6.3.2. Climate-adjusted Peak Discharges

Historical peak discharges (based on the provincial model) on the Regional FFA and climate-adjusted peak discharges for Eagle Creek are presented in Figure 6-1. The provincial index-flood model was selected because it is slightly more conservative than the regional model.

The climate-adjusted peak discharge estimated are presented in Table 6-5. The historic peak discharge estimates based on the Regional FFA were adjusted by 20% to account for the impacts of climate change as per Section 4 of the Methodology Report (BGC, March 31, 2020b).

Table 6-5. Climate-adjusted peak discharge estimates for Eagle Creek.

Return Period (years)	Annual Exceedance Probability	Non-adjusted Peak Discharges (m^3/s)	Climate-adjusted Peak Discharges (m^3/s)
2	0.5	10	15
20	0.05	25	30
50	0.02	30	35
200	0.005	35	45
500	0.002	40	50

6.3.3. Sediment Concentration Adjusted Peak Discharges

Table 6-6 shows the bulked frequency-discharge relationship for Eagle Creek. These bulked peak discharges were used in the numerical modelling.

Table 6-6. Bulking factors for each return period's peak discharge and justification.

Return Period (years)	Bulking Factor	Bulked Peak Discharge (m^3/s)	Key Considerations	
			Debris Flood Type	Comments
20	1.02	30	1	Few landslides in lower 10 km of watershed. Active side slope landslide 8 km upstream of fan-delta apex.
50	1.05	35	1	Landslide activity in lower 10 km of watershed would increase to "several landslides".
200	1.2	50	1	Several landslides in lower 10 km of watershed, more woody debris expected. Tributaries with moderate activity.
500	1.3	70	1	Landslide activity in lower 10 km of watershed would increase to "many landslides". Debris flows in two main lower channel tributaries. (note: a case could be made here for Type 3 debris flood but the selected bulking factor of 1.3 is likely more conservative).

Note: Refer to Section 2 of the Methodology Report (BGC, March 31, 2020b) for details on bulking method.

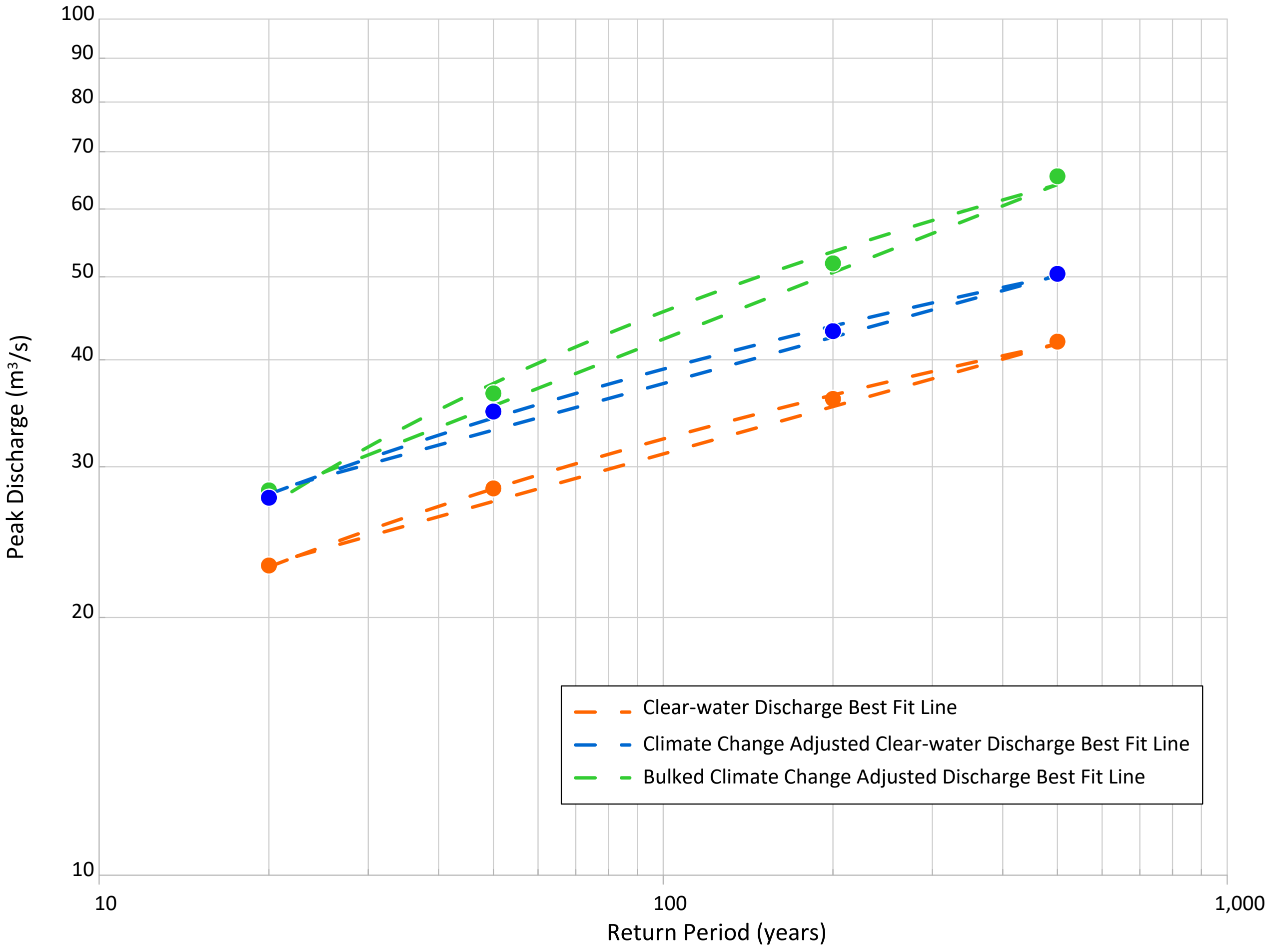


Figure 6-1. Frequency-discharge relationship for Eagle Creek.

6.4. Frequency-Volume Relationship

6.4.1. General

BGC used several independent approaches to create a frequency-volume relationship for Eagle Creek. These included air photo analysis of sediment deposits, test pitting, dendrochronology, sediment transport equations, and application of regional relationships for fan-delta area – sediment volume and watershed area – sediment volume. The different methods were compared. For numerical modelling, the regional relationships were applied as they provided the most reasonable results and were consistent with the airphoto analysis (i.e., Table 6-4). Volumes for each return period based on this regional curve are summarized in Table 6-7. These sediment volumes are all associated with Type 1 debris floods.

Table 6-7. Summary of event volumes for each return period based on the regional frequency-volume curve.

Return Period (years)	Event Volume (m^3)
20	80,000
50	100,000
200	140,000
500	160,000

Note; this relationship was specifically developed for modelling results verification only. It is not suitable to inform mitigation design.

6.4.2. Wildfire Effects on Debris Flood Sediment Volumes

The effect of wildfires on debris flood hazards is extremely complex and cannot be solved deterministically. Regional climate change projections indicate that there will be an increase in the hourly intensity of extreme rainfall and increase in frequency of events (Prein et al., 2017). Changes to short duration (one hour and less) rainfall intensities are particularly relevant for post-fire situations in debris-flow and debris flood generating watersheds. Within the year to a few years after a wildfire affecting large portions of a given watershed, short duration and high intensity rainfall events are much more likely to trigger debris flows or debris floods, than prior to a wildfire event.

- The elevation of the fires in the watersheds (fires at higher elevation could The ratio of the total watershed area to the burned area (i.e., the lower this ratio, the higher the runoff effect)
- The burn severity (i.e., the higher the burn severity, the greater the hydrological and geomorphic response)
- The debris-flow response in tributaries (i.e., if there are post-fire debris flows discharging into the main channel, the geomorphic response of the main channel will be amplified).
- The type of system, as supply-unlimited basins will respond with high volumes every time after a wildfire, whereas supply-limited basins may respond with reduced volumes depending on their respective recharge rates.

As the location, size and severity of a wildfire cannot be predicted, neither can the associated streamflow response post-wildfire. A method to evaluate more fully would be to stochastically examine a suite of scenarios and their respective fluvial and geomorphic response. By doing so, the most likely model scenario could be selected immediately after a wildfire to link the expected discharge and bulking scenario to a runout model. This would prevent the substantial lag time between the wildfire occurring and having tangible results for emergency planning.

The results of this study should not be relied upon to predict post-wildfire behaviour in the Eagle Creek watershed, especially for large moderate to high burn severity wildfires.

6.5. Numerical Debris Flood Modelling

A summary of the key observations from the debris flood modelling is included in Table 6-8. The model results are presented in Cambio Communities and a representative example is shown on Drawing 07.

A Cambio user guide is included in the Summary Report.

Table 6-8. Summary of modelling results.

Process	Key Observations
Clearwater inundation (HEC-RAS results for all return periods)	• Eagle Creek remains channelized for all flows except the bridge blockage scenario that was invoked for return periods of 200 to 500 years. • Bridge blockage will result in the flow avulsing from its channel towards the northeast where it will preferentially follow existing paleochannels.
Sedimentation	• Sedimentation will likely be confined to the existing channel and will concentrate in the fan-delta area where the lowest gradients persist, and the floodplain has little confinement.
Bank Erosion	• Bank erosion could reach up to approximately 80 m for the 50th percentile probability at the 500-year return period. This total is for erosion on both sides of the creek; however, the proportion of the total erosion affecting each bank contains some uncertainty. For most of the area, this is not a significant issue as areas along the upper and mid-fan-delta are undeveloped. On the lower fan-delta, however, portions of the community of Edgewood could be affected by bank erosion to the south in the tall escarpment of glaciofluvial sediments over time.
Auxiliary Hazards	• Bank erosion along the high glaciofluvial deposits could lead to isolated deeper seated landsliding. • Uncontrolled and concentrated runoff from the uplands on which Edgewood is situated could lead to severe gullying of the escarpment to the south • In case of a fan-delta apex avulsion and major flow redirection down the central avulsion channel on Eagle Creek fan-delta, substantial sediment volumes could be delivered to Inonoaklin Creek leading to localized flooding associated with Inonoaklin Creek.

6.6. Bank Erosion Assessment

The air photo assessment compared available air photos from 1939 to 2005 to determine the historical changes in channel width at the nine cross-sections considered in the bank erosion assessment. Table 6-9 summarizes the maximum channel width change between successive pairs of air photos at the cross-section at which it was observed. The maximum observed change in channel width between two successive air photos on Eagle Creek was 24 m, between 1995 and 2001 at cross-section 9 (see Drawings 02A, 02B for cross-section locations). To provide context for these values, the average current bankfull width is 40 m at the cross sections analyzed (Section 3.4). Potential error or uncertainty in these measurements may be introduced by shadows from vegetation, poor image quality, or stretching during rectification. BGC estimates the total error associated with the above factors is less than 5 m.

Table 6-9. Summary of channel width change for each air photo.

Air Photo Interval	Maximum Channel Width Change Between Photos (m)	Cross-Section of Maximum Channel Width Change (Drawings 02A, 02B)
1939-1945	5	5
1945-1952	19	9
1952-1964	11	8
1964-1969	19	8
1969-1976	12	2
1976-1990	6	4
1990-1995	1	8
1995-2001	24	9
2001-2005	13	4

A summary of the bank erosion model results by return period is outlined in Table 6-10. This table displays the minimum, maximum, and average erosion modelled across all cross-sections considered at each of the four return periods modelled. Cambio Communities shows bank lines indicating the 50% exceedance probability of the modelled erosion (i.e., the bank erosion that is predicted to be exceeded in 50% of the model runs) for each return period as two corridors: the likely erosion corridor and the potential/improbable erosion corridor.

Table 6-10. Summary of bank erosion model results by return period.

Return Period (years)	Minimum Erosion (m)	Average Erosion (m)	Maximum Erosion (m)
20	0	5	16
50	0	12	26
200	21	31	42
500	42	58	78

The potential/improbable erosion corridor shows the corridor outlining the full modelled erosion if it were applied to both banks. The likely erosion corridor scales the predicted erosion on either side of the channel based on the elevation of the surrounding terrain; if the elevation of the surrounding terrain is high relative to the channel elevation, for example, then the predicted erosion distance decreases to account for the larger volume of material that would need to be eroded (Section 2 of Methodology Report (BGC, March 31, 2020b)). Both the potential/improbable and likely erosion corridors account for the inherent uncertainty in assigning erosion to a particular bank.

Figure 6-2 shows the 50% percentile modelled bank erosion at each cross-section. The predicted erosion differs between cross-sections based on the cross-section characteristics (e.g., channel geometry, channel slope, D_{84} grain size). Of note is that the predicted bank erosion is relatively high at cross-sections 3 and 4 compared to other sections for all return periods. This area is not currently developed, being located approximately 1 km upstream from the current development.

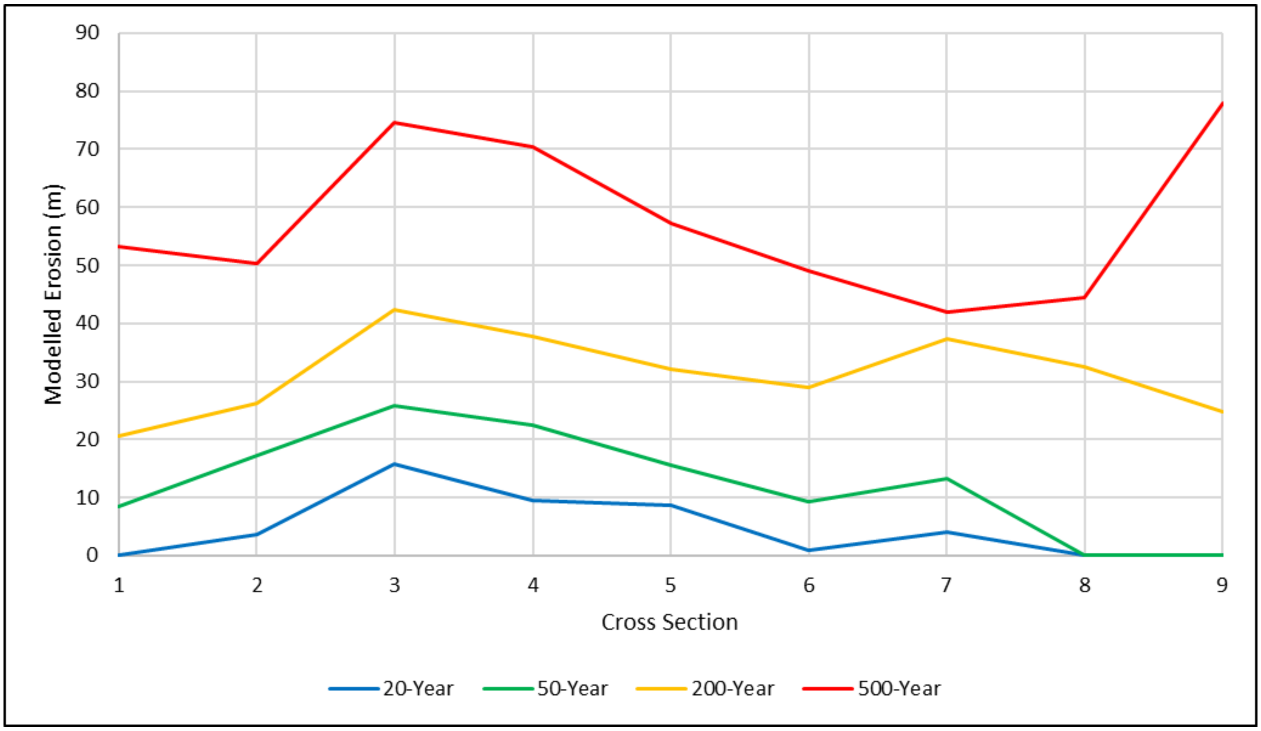


Figure 6-2. Eagle Creek 50th percentile bank erosion model results at each cross-section.

For the 500-year return period debris flood, modelled erosion is greatest at cross-section 9, located adjacent to Monashee Avenue. The potential erosion could impact Monashee Avenue and the properties along it; however, the likely erosion of the left bank is 3 m at this location. Longer-term progressive erosion could also impact this location.

6.7. Hazard Mapping

Drawing 07 provides a representative hazard scenario map for the 200-year return period. Drawing 08 provides a composite hazard rating map showing the maximum extent of all hazard scenarios.

As noted in Section 5.6, hazard ratings shown on the composite hazard rating map reflect categorization applicable to a wide range of hazard types, from clearwater floods to large landslides. The choice of categorization may affect interpretation by the map user and is subject to review and discussion with RDCK.

The composite hazard rating map demonstrates that the majority of the active fan-delta of Eagle Creek is located within the yellow (low) hazard area. On the southern end of the fan, flow is generally confined to the active floodplain. When the Worthington Creek FSR bridge is blocked near the fan apex, it causes an avulsion to the north where the flow spreads and follows numerous paleochannels. The orange (moderate) and red (high) hazard areas are confined to the main channel and one avulsion path to the north. The dotted zones indicate areas that will likely be inundated with sediment up to 1 m deep outside the active channel and up to 3 m in the active channel.

7. SUMMARY AND RECOMMENDATIONS

7.1. Introduction

This report and appendices provide a detailed hazard assessment of the Eagle Creek fan-delta. This creek was chosen as a high priority creek amongst hundreds in the RDCK due to its comparatively high risk. This report has resulted in digital hazard maps that provide the backbone of any eventual quantitative risk assessment. It also provides the basis to inform the conceptualization and eventual design and construction of mitigation measures should those be found to be required for Eagle Creek.

A variety of analytical desktop and field-based tools and techniques were combined to decipher Eagle Creek's geomorphological and hazard history, its hydrology and hydraulics.

7.2. Summary

7.2.1. Air Photo Interpretation, Dendrogeomorphology and Test Pitting

These techniques were completed to gain an understanding of watershed and channel changes on the fan-delta and help with the construction of an F-M relationship. Some highlights from these analyses are:

- The largest debris flood occurred between 1948 and 1968 as 1968 air photos show an area of freshly deposited debris of approximately 240,000 m^2.
- Dendrochronological investigations are not extensive enough to provide results usable for the development of the F-M curve.
- Test pitting primarily confirmed that the central portion of the Eagle Creek fan-delta can be classified as a paleofan as near surface (< 1.2 m depth) radiocarbon dates were in the thousands of years before present. From a fan-delta-activity point of view, this confirms that the overall location of Edgewood is, apart from bank erosion issues, subject to low hazards.
- At least five notable hydrogeomorphic events have occurred since 1894. BGC interprets that all the noted events are likely Type 1 debris flood events due to their extensive erosion, avulsions and observed movement of sediment in air photos.

7.2.2. Peak Discharge Estimates

In recognition of the impacts of climate change and potential bedload and suspended sediment loads, the clearwater flows estimated from a regional FFA were adjusted. There are no reliable methods to predict sediment concentrations for streams in which those variables have not been measured, and hence sediment concentration estimates are associated with substantial uncertainty. Key findings from estimating peak discharges suitable for modelling are:

- The climate change impact assessment results were difficult to synthesise in order to select climate-adjusted peak discharges on a site-specific basis. Consequently, a 20% increase in peak discharge was adopted as per Section 4 of the Methodology Report (BGC, March 31, 2020b).

- The climate-change adjusted peak discharges for Eagle Creek range from 15 m^3/s (20-year flood) to 50 m^3/s (500-year flood).
- Sediment bulking factors of 1.02 (2% increase for the 20-year debris flood) to 1.3 (30% increase for the 500-year return period event) were adopted as input to numerical modelling.
- Consideration of climate change and sediment bulking increase the clearwater discharge estimate from 25 to 30 m^3/s for the 20-year debris flood, and from 40 to 70 m^3/s for the 500-year event.

7.2.3. Frequency-Magnitude Relationship

Frequency-magnitude relationships were constructed for peak discharges associated with those events as summarized in Table 7-1.

Table 7-1. Eagle Creek debris flood frequency-magnitude relationship.

Return Period (years)	Adjusted Peak Discharge (m^3/s)
20	30
50	35
200	50
500	70

7.2.4. Numerical Flood and Debris Flood Modelling

Two numerical models were employed to simulate the chosen hazard scenarios on the Eagle Creek fan-delta. The two models were complimentary, in that results could be compared to facilitate flexibility in the interpretation of results in consideration of the advantages and shortcomings of the individual models. Table 7-2 provides key observations derived from the numerical modelling.

Table 7-2. Key findings from numerical modelling of Eagle Creek debris floods.

Process	Key Observations
Clearwater inundation	• Eagle Creek remains channelized for all flows except the bridge blockage scenario that was modelled for return periods of 200 and 500 years. • Bridge blockage will result in the flow avulsing from its channel towards the northeast where it will preferentially follow existing paleochannels
Sedimentation	• Sedimentation will likely be confined to the existing channel and will concentrate in the fan-delta.
Auxiliary Hazards	• Bank erosion along the high glaciofluvial deposits may lead to isolated deeper seated landsliding. • Uncontrolled runoff from the uplands on which Edgewood is situated could lead to severe gullying of the escarpment to the south • In case of a fan-delta apex avulsion and major flow redirection down the central avulsion channel on Eagle Creek fan-delta, substantial sediment volumes could be delivered to Inonoaklin Creek leading to localized flooding associated with Inonoaklin Creek.

The multiple process numerical modelling ensemble approach demonstrates that the key hazards and associated risks at Eagle Creek stem from the potential of a bridge blockage at the fan-delta apex and subsequent dike breaches and avulsions.

7.2.5. Bank Erosion Assessment

A bank erosion assessment was completed because debris floods can be highly erosive, undercutting unstable banks and leading to bridge abutment scour or isolation, as well as undermining and eroding non-standard dikes. The key findings from the bank erosion assessment are:

- The predicted bank erosion compared well with the air photo record accounting for likelihood of a 50-year return period flood having occurred within the air photo record.
- Total bank erosion (both channel sides) is predicted to range between a maximum of 15 m for a 20-year debris flood event to approximately 80 m for a 500-year return period debris flood.
- Key locations in which bank erosion could lead to greater risk are near the fan-delta apex, where existing orphan dikes could be eroded and lead to avulsions down the northern and north-central portions of Eagle Creek fan-delta, and the lower north bank, where the erosion of a steep embankment could eventually encroach onto existing properties near the southern end of Monashee Avenue.

7.2.6. Hazard Mapping

Model results are cartographically expressed in two ways:

- The individual hazard scenarios are captured through an index of impact force that combines flow velocity, bulk density and flow depth for a nominal 1 m width flow path. These maps are useful for assessments of development proposals and emergency planning.
- A composite hazard rating map that combines the debris flood intensity (impact force) and frequency up to the 500-year return period event. This map is useful to designate hazard zones.

Both the individual scenario impact force hazard maps and the composite impact intensity frequency map serve as decision-making tools to guide subdivision and other development permit approvals.

7.3. Limitations and Uncertainties

While systematic scientific methods were applied in this study, some uncertainties prevail. As with all hazard assessment and concordant maps, the hazard maps prepared at Eagle Creek represent a snapshot in time. Future changes to the Eagle Creek watershed or fan-delta including the following may warrant re-assessment and/or re-modelling:

- Future fan-delta development
- Substantial flood or debris flood events
- Development of large landslides in the watershed with the potential to impound Eagle Creek
- Bridge re-design
- Alteration to the existing dikes near the fan-delta apex
- Substantial changes to Lower Arrow Lake levels
- Significant wildfire events in the watershed.

The assumptions made on changes in runoff due to climate change and sediment bulking, while well-reasoned, are not infallible and will likely need to be updated occasionally as scientific understanding of such processes evolves.

BGC recognizes that all hazard processes display some chaotic behaviour and therefore not all hazards or hazard scenarios can be adequately modelled. For example, unforeseen log jams may alter flow directions and create avulsions into areas not specifically considered in the individual hazard scenarios. Despite these limitations and uncertainties, BGC believes that a credible hazard assessment has been achieved on which land use decisions can be made.

7.4. Considerations for Hazard Management

Recommendations are provided in the Summary Report (BGC, March 31 2020a) as they pertain to all studied RDCK creeks. This section notes Eagle Creek-specific issues that could be considered in the short term given the findings of this report. They are purposely not named "recommendations" as those would come out of a more in-depth discussion on what potential losses due to debris flooding would be considered intolerable by the District. It would also require discussions with other stakeholders with assets on the Harrop Creek fan-delta.

Recommendations are provided in the Summary Report (BGC, March 31, 2020a) as they pertain to all studied RDCK creeks. This section notes Eagle Creek-specific issues that could be considered given the findings of this report. They are purposely not named “recommendations” as those would come out of a more in-depth discussion on what potential losses due to debris flooding would be considered intolerable by the District. It would also require discussions with other stakeholders with assets on the Eagle Creek fan-delta.

As for all steep creeks with high sediment transport potential, the following key considerations ought to be acknowledged when trying to achieve successful risk reduction for existing and future developments:

- Stopping organic and mineral debris near the fan apex to avoid downstream aggradation and concordant avulsions. This strategy, while being effective, is expensive and requires regular maintenance to remove debris from the basin area and thus maintain storage capacity. Stream downcutting downstream of the structure which follows when the creek is depleted from its sediment source upstream, can be avoided by allowing grains of a specific size to pass through the structure. This will also be beneficial for downstream fish habitat.
- Most creeks on fans and fan-deltas tend to be wide and laterally unstable. Forcing the creek in between berms flanking the creek narrowly on either side is undesirable. Deepening the channel through excavation in the absence of upstream sediment retention will invariably be followed by infill causing a cycle of expensive and potentially disruptive gravel excavations. Fortuitously, this is not required at Eagle Creek because on the north side it is flanked by a tall paleosurface and on the south side there is no development and the creek is (and should be) allowed to migrate freely.

Most of the existing development on the Eagle Creek fan-delta is situated on a paleosurface that protects much of the development from impact even in rare debris floods. The principal hazard and associated risk are derived from the potential for existing orphan dike erosion and breach on the north side of the fan apex. In that case large portions of the central and northern portion of Eagle Creek would be inundated with water and debris. Hence, an upgraded dike to prevent such avulsions will substantially decrease the likelihood of such occurrence.

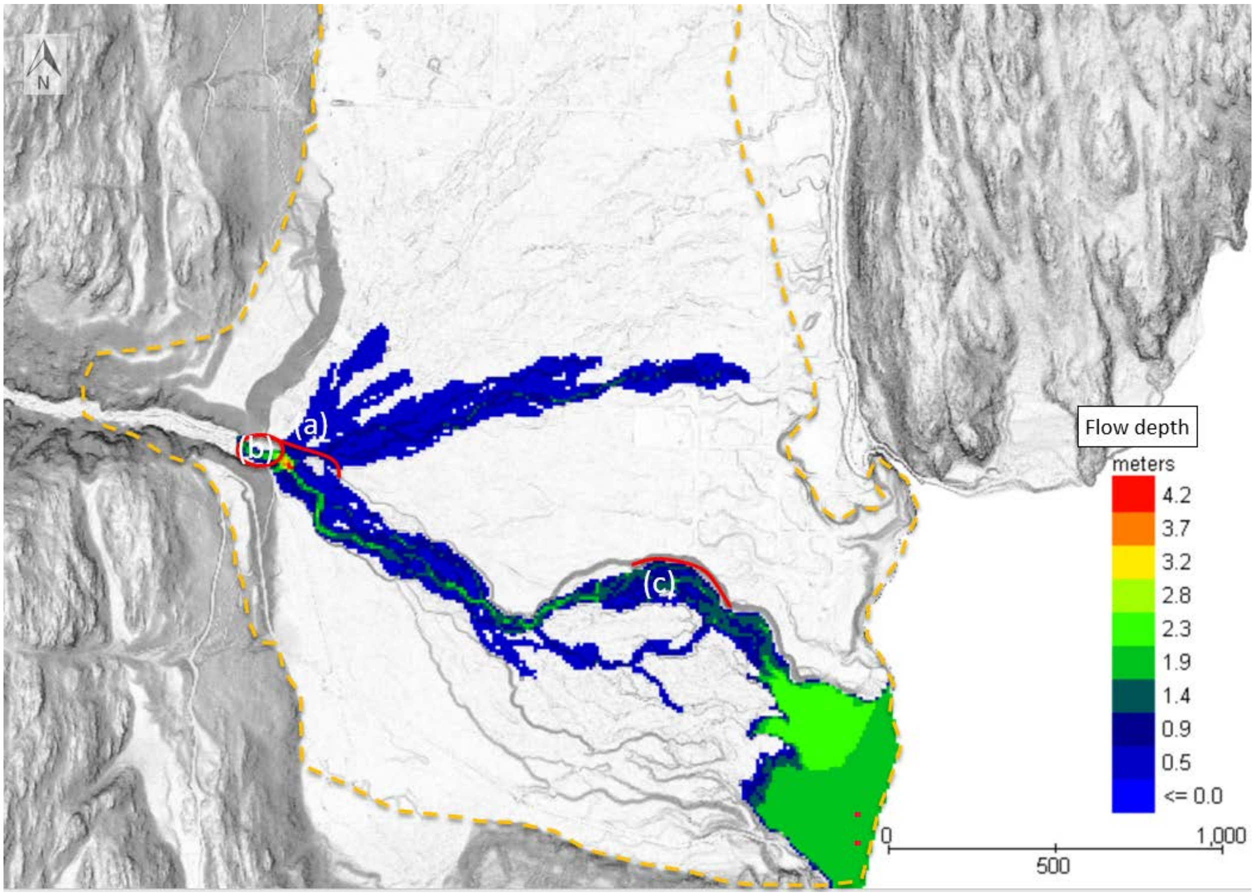


Figure 7-1. Debris-flood inundation map showing flow depths for a 200-year return period debris flood on Eagle Creek from FLO 2D modeling. The figure shows conceptual-level mitigation options for Eagle Creek fan-delta. Note that these mitigation options have not been tested by numerical modelling and only serve as an impetus for further discussion. Other options will likely be developed at the conceptual design level.

With reference to Figure 7-1, the following specific mitigation measures could be considered to reduce hazards and risks on Eagle Creek. Additional details is provided below.

Table 7-3. Mitigation considerations for Eagle Creek fan-delta

Option	Description	Effect on Flood Hazard Reduction
(a)	Update to an appropriately engineered deflection berm with substantial toe erosion protection	Substantial reduction in avulsion potential to the north
(b)	Bridge replacement with larger spans and appropriately protected abutments	Substantial reduction in bridge blockage or superstructure failure and hence reduced avulsion potential, plus maintenance of important access road
(c)	Upgrade of existing toe protection of steep paleosurface south of Eagle Crescent and Monashee Ave.	Reduction in bank erosion potential and paleofan surface retrogression

BGC understands that FLNRORD is currently considering a bridge replacement. BGC encourages the District to share the results of this report with FLNRORD to support the design of such a replacement.

The auxiliary hazard assessment suggests a potentially significant interaction of Eagle Creek in a northern avulsion scenario with Inonoaklin Creek whereby the latter could avulse in lower reaches due to excess sediment accumulations, which could lead to erosion of the eastern paleoflood banks. These processes are not modeled as such models are associated with too many uncertainties but ought to be considered in further development approvals.

The application of the composite hazard rating map requires discussions and regulatory decisions on which hazard zone is attributed to specific land use prescriptions, covenants, bylaws or other limiting clauses for both existing and proposed development.

Table 7-3 demonstrates that, compared to many of the other creeks examined as part of the larger detailed fan-delta study, existing development can be protected successfully with relatively minor effort.

In addition to the mitigation considerations listed above, several other measures are conceivable:

- Enforcement of channel erosion-related construction setbacks from top of bank to avoid undercutting of building foundations during debris floods.
- Establishment and enforcement of construction recommendations based on the composite hazard rating map and RDCK engineering guidelines for construction on alluvial fans. These could be fan-segment specific but would have to be refined for all new building permit applications by qualified professionals.

Given that funding for any of the measures listed in Table 7-3 is presently uncertain, the above two bullets could be implemented immediately irrespective of any future funding for more elaborate mitigation measures.

8. CLOSURE

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

Yours sincerely,

BGC ENGINEERING INC.
per:

Matthias Jakob, Ph.D., P.Geo.
Principal Geoscientist

Matthias Busslinger, M.A.Sc., P.Eng. (BC),
Senior Geotechnical Engineer

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

Reviewed by:

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

KH/HW/mjp/mm

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

REFERENCES

About ten miles of the Edgewood-Vernon road has been burned over. (1925, July 24). *Arrow Lakes News*.

Barlow, D. (1996, January 22). *Eagle Creek at Edgewood* [Letter]. Victoria, BC: British Columbia Ministry of Environment, Lands and Parks.

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: Flood Mapping Program* [Proposal]. Prepared for Regional District of Central Kootenay.

BGC Engineering Inc. (2019, June 20). *Consulting Services Agreement – RDCK Flood Hazard Risk Assessment* [Contract]. Prepared for Regional District of Central Kootenay.

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

BGC Engineering Inc. (March 31, 2020a). *Summary Report* [Report]. Prepared for the Regional District of Central Kootenay.

BGC Engineering Inc. (March 31, 2020b). *Steep Creek Assessment Methodology Report* [Report]. Prepared for the Regional District of Central Kootenay

Boyer, D. (1988, September). *Eagle Creek study* [Report]. Prepared for Water Management Branch.

British Columbia Ministry of Environment and Climate Change Strategy (n.d.). *Ground water wells* [GIS data]. Retrieved from https://catalogue.data.gov.bc.ca/dataset/ground-water-wells

British Columbia Ministry of Environment and Climate Change Strategy (2016). TEI – Data distribution packages [GIS data]. Retrieved from https://catalogue.data.gov.bc.ca/dataset/terrestrial-ecosystem-information-tei-data-distribution-packages/resource/93e33397-bea0-4dd5-bffc-6fd854643f82

British Columbia Ministry of Environment, Lands and Parks. (1994, September 22). *Site inspection: D.L. 102: Eagle Creek* [Memo]. Nelson, BC: Author.

British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development (n.d.) Fire perimeters - Historical [GIS data]. Retrieved from https://catalogue.data.gov.bc.ca/dataset/fire-perimeters-historical

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

Cesca, M., & D'Agostino, V. (2008). Comparison between FLO-2D and RAMMS in debris-flow modelling: a case study in the Dolomites. *Monitoring, Simulation, Prevention and Remediation of Dense Debris Flows II*. doi: 10.2495/deb080201

Church, M. & Jakob, M. (2020). What is a debris flood? Submitted to Water Resources Research.
Columbia Basin Trust (CBT). (2017). *Water Monitoring and Climate Change in the Upper Columbia Basin – Summary of Current Status and Opportunities*.

Cui, Y., Miller, D., Nixon, G., & Nelson, J. (2015, February). *British Columbia digital geology* [GIS data]. Retrieved from the British Columbia Geological Survey website: https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/geology/bcdigitalgeology

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

Edgewood History Book Committee. (1991). *Just where is Edgewood?* Edgewood, BC: Author.

Edgewood near isolation: House evacuated. (1948, June). *Arrow Lakes News*.

Edgewood-Vernon culverts go. (1925, July). *Arrow Lakes News*.

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

Environment and Climate Change Canada. (n.d.). *Canadian Climate normals 1981-2010 Station Data – Fauquier* [Data]. Extracted August 14, 2019, from the Environment and Climate Change Canada Canadian Climate Normals website: http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?searchType=stnName&txtStationName=fauquier&searchMethod=contains&txtCentralLatMin=0&txtCentralLatSec=0&txtCentralLongMin=0&txtCentralLongSec=0&stnID=1117&dispBack=1

Farjan, B., Gupta, A., and 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.

FLO-2D Software, Inc. (2017). FLO-2D Reference Manual. Build No. 16 January 2017.

Fulton, R.J., & Smith, G.W. (1978). Late Pleistocene stratigraphy of south-central British Columbia. *Canadian Journal of Earth Sciences, 15*, 971-980.

Fulton, R.J., Warner, B.G., Kubiw, H.J., & Achard, R.A. (1989). Geology and paleoecology of early Holocene lacustrine deposits in the Columbia River valley near Fauquier, southern British Columbia. *Canadian Journal of Earth Sciences*, *26*, 257-265.

Government of British Columbia. (2020). *Flood Protection Structures in B.C.* Internet webpage. URL last accessed February, 2020: https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/drought-flooding-dikes-dams/integrated-flood-hazard-management/dike-management/flood-protection-structures

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.

Holland, S.S. (1976). *Landforms of British Columbia – A physiographic outline* (Bulletin 48). Victoria, BC: British Columbia Department of Mines and Petroleum Resources.

Holm, K., Jakob, M., Scordo, E., Strouth, A., Wang, R., & Adhikari, R. (2016). Identification, Prioritization, and Risk Reduction: Steep Creek Fans Crossed by Highways in Alberta. *GeoVancouver 2016.* Vancouver, Canada.

Horizon Geotechnical Ltd. (2005, April 18). *Geotechnical assessment of flood plain proposed building site for modular home Lot A, Plan NEP 21088, DL 183A, ODYD PID 018-642-233, Edgewood, B.C.* [Report for Precondition for Building Permit]. Prepared for Michael Quigley and Barbara Quigley.

Horizon Geotechnical Ltd. (2010, August 18). *Geotechnical assessment of flood plain proposed addition to store Lot 16, Plan 6069, DL 183A, Parcel A, Except Plan 7776 217 Lakeshore Ave, Edgewood, B.C.* [Report for Precondition for Building Permit]. Prepared for Edgewood General Store Ltd.

Inonoaklin River cuts new course. (1948, June). *Arrow Lakes News*.

Jakob, M. (2005). Debris-flow hazard analysis. In M. Jakob, and O. Hungr (Ed.), *Debris-flow Hazards and Related Phenomena* (pp. 411-437). Berlin, Germany: Springer-Verlag Berlin and Heidelberg GmbH & Co.

Kline, B. (2018, August 23). Evacuation alerts issued as Kootenay fires grow. *Castlegar News*.

Kline, B. (2018, August 30). Edgewood on evacuation notice due to wildfire. *Arrow Lakes News*.

Klohn Crippen Consultants Ltd. (1998, February 23). Alluvial and debris fan inventory, Kootenay Region. Fan code: 82E/16_004.

Lau, CA. (2017). *Channel scour on temperate alluvial fans in British Columbia* (Master's thesis). Simon Fraser University, Burnaby, BC. Retrieved from http://summit.sfu.ca/item/17564.

Loukas, A., and Quick, M.C. (1999). The effect of climate change on floods in British Columbia. Nordic Hydrology 30: 231-256.

McMurray, J. (2007, May 9). BC Hydro repairs Eagle Creek berm near Edgewood. *Arrow Lakes News*.

Ministry of Forests, Lands, Natural Resources Operations and Rural Development (n.d.). *Harvested areas of BC (Consolidated Cutblocks)* [GIS data]. Retrieved from https://catalogue.data.gov.bc.ca/dataset/harvested-areas-of-bc-consolidated-cutblocks-#edc-pow

Ministry of Forests, Lands, Natural Resources Operations and Rural Development (n.d.). *Fire perimeters – historical* [GIS data]. Retrieved from https://catalogue.data.gov.bc.ca/dataset/fire-perimeters-historical

Ministry of Transportation and Infrastructure (MoTI). (2019). Historical DriveBC Events [Database]. Retrieved from https://catalogue.data.gov.bc.ca/dataset/historical-drivebc-events

Mitchell, T.D. & Jones, P.D. (2005). An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *International Journal of Climatology, 25*(6), 693-712. https://doi.org/10.1002/joc.1181

Nakusp & District Chamber of Commerce. (2020). Edgewood. Retrieved from http://nakusparrowlakes.com/visiting/about-the-area/edgewood/

Nelson Star. (2013, June 20). UPDATE: Kootenay homes damaged by Hamill Creek flood. *Nelson Star.*

Nelson Star (2014, Feb 30). Edgewood was once Killarney. *Nelson Star.* Retrieved from https://www.nelsonstar.com/community/edgewood-was-once-killarney/

Okanagan Nation Alliance. (2017, April). *Eagle Creek feasibility assessment: Improving Kokanee access to spawning habitat in Eagle Creek (2016-2017)* [Report]. Prepared for Fish and Wildlife Compensation Program.

Orlando, A. (2007, May 9). Peterson wants Edgewood's flood plain status removed. *Arrow Lakes News*, pp. 1-2, 16.

Orlando, A. (2007, March 7). Residents concerned about flood potential at Edgewood. *Arrow Lakes News*.

Mitchell, T. D., & Jones, P. D. (2005). An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *International Journal of Climatology: A Journal of the Royal Meteorological Society, 25*(6), 693-712.

Perdue Geotechnical Services Ltd. (2008, August 11). *Natural hazard assessment Lot 11, Plan 7712, Section 13, Township 71, Kootenay District* [Report for Precondition for Building Permit]. Prepared for Gordon Tetroe.

Perdue Geotechnical Services Ltd. (2010, October 23). *Natural hazard assessment Parcel A (Explanatory Plan 7776) of Lot 16, District Lot 183A, Plan 6069, Kootenay District* [Report for Precondition for Building Permit]. Prepared for Chris Davidson.

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.*

Public Safety Canada (n.d.). *The Canadian disaster database* [GIS data]. Retrieved from https://www.publicsafety.gc.ca/cnt/rsrcs/cndn-dsstr-dtbs/index-en.aspx

Regional District of Central Kootenay (RDCK). (2019). Edgewood Water System. Retrieved from https://rdck.ca/EN/main/services/water/rdck-water-systems/edgewood-water-system.html

Rilkoff, S.W. (1997, May 30). *Lot 1, Sec. 13, Tp. 71, K.D., Plan 6315 MacCreadie residence, Edgewood townsite* [Report for Precondition for Building Permit]. Prepared for Lockland MacCreadie.

Road disappears ahead of Inonoaklin driver. (1948, June). *Nelson Daily News*.

Rossland Lands Department. (1912). *Indian Trails 1912 – showing Inonoaklin Valley area* [Map].

Salway, A. A. (1986). *Water quality monitoring of twenty nine creeks in the Nelson Forest Region: Data presentation, analysis and recommendations* [Report]. Prepared for B.C. Ministry of Forests, Nelson region.

Schnorbus, M., Werner, A., and Bennett, K. (2014). Impacts of climate change in three hydrologic regimes in British Columbia, Canada. Hydrological Processes 28: 1170-1189.

Septer, D. (2007). *Flooding and landslide events: southern British Columbia, 1808-2006*. Victoria, British Columbia: Province of British Columbia, Ministry of Environment. Available from http://www.for.gov.bc.ca/hfd/library/documents/bib106111south1.pdf

Statistics Canada. (2016). Census Profile, 2016 Census [Webpage]. Retrieved from https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/details/page.cfm?Lang=E&Geo1=DPL&Code1=590126&Geo2=PR&Code2=24&Data=Count&SearchText=Edgewood&SearchType=Begins&SearchPR=01&B1=All&TABID=1

Tempelman-Kluit, D.J. (1989). *Geology, Penticton, British Columbia* [Map]. 1:250 000. Geological Survey of Canada, Map 1736A. Geological Survey of Canada.

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.

WD Modern Dimensions Design Inc. (2017, November 21). *Geotechnical investigation: MDD-17-033 – Edgewood Firehall, Edgewood BC* [Report for Precondition for Building Permit]. Prepared for Edgewood Volunteer Fire Department Society.

Woods Associates Engineering. (2000, October 3). *Landslide assessment, Edgewood, BC* [Letter report]. Prepared for Kala Groundwater Consulting, Ltd.

APPENDIX A
TERMINOLOGY

Table A-1 provides defines terms that are commonly used in geohazard assessments. BGC notes that the definitions provided are commonly used, but international consensus on geohazard terminology does not fully exist. **Bolded terms** within a definition are defined in other rows of Table 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
Elements at Risk (E)	This term is used in two ways: a) To describe things of value (e.g., people, infrastructure, environment) that could potentially suffer damage or loss due to a **geohazard**. b) For risk analysis, as a measure of the value of the elements that could potentially suffer damage or loss (e.g., number of persons, value of infrastructure, value of loss of function, or level of environmental loss).	BGC
Encounter Probability	This term is used in two ways: a) **Probability** that an event will occur and impact an element at risk when the element at risk is present in the **geohazard** zone. It is sometimes termed **"partial risk"** b) For quantitative analyses, the **probability** of facilities or vehicles being hit at least once when exposed for a finite time period L, with events having a **return period** T at a location. In this usage, it is assumed that the events are rare, independent, and discrete, with arrival according to a statistical distribution (e.g., binomial or Bernoulli distribution or a Poisson process).	BGC
Erosion	The part of the overall process of denudation that includes the physical breaking down, chemical solution and transportation of material.	Oxford University Press (2008)

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

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

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

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

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

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

REFERENCES

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

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

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

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

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

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

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

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

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

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

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

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

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

APPENDIX B
SITE PHOTOGRAPHS

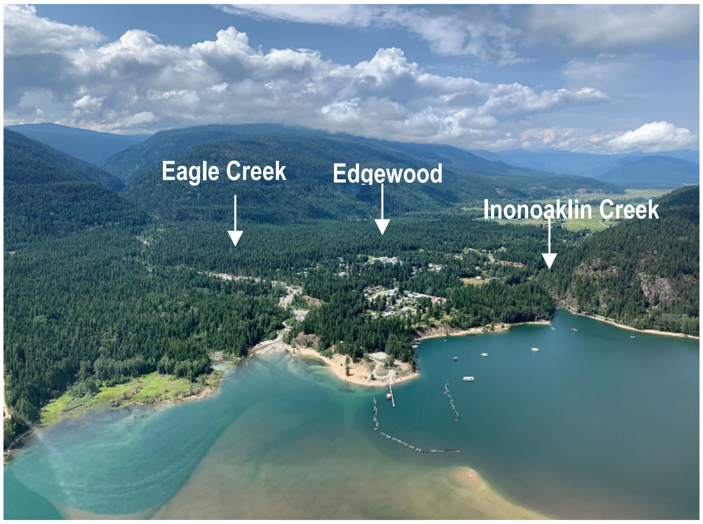


Photo 1.

Eagle Creek fan – delta looking northwest with the community of Edgewood and channel outlet at Lower Arrow Lake. Inonoaklin Creek is flowing into Lower Arrow Lake from the right. Photo: BGC, July 6, 2019.

Photo 2.

Overview of the Eagle Creek alluvial fan and the community of Edgewood. Looking southeast at Eagle Creek outlet into Lower Arrow Lake. Photo: BGC, July 6, 2019.

Photo 3.

Overview from helicopter, looking north at the northern margin of the Eagle Creek alluvial fan and the Inonoaklin Creek floodplain. Photo: BGC, July 6, 2019.

Photo 4.

Eagle Creek alluvial fan, looking northeast at with the aggraded reach of the channel, and the outlet at Lower Arrow Lake. Photo: BGC, July 6, 2019.

Photo 5.

Looking north at a recent landslide in presumably fluvioglacial or till sediments in the upper watershed, approximately 13 km upstream of the fan apex and El. 1500 m. Photo: BGC, July 6, 2019.

Photo 6.

Looking north at a recent landslide in presumably fluvioglacial or till sediment in the central watershed approximately 8 km upstream of the fan apex and 1000 masl. Photo: BGC, July 6, 2019.

Photo 7.

Photo from helicopter overflight looking northwest at a recent landslide in the central watershed approximately 8 km upstream of the fan apex, and El. 1000 m. Stratification in the upper escarpment suggests fluvioglacial sediments, possibly overlying till. Photo: BGC, July 6, 2019.

Photo 8.

Standing at top of approximately 15 m high left bank looking upstream (northwest). The bank is comprised of a 0.3 m thick soil horizon overlying fluvial gravel and cobbles in a sandy matrix. The bank is presumably a paleo - river terrace. Photo: BGC, July 23, 2019.

Photo 9.

Standing at top of approximately 15 m high bank looking downstream (southeast) at the aggraded reach of Eagle Creek in the alluvial fan. The active floodplain is approximately 30 m wide at this location, and the bank is presumably a paleo – river terrace. Photo: BGC, July 23, 2019.

Photo 10.

The Forest Service Road bridge near the fan apex partially obstructed by a half-fallen birch tree. Bridge is constructed of steel beams and railway ties and supported by timber retaining walls on either side of bridge. Looking upstream (northwest). Cross Section EGL-01 was taken under the bridge. Photo: BGC, July 23, 2019.

Photo 11.

Standing on the active fan delta, approximately 200 m from the shoreline. Looking downstream (southeast) at Wolman count location and channel outlet at Lower Arrow Lake. Photo: BGC, July 23, 2019.

Photo 12.

Standing on a gravel bar to the right (west) of the Eagle Creek channel approximately 500 m upstream of the outlet to Lower Arrow Lake. Looking at aggraded reach of channel with cobble and gravel bars. The active (unvegetated) floodplain width is approximately 65 m. Photo: BGC, July 23, 2019.

APPENDIX C
SEDIMENT SIZE SAMPLING

C.1. SAMPLING LOCATIONS

At Eagle Creek, two Wolman Samples were taken, one just downstream of the fan apex, and the other near the confluence with Lower Arrow Lake. The sampling locations (referred to as Eagle 1 and Eagle 2) are shown in Figure C-1 and in Table C-1. Bed material conditions at each site are shown on Figure C-2, and Figure C-3.

Table C-1. Wolman sampling locations.

Site Name	Eagle 1	Eagle 2
Location	Downstream of fan apex	Confluence with Lower Arrow Lake
Longitude	118° 9'52.22"W	118° 8'30.67"W
Latitude	49°46'50.16"N	49°46'25.29"N
Number of stones measured	98	138

Figure C-1. Wolman sampling locations along Eagle Creek. Google Earth image of September 4, 2019.

Figure C-2. Photograph taken of Wolman sampling location Eagle 1. BGC photograph of November 18, 2019.

Figure C-3. Photograph taken of Wolman sampling location Eagle 2. BGC photograph of July 23, 2019.

At the Eagle 1 sampling location, the measuring tape was 30 m long and samples were randomly selected at intervals of 30 cm. At the Eagle 2 sampling location, the measuring tape was 70 m long and samples were randomly selected at intervals of 50 cm.

C.2. RESULTS

The results of the Wolman counts are shown in Table C-2 and on Figures J-4 and J-5.

Table C-2. Eagle Creek sediment distribution from Wolman Count Data.

Grain Size	Eagle 1	Eagle 2
D95 (mm)	233	176
D84 (mm)	188	126
D50 (mm)	66	34
D15 (mm)	18	<2
D5 (mm)	<2	<2

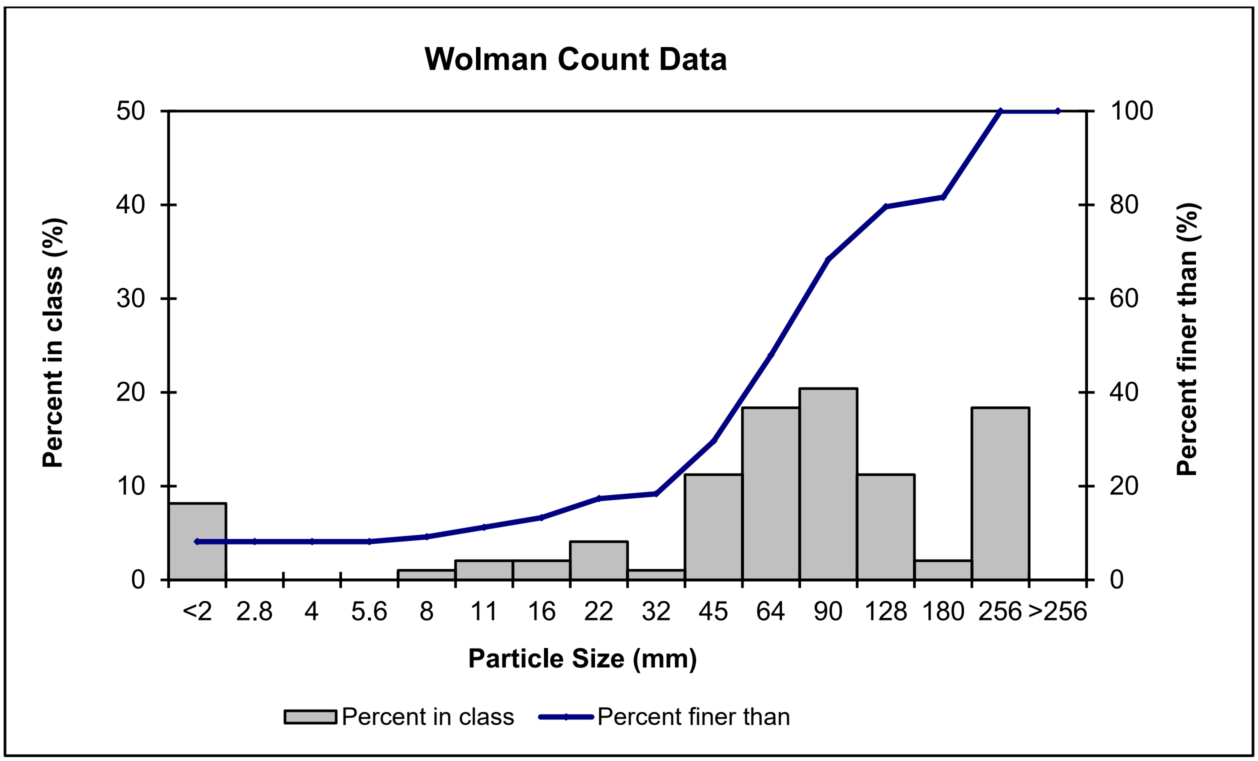


Figure C-4. Eagle Creek grain size distribution at Eagle 1 (downstream of fan apex) from Wolman count.

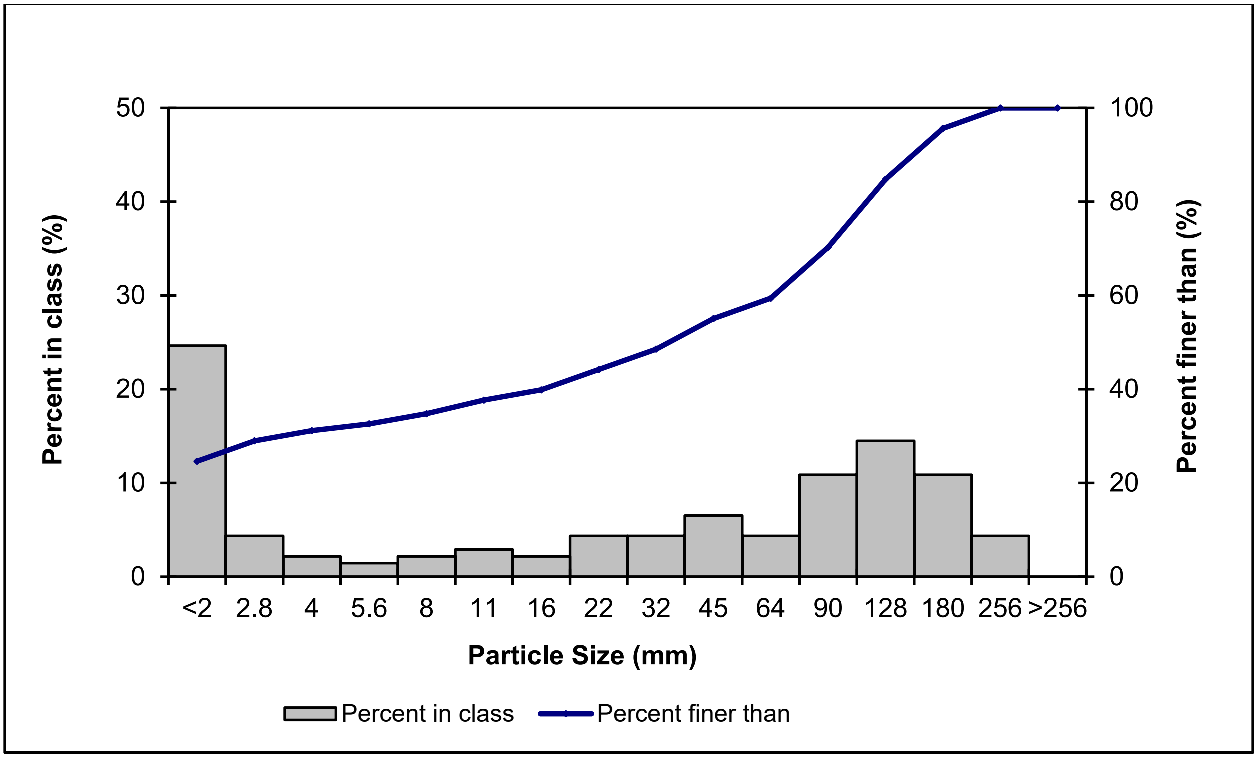


Figure C-5. Eagle Creek grain size distribution at Eagle 2 (confluence with Columbia River) from Wolman count.

As expected, given the reduction in channel gradient, bed material size decreases in a downstream direction along the fan. In order to predict sediment size distributions at locations not sampled, linear interpolation between the D_{84} values collected at the sampling locations and distance from fan apex was used.

APPENDIX D
AIR PHOTO RECORDS

Table D-1 presents air photo records from the Eagle Creek analysis.

Table D-1. Eagle Creek air photo records.

Year	Date	Roll Number	Photo Number	Scale
2011	8/7/2011	BCD11204	125-120, 237-240	20,000
2005	7/20/2005	BCC05004	31-35, 100-102	20,000
2004	7/14/2004	BCC04014	13-15	30,000
2001	7/10/2001	BCC01008	96-97	35,000
2000	8/22/2000	BCB00032	246-249	35,000
1998	9/27/1998	BCC98058	96-100, 112-116, 80-84	10,000
1997	9/8/1997	BCB97093	36-39, 57-61	15,000
1995	9/24/1995	BCC95113	17-22, 34-39, 69-72	10,000
	9/24/1995	BCB95032	124-125, 201-202	15,000
1990	9/9/1990	BCB90134	73-75, 20-24	15,000
1982	8/24/1982	BC82035	13-Dec	54,000
1976	7/15/1976	BC7853	94-95	20,000
1974	9/12/1974	BC7677	200-205, 213-217	15,000
	10/8/1974	BC5636	82-85	12,000
	10/8/1974	BC7692	292-300, 280-286	6,000
1972	3/8/1972	BC5503	24-26	32,000
1969	5/9/1969	BC5326	120-121, 135-136	32,000
1968	7/30/1968	BC5299	239-240	32,000
1966	7/29/1966	BC4377	234	15,840
1964	7/20/1964	BC4242	246-250, 234-237	15,840
	8/7/1964	BC4257	117-118	15,840
1952	7/30/1952	BC1530	2-3, 5	31,680
1945	9/27/1945	A9508	61, 64	25,000
1939	8/1/1939	BC164	34-35	31,680

APPENDIX E
TEST PIT DETAILED LOGS AND PHOTOGRAPH LOGS

TP-BGC19-EGL-01

Project: RDCK Floodplain and Steep Creek Study | **Location** : Edgewood, BC | **Project No.** : 0268007

Survey Method : GPS
Coordinates : 416,692.E, 5,515,108.N
Ground Elevation (m) :490
Datum : NAD83

Start Date : 25 Jul 19
Finish Date: 25 Jul 19
Final Depth of Pit (m) : 3.0
Logged by : CAL/BCP
Reviewed by : N/A

Depth (m)	Symbol	Sample Material for Dating	Sample Age	Lithologic Description
0				Duff layer removed.
				UNIT 1: PALEOSOL Sand, medium, trace cobbles, gap graded, loose, rounded to subrounded, orange brown, moist, homogeneous.
				UNIT 2: DEBRIS FLOOD DEPOSIT Gravel and sand, with cobbles, trace boulders, well graded, loose, subrounded, tan, dry, homogeneous, no cementation, Dmax = 20 cm.
1				
				UNIT 3: DEBRIS FLOOD DEPOSIT Gravel and sand, coarse, with cobbles and boulders, well graded, loose, subangular to subrounded, tan, dry, homogeneous, no cementation. Dmax=60 cm, D90 = 40 cm, D50 = 60 cm.
2				
3				END OF TEST PIT 3.0 m.
4				

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

Client: RDCK

TP-BGC19-EGL-02

Project: RDCK Floodplain and Steep Creek Study | ***Location*** : Edgewood, BC | ***Project No.*** : 0268007

Survey Method : GPS
Coordinates : 417,633.E, 5,515,686.N
Ground Elevation (m) :458
Datum : NAD83

Start Date : 25 Jul 19
Finish Date: 25 Jul 19
Final Depth of Pit (m) : 2.9
Logged by : CAL/BCP
Reviewed by : N/A

Depth (m)	Symbol	Sample Material for Dating	Sample Age	Lithologic Description
0				Modern soil horizon removed.
				UNIT 1: FLUVIAL DEPOSIT Sand, medium to coarse, and gravel, well graded, loose, subrounded to subangular, brown, moist, homogeneous.
				UNIT 2: FLUVIAL DEPOSIT Sand, medium, uniformly graded, loose, tan, dry, lightly laminated within medium-grained sand lenses of charcoal
		GS-1 Charcoal w. paleosol (0.55 m)	550 - 658 cal BP	PALEOSOL Sand, fine, dark grey, compact, 2% charcoal.
				UNIT 2: FLUVIAL DEPOSIT (as above)
1				UNIT 3: FLUVIAL DEPOSIT Gravel and sand, well graded, loose, subrounded, tan, clast supported.
				UNIT 4: FLUVIAL DEPOSIT Sand, medium to coarse, trace gravel, well graded, loose, tan, dry, laminated.
2				UNIT 5: DEBRIS FLOOD DEPOSIT Gravel and sand, some cobbles, well graded, subrounded, loose, tan and mottled orange, dry, homogeneous, D50 = 10 cm, Dmax = 15 cm.
3				END OF TEST PIT 2.9 m.
4				

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

Client: RDCK

TP-BGC19-EGL-03

Project: RDCK Floodplain and Steep Creek Study **Location** : Edgewood, BC **Project No.** : 0268007

Survey Method : GPS
Coordinates : 417,674.E, 5,515,029.N
Ground Elevation (m) :461
Datum : NAD83

Start Date : 25 Jul 19
Finish Date: 25 Jul 19
Final Depth of Pit (m) : 3.0
Logged by : CAL/BCP
Reviewed by : N/A

Depth (m)	Sample Material for Dating	Sample Age	Lithologic Description
0			Duff layer removed.
			UNIT 1: FLUVIAL DEPOSIT Sand, medium, uniformly graded, compact, medium brown to tan, moist, oxidized.
1			UNIT 2: FLUVIAL DEPOSIT Sand, fine, compact (stiffer than above), uniformly graded, tan, dry, homogeneous. Transitional contact with fluvial units above and below.
	GS-1 Charcoal (1.3 m)	2953 - 3156 cal BP	UNIT 3: FLUVIAL DEPOSIT Sand, coarse, uniformly graded, loose, dark orange for first 10 cm then becomes medium brown, dry, homogeneous.
2			UNIT 4: DEBRIS FLOOD DEPOSIT Gravel and sand, with cobbles, well graded, loose, subrounded to subangular, tan, dry, homogeneous, Dmax = 20 cm, D50 = 10 cm.
			UNIT 5: FLUVIAL DEPOSIT Sand, medium, uniformly graded, loose, medium brown, moist to dry, homogeneous, oxidized from 2.70 to 2.85 m.
3			END OF TEST PIT 3.0 m.
4			

TP-BGC19-EGL-04

Project: RDCK Floodplain and Steep Creek Study **Location** : Edgewood, BC **Project No.** : 0268007

Survey Method : GPS
Coordinates : 417,782.E, 5,515,753.N
Ground Elevation (m) :458
Datum : NAD83

Start Date : 25 Jul 19
Finish Date: 25 Jul 19
Final Depth of Pit (m) : 3.0
Logged by : CAL/BCP
Reviewed by : N/A

Depth (m)	Symbol	Sample Material for Dating	Sample Age	Lithologic Description
0				Topsoil removed 0.20 - 0.35 m: Mottled horizon
		GS-3 Charcoal (0.8 m)	4247 - 4429 cal BP	UNIT 1: FLUVIAL DEPOSIT Sand, fine to medium, uniformly graded, loose, tan, dry, stratified, no cementation.
1		GS-1 Charcoal (1.2 m) GS-2 Organics (1.2 m)	7576 - 7666 cal BP Not tested	UNIT 2: FLUVIAL DEPOSIT Sand, medium to coarse, uniformly graded, loose, tan, with some dark brown inclusions, dry, stratified, no cementation.
2				UNIT 3: FLUVIAL DEPOSIT Sand, medium, uniformly graded, loose, tan and mottled orange, dry, poorly stratified, no cementation.
				UNIT 4: DEBRIS FLOOD DEPOSIT Gravel and sand, well graded, loose, medium brown, dry, homogeneous, clast supported, Dmax = 7 cm, D50 = 5 cm.
				UNIT 5: FLUVIAL DEPOSIT Sand, medium to coarse, uniformly graded, loose, moist, homogeneous, highly oxidized.
3				END OF TEST PIT 3.0 m.
4				

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

Client: RDCK

TP-BGC19-EGL-05

Project: RDCK Floodplain and Steep Creek Study **Location** : Edgewood, BC **Project No.** : 0268007

Survey Method : GPS
Coordinates : 417,515.E, 5,515,239.N
Ground Elevation (m) :464
Datum : NAD83

Start Date : 25 Jul 19
Finish Date: 25 Jul 19
Final Depth of Pit (m) : 3.0
Logged by : CAL/BCP
Reviewed by : N/A

Depth (m)	Symbol	Sample Material for Dating	Sample Age	Lithologic Description
0				Reworked topsoil, possibly due to yard activities.
				UNIT 1: SAND Coarse, with gravel, rounded, tan, moist.
		GS-1 Paleosol (sand) (0.4 m)	Not tested	PALEOSOL Sand, fine, with gravel, possibly reworked, moist.
1				UNIT 1: DEBRIS FLOOD DEPOSIT Gravel and sand, coarse, with cobbles, well graded, loose, subrounded, medium brown, homogeneous, clast supported, no cementation, volcanic and granodioritic clasts, Dmax = 30 cm, D50 = 10 cm.
				SAND Discontinuous layer 10-20 cm thick, medium to coarse, trace gravel, trace cobbles, well graded, subrounded, loose, tan with some 1 cm thick black layers, no cementation.
2				UNIT 1: DEBRIS FLOOD DEPOSIT (as above)
3				END OF TEST PIT 3.0 m.
4				

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

Client: RDCK

TP-BGC19-EGL-Waterline-05

Project: RDCK Floodplain and Steep Creek Study ***Location*** : Edgewood, BC ***Project No.*** : 0268007

Survey Method : GPS
Coordinates : 417,053.E, 5,514,633.N
Ground Elevation (m) :478
Datum : NAD83

Start Date : 25 Jul 19
Finish Date: 25 Jul 19
Final Depth of Pit (m) : 1.0
Logged by : CAL/BCP
Reviewed by : N/A

Depth (m)	Symbol	Sample Material for Dating	Sample Age	Lithologic Description
0				Topsoil removed.
				UNIT 1: DEBRIS FLOOD DEPOSIT Gravel and sand, coarse to medium, some cobbles, well graded, subrounded, loose, brown, dry, homogeneous, fining downwards from clast supported to matrix supported, volcanic and granodioritic clasts, no fines, D50 = 10 cm, Dmax = 20 cm.
				UNIT 2: FLUVIAL DEPOSIT Sand, medium, uniformly graded, loose, rounded, light brown, dry, laminated, clasts consist of quartz, feldspars and hornblende (granodioritic), no weathering, no cementation.
1				END OF TEST PIT AT 0.95 m.
2				
3				
4				

TP-BGC19-EGL-Waterline-07

Project: RDCK Floodplain and Steep Creek Study ***Location*** : Edgewood, BC ***Project No.*** : 0268007

Survey Method : GPS
Coordinates : 417,165.E, 5,514,637.N
Ground Elevation (m) :475
Datum : NAD83

Start Date : 25 Jul 19
Finish Date: 25 Jul 19
Final Depth of Pit (m) : 1.0
Logged by : CAL/BCP
Reviewed by : N/A

Depth (m)	Symbol	Sample Material for Dating	Sample Age	Lithologic Description
0				Burn horizon, black and white with organics.
				UNIT 1: DEBRIS FLOOD DEPOSIT Gravel and sand, coarse to medium, some cobbles, well graded, subrounded, loose, brown, dry, homogeneous, fining downwards from clast supported to matrix supported, volcanic and granodioritic clasts, no fines, D50 = 10 cm, Dmax = 20 cm.
				UNIT 2: FLUVIAL DEPOSIT Sand, medium, uniformly graded, loose, rounded, light brown, dry, laminated, clasts consist of quartz, feldspars and hornblende (granodioritic), no weathering, no cementation.
1				END OF TEST PIT AT 1.00 m.
2				
3				
4				

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

Client: RDCK

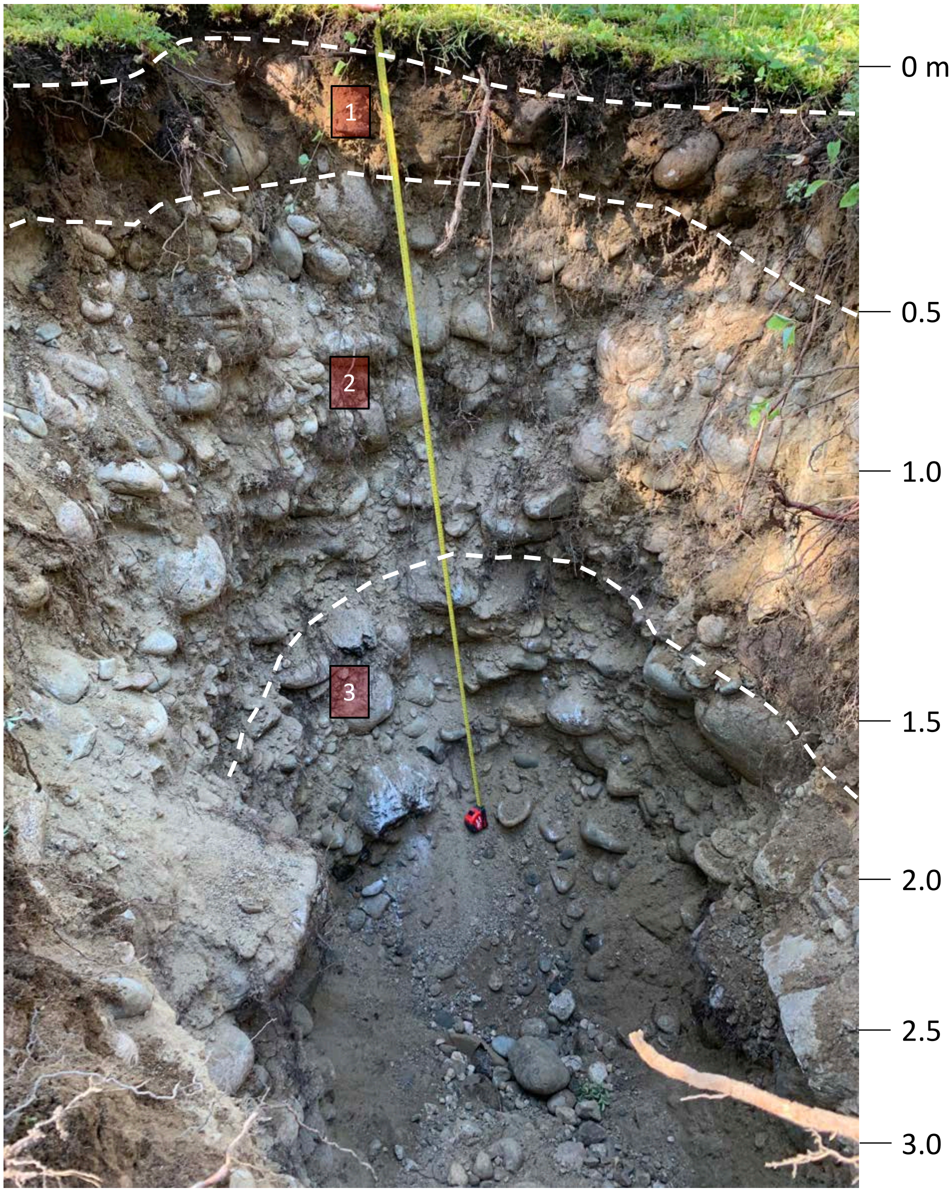
TP-BGC19-EGL-Waterline-08

Project: RDCK Floodplain and Steep Creek Study **Location** : Edgewood, BC **Project No.** : 0268007

Survey Method : GPS
Coordinates : 417,102.E, 5,514,636.N
Ground Elevation (m) :477
Datum : NAD83

Start Date : 25 Jul 19
Finish Date: 25 Jul 19
Final Depth of Pit (m) : 0.8
Logged by : CAL/BCP
Reviewed by : N/A

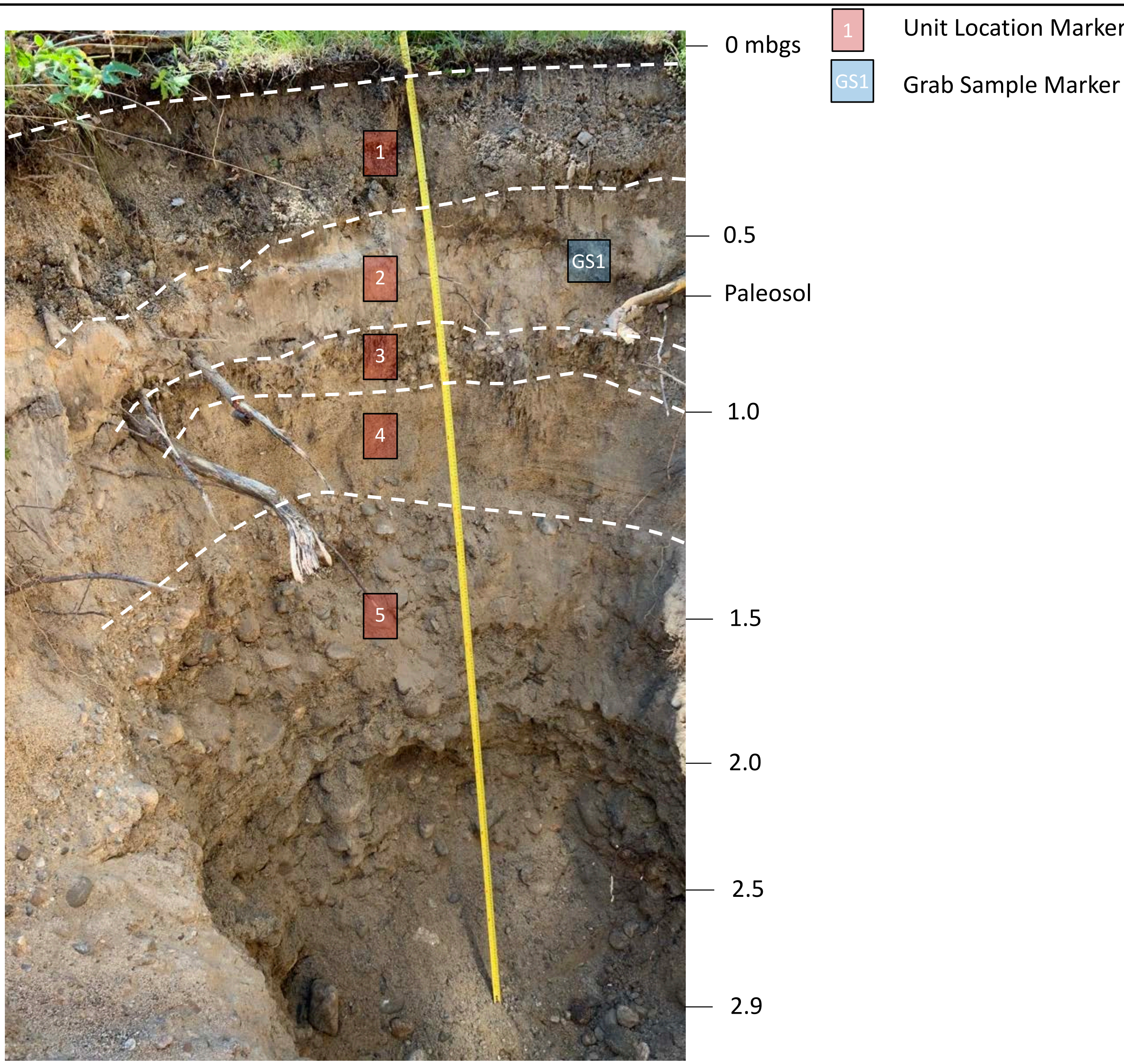
Depth (m)	Symbol	Sample Material for Dating	Sample Age	Lithologic Description
0				Burn horizon, black and white with organics.
				UNIT 2: FLUVIAL DEPOSIT Sand, medium, uniformly graded, loose, rounded, light brown, dry, laminated, clasts consist of quartz, feldspars and hornblende (granodioritic), no weathering, no cementation.
		GS-1 Charcoal (0.9 m, 8 m east in trench)	4570 - 4823 cal BP	UNIT 3: FLUVIAL DEPOSIT Sand, coarse, and gravel, fine to coarse (coarsens downwards), well graded, compact, subangular to subrounded, brown, moist, no cementation, gravel clasts are granodioritic and volcanic, Dmax = 12 cm, D50 = 5 cm.
				END OF TEST PIT AT 0.80 m.
1				
2				
3				
4				



1. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY – EAGLE CREEK" AND DATED FEBRUARY 2020.
2. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS FIGURE 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:	DATE: 02-2020	PREPARED BY: DB	CHECKED BY: BCP	APPROVED BY: CAL
REGIONAL DISTRICT CENTRAL KOOTENAY	BGC	REPORT TITLE: RDCK FLOODPLAIN AND STEEP CREEK STUDY – EAGLE CREEK		
		FIGURE TITLE: TP-BGC19-EGL-01		
		PROJECT NO: 0268-007	FIGURE NO: C-1	

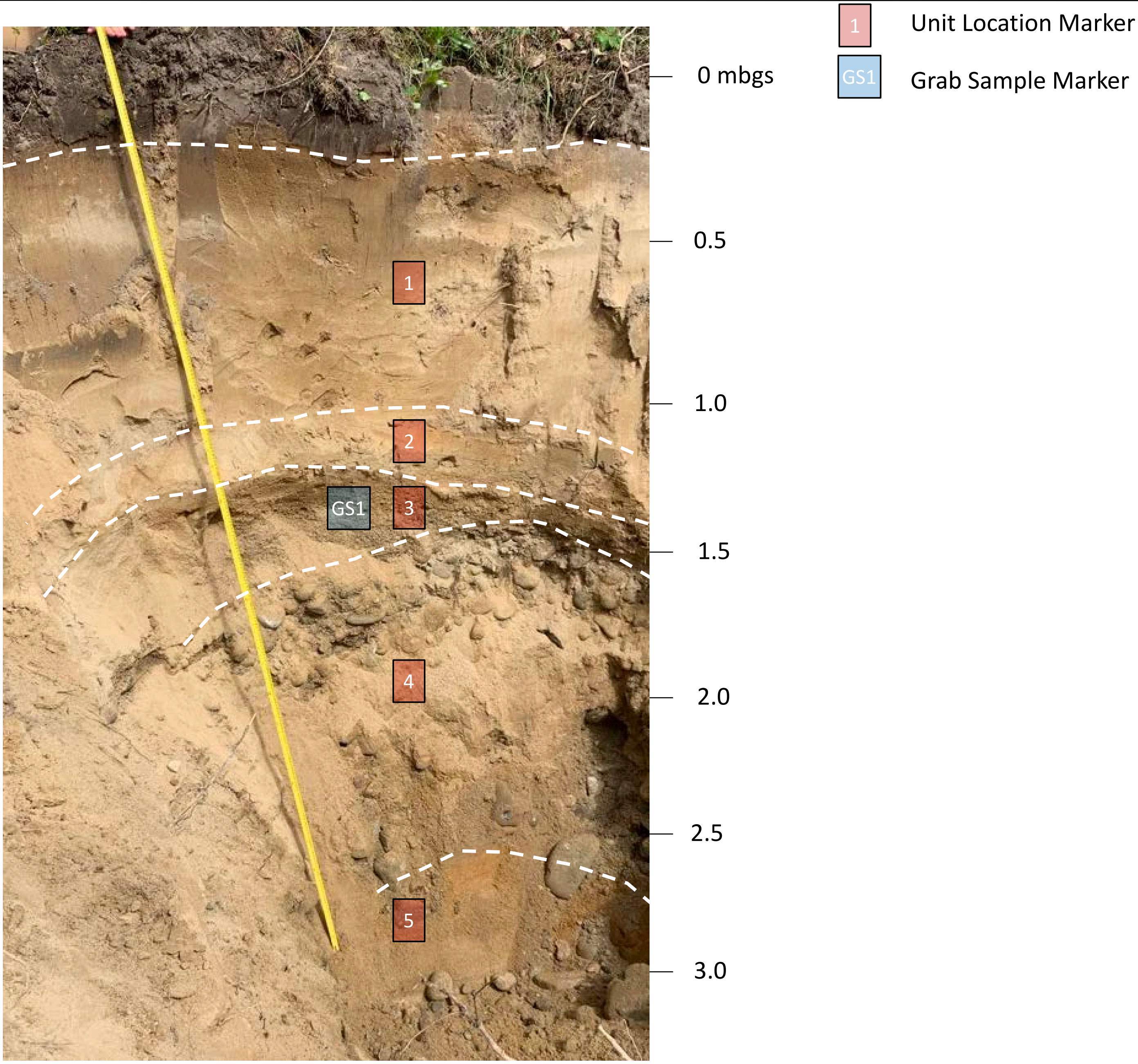
0 5 10mm in ANSI A sized paper



1. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY – EAGLE CREEK" AND DATED FEBRUARY 2020.
2. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS FIGURE 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:	DATE: 02-2020	PREPARED BY: DB	CHECKED BY: BCP	APPROVED BY: CAL
REGIONAL DISTRICT CENTRAL KOOTENAY	BGC	REPORT TITLE: RDCK FLOODPLAIN AND STEEP CREEK STUDY – EAGLE CREEK		
		FIGURE TITLE: TP-BGC19-EGL-02		
		PROJECT NO: 0268-007	FIGURE NO: C-2	

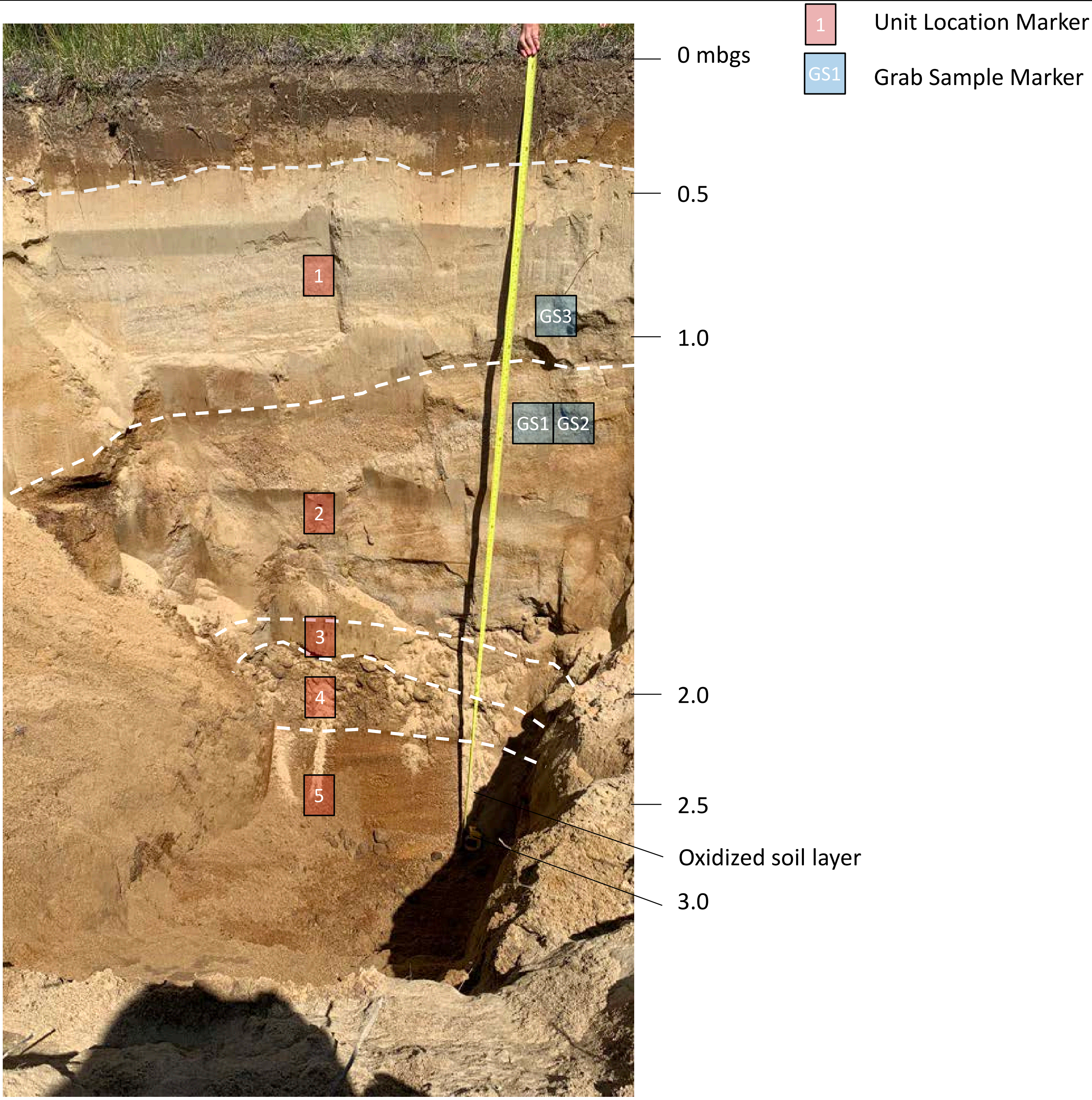
0 5 10mm in ANSI A sized paper



1. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY – EAGLE CREEK " AND DATED FEBRUARY 2020.
2. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS FIGURE 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:	DATE: 02-2020	PREPARED BY: DB	CHECKED BY: BCP	APPROVED BY: CAL
		REPORT TITLE: RDCK FLOODPLAIN AND STEEP CREEK STUDY – EAGLE CREEK		
		FIGURE TITLE: TP-BGC19-EGL-03		
		PROJECT NO: 0268-007	FIGURE NO: C-3	

0 5 10mm in ANSI A sized paper



1. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY – EAGLE CREEK " AND DATED FEBRUARY 2020.
2. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS FIGURE 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:	DATE: 02-2020	PREPARED BY: DB	CHECKED BY: BCP	APPROVED BY: CAL

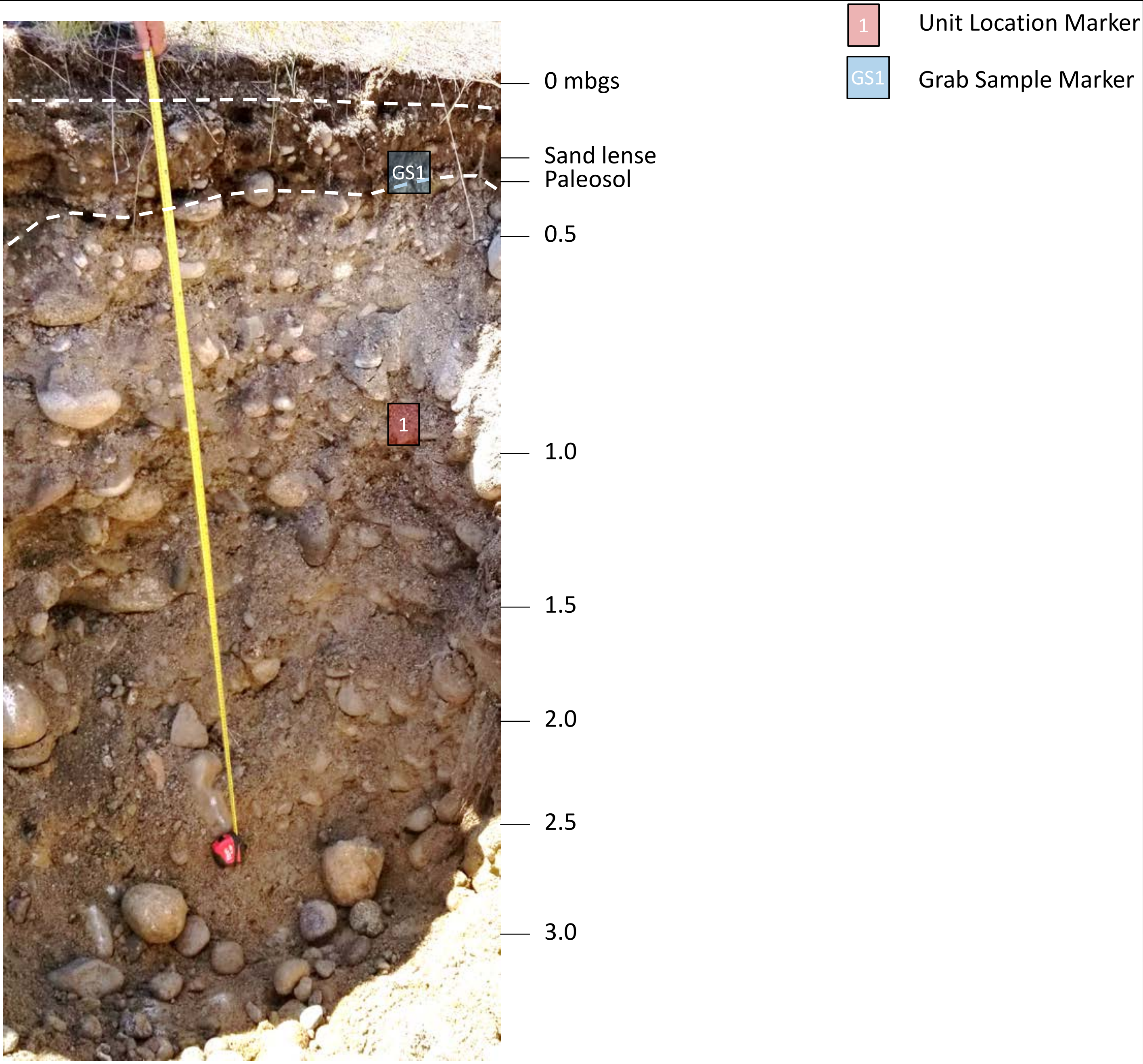
REPORT TITLE: RDCK FLOODPLAIN AND STEEP CREEK STUDY – EAGLE CREEK

FIGURE TITLE: TP-BGC19-EGL-04

PROJECT NO: 0268-007

FIGURE NO: C-4

0 5 10mm in ANSI A sized paper



1. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY – EAGLE CREEK " AND DATED FEBRUARY 2020.
2. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS FIGURE 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.

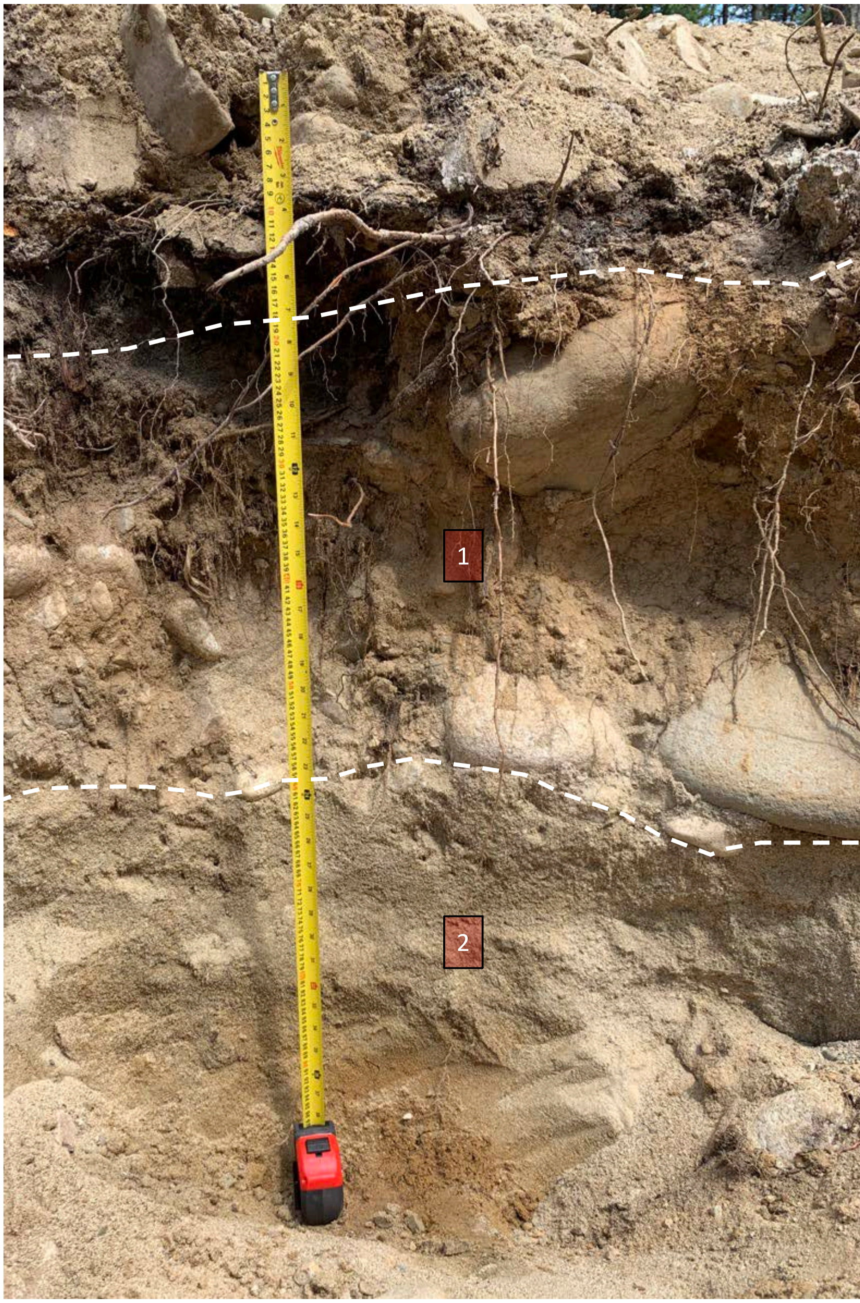
SCALE:	DATE: 02-2020	PREPARED BY: DB	CHECKED BY: BCP	APPROVED BY: CAL
		REPORT TITLE: RDCK FLOODPLAIN AND STEEP CREEK STUDY – EAGLE CREEK		
		FIGURE TITLE: TP-BGC19-EGL-05		
		PROJECT NO: 0268-007	FIGURE NO: C-5	

0 5 10mm in ANSI A sized paper

1. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED “RDCK FLOODPLAIN AND STEEP CREEK STUDY – EAGLE CREEK ” AND DATED FEBRUARY 2020.
2. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS FIGURE 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:	DATE: 02-2020	PREPARED BY: DB	CHECKED BY: BCP	APPROVED BY: CAL
		REPORT TITLE: RDCK FLOODPLAIN AND STEEP CREEK STUDY – EAGLE CREEK		
		FIGURE TITLE: TP-BGC19-EGL-Waterline-05		
		PROJECT NO: 0268-007	FIGURE NO: C-6	

0 5 10mm in ANSI A sized paper



1 Unit Location Marker

GS1 Grab Sample Marker

1. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY – EAGLE CREEK " AND DATED FEBRUARY 2020.
2. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS FIGURE 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:	DATE: 02-2020	PREPARED BY: DB	CHECKED BY: BCP	APPROVED BY: CAL
REGIONAL DISTRICT CENTRAL KOOTENAY	BGC	REPORT TITLE: RDCK FLOODPLAIN AND STEEP CREEK STUDY – EAGLE CREEK		
		FIGURE TITLE: TP-BGC19-EGL-Waterline-07		
		PROJECT NO: 0268-007	FIGURE NO: C-7	

0 5 10mm in ANSI A sized paper

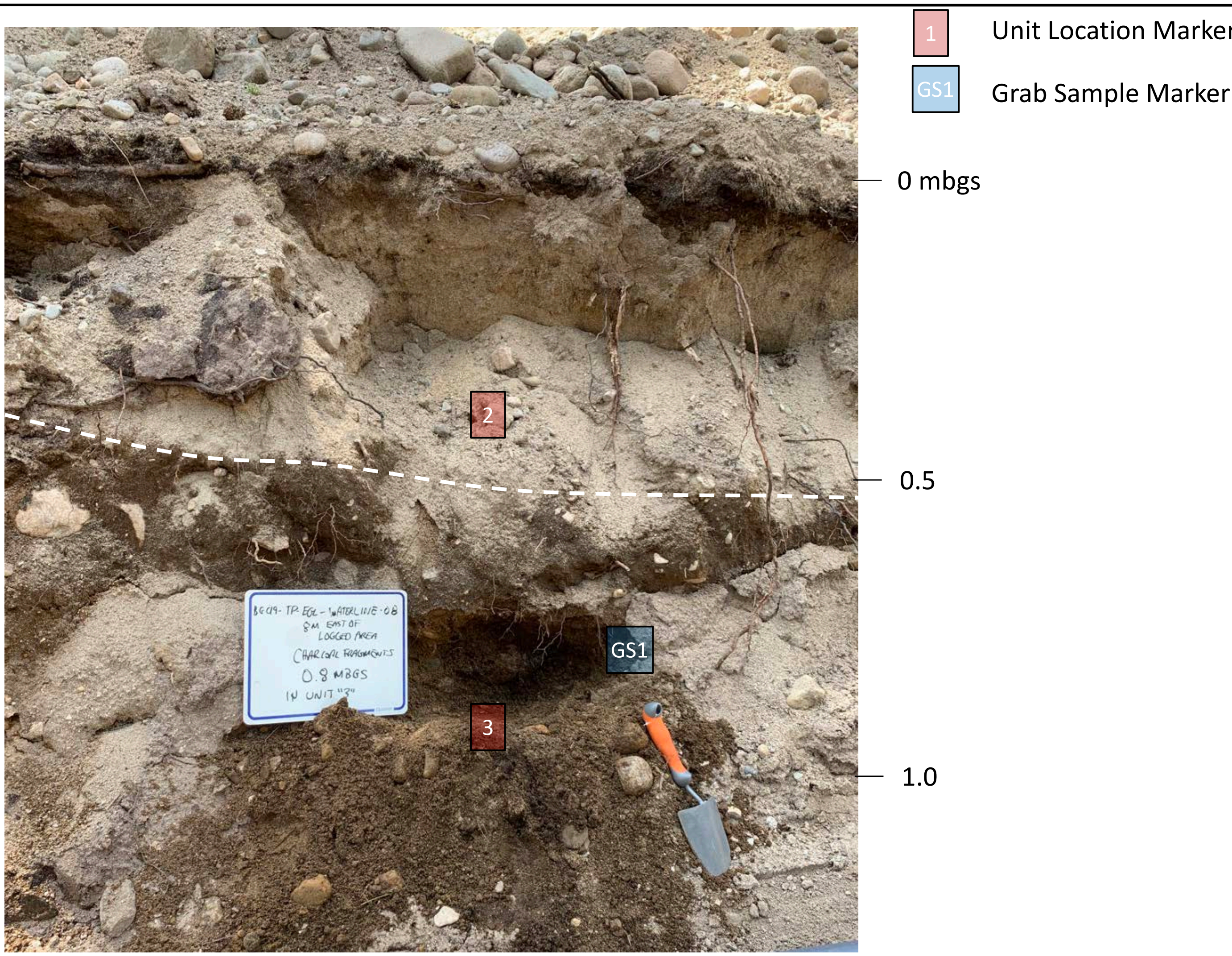
1 Unit Location Marker

GS1 Grab Sample Marker

1. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED “RDCK FLOODPLAIN AND STEEP CREEK STUDY – EAGLE CREEK ” AND DATED FEBRUARY 2020.
2. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS FIGURE 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:	DATE: 02-2020	PREPARED BY: DB	CHECKED BY: BCP	APPROVED BY: CAL
REGIONAL DISTRICT CENTRAL KOOTENAY	BGC	REPORT TITLE: RDCK FLOODPLAIN AND STEEP CREEK STUDY – EAGLE CREEK		
		FIGURE TITLE: TP-BGC19-EGL-Waterline-08		
		PROJECT NO: 0268-007	FIGURE NO: C-8	

0 5 10mm in ANSI A sized paper



1. THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE REPORT ENTITLED “RDCK FLOODPLAIN AND STEEP CREEK STUDY – EAGLE CREEK ” AND DATED FEBRUARY 2020.
2. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS FIGURE 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:	DATE: 02-2020	PREPARED BY: DB	CHECKED BY: BCP	APPROVED BY: CAL

REPORT TITLE: RDCK FLOODPLAIN AND STEEP CREEK STUDY – EAGLE CREEK

FIGURE TITLE: TP-BGC19-EGL-Waterline-08 G1 Location

PROJECT NO: 0268-007

FIGURE NO: C-9

0 5 10mm in ANSI A sized paper

APPENDIX F
MODELLING SCENARIOS

F.1. MODELLING SCENARIOS

The scenarios analyzed for Eagle Creek are presented in Table F-1, along with the information on the bulking factor. Sediment concentration total discharge and the type of modelling executed are also described.

Table F-1. Example Modeling Scenario Summaries for Eagle Creek.

Scenario Name	Return Period (yrs)	Process Type	Bulking Factor	Bulked Peak Discharge (m^3/s)	Conveyance Structures			Flood Protection Structures				
					Name	Estimated Capacity (m^3/s)	Assumption	Name	Type	Bank Erosion Encroaching	$\tau/\tau c \geq 2$	Assumption
EGL-1	20	Debris Flood (Type 1)	1.02	28	Worthington Creek FSR Bridge	140	Functioning as intended	EGL_1 Berm	Tiered berm near fan apex, left bank, orphaned	-	N	Will not function as intended[1].
								EGL_2 Berm	Bank erosion protection, left bank, orphaned[2]	-	N	Ignore lower bank protection due to high banks.
EGL-2	50	Debris Flood (Type 1)	1.05	37	Worthington Creek FSR Bridge	140	Functioning as intended	EGL_1 Berm	Tiered berm near fan apex, left bank, orphaned	✓	N	Will not function as intended[1].
								EGL_2 Berm	Bank erosion protection, left bank, orphaned[2]	✓	N	Ignore lower bank protection due to high banks.
EGL-3a	200	Debris Flood (Type 1)	1.2	52	Worthington Creek FSR Bridge	140	Functioning as intended	EGL_1 Berm	Tiered berm near fan apex, left bank, orphaned	✓	Y	Will not function as intended[1].
								EGL_2 Berm	Bank erosion protection, left bank, orphaned[2]	✓	Y	Ignore lower bank protection due to high banks.
EGL-3b	200	Debris Flood (Type 1)	1.2	52	Worthington Creek FSR Bridge	140	Bridge blocked	EGL_1 Berm	Tiered berm near fan apex, left bank, orphaned	✓	-	Will not function as intended[1].
								EGL_2 Berm	Bank erosion protection, left bank, orphaned[2]	✓	-	Ignore lower bank protection due to high banks.
EGL-4a	500	Debris Flood (Type 1)	1.3	66	Worthington Creek FSR Bridge	140	Functioning as intended	EGL_1 Berm	Tiered berm near fan apex, left bank, orphaned	✓	Y	Will not function as intended[1].
								EGL_2 Berm	Bank erosion protection, left bank, orphaned[2]	✓	Y	Ignore lower bank protection due to high banks.
EGL-4b	500	Debris Flood (Type 1)	1.3	66	Worthington Creek FSR Bridge	140	Bridge blocked	EGL_1 Berm	Tiered berm near fan apex, left bank, orphaned	✓	-	Will not function as intended[1].
								EGL_2 Berm	Bank erosion protection, left bank, orphaned[2]	✓	-	Ignore lower bank protection due to high banks.

Notes:

1. Memo from D. Barlow (BCMELP) Jan 22, 1996 to D. Boyer(page 16 of 75 in file titled "1061 Eagle Creek.pdf" provided by BCMFLNRORD) states: "Clearly the construction of the berm does not meet Ministry standards for a dyke that is intended to protect property."
2. Potentially installed by BCHydro.

APPENDIX G
LABORATORY TESTING RESULTS

Table D-1. Summary of samples sent for laboratory testing.

Field Sample ID	Laboratory	Beta ID	Analysis	Sample Type	Unit	Depth (mbgs)	Conventional Age (years BP)
TP-BGC19-EGL-02-GS1	Beta Analytics	532759	Standard AMS	Charcoal w. paleosol	2	0.55	604
TP-BGC19-EGL-03-GS1	Beta Analytics	532760	Standard AMS	Charcoal	2	1.30	3018
TP-BGC19-EGL-04-GS1	Beta Analytics	532761	Standard AMS	Charcoal	2	1.20	7621
TP-BGC19-EGL-04-GS3	Beta Analytics	532762	Standard AMS	Charcoal	1	0.80	4338
BGC19-EGL-Waterline-08	Beta Analytics	532763	Standard AMS	Charcoal	3	0.90	4697

Beta Analytic Inc
4985 SW 74 Court
Miami, Florida 33155
Tel: 305-667-5167
Fax: 305-663-0964
info@betalabservices.com

ISO/IEC 17025:2005-Accredited Testing Laboratory

August 16, 2019

Ms. Emily Moase
BGC Engineering
500-980 Howe Street
Vancouver, BC V6Z 0C8
Canada

RE: Radiocarbon Dating Results

Dear Ms. Moase,

Enclosed are the radiocarbon dating results for ten samples recently sent to us. As usual, the method of analysis is listed on the report with the results and calibration data is provided where applicable. The Conventional Radiocarbon Ages have all been corrected for total fractionation effects and where applicable, calibration was performed using 2013 calibration databases (cited on the graph pages).

The web directory containing the table of results and PDF download also contains pictures, a cvs spreadsheet download option and a quality assurance report containing expected vs. measured values for 3-5 working standards analyzed simultaneously with your samples.

Reported results are accredited to ISO/IEC 17025:2005 Testing Accreditation PJLA #59423 standards and all chemistry was performed here in our laboratory and counted in our own accelerators here. Since Beta is not a teaching laboratory, only graduates trained to strict protocols of the ISO/IEC 17025:2005 Testing Accreditation PJLA #59423 program participated in the analyses.

As always Conventional Radiocarbon Ages and sigmas are rounded to the nearest 10 years per the conventions of the 1977 International Radiocarbon Conference. When counting statistics produce sigmas lower than +/- 30 years, a conservative +/- 30 BP is cited for the result. The reported d13C values were measured separately in an IRMS (isotope ratio mass spectrometer). They are NOT the AMS d13C which would include fractionation effects from natural, chemistry and AMS induced sources.

When interpreting the results, please consider any communications you may have had with us regarding the samples.

Thank you for prepaying the analyses. As always, if you have any questions or would like to discuss the results, don't hesitate to contact us.

Sincerely,

Chris Patrick

Digital signature on file

Chris Patrick Director

Beta Analytic Inc
4985 SW 74 Court
Miami, Florida 33155
Tel: 305-667-5167
Fax: 305-663-0964
info@betalabservices.com

ISO/IEC 17025:2005-Accredited Testing Laboratory

REPORT OF RADIOCARBON DATING ANALYSES

Emily Moase | Report Date: August 16, 2019

BGC Engineering | Material Received: August 01, 2019

Laboratory Number	Sample Code Number	Conventional Radiocarbon Age (BP) or Percent Modern Carbon (pMC) & Stable Isotopes Calendar Calibrated Results: 95.4 % Probability High Probability Density Range Method (HPD)	
Beta - 532759	**TP-BGC19-EGL-02-GS1**	**620 +/- 30 BP**	IRMS δ13C: -22.2 o/oo

(95.4%) **1292 - 1400 cal AD** **(658 - 550 cal BP)**

Submitter Material:	Charcoal
Pretreatment:	(charred material) acid/alkali/acid
Analyzed Material:	Charred material
Analysis Service:	AMS-Standard delivery
Percent Modern Carbon:	92.57 +/- 0.35 pMC
Fraction Modern Carbon:	0.9257 +/- 0.0035
D14C:	-74.28 +/- 3.46 o/oo
Δ14C:	-81.97 +/- 3.46 o/oo(1950:2,019.00)
Measured Radiocarbon Age:	(without d13C correction): 570 +/- 30 BP
Calibration:	BetaCal3.21: HPD method: INTCAL13

Results are ISO/IEC-17025:2005 accredited. No sub-contracting or student labor was used in the analyses. All work was done at Beta in 4 in-house NEC accelerator mass spectrometers and 4 Thermo IRMSs. The "Conventional Radiocarbon Age" was calculated using the Libby half-life (5568 years), is corrected for total isotopic fraction and was used for calendar calibration where applicable. The Age is rounded to the nearest 10 years and is reported as radiocarbon years before present (BP), "present" = AD 1950. Results greater than the modern reference are reported as percent modern carbon (pMC). The modern reference standard was 95% the 14C signature of NIST SRM-4990C (oxalic acid). Quoted errors are 1 sigma counting statistics. Calculated sigmas less than 30 BP on the Conventional Radiocarbon Age are conservatively rounded up to 30. d13C values are on the material itself (not the AMS d13C). d13C and d15N values are relative to VPDB-1. References for calendar calibrations are cited at the bottom of calibration graph pages.

Beta Analytic Inc
4985 SW 74 Court
Miami, Florida 33155
Tel: 305-667-5167
Fax: 305-663-0964
info@betalabservices.com

ISO/IEC 17025:2005-Accredited Testing Laboratory

REPORT OF RADIOCARBON DATING ANALYSES

Emily Moase	Report Date: August 16, 2019
BGC Engineering	Material Received: August 01, 2019

Laboratory Number	Sample Code Number	Conventional Radiocarbon Age (BP) or Percent Modern Carbon (pMC) & Stable Isotopes Calendar Calibrated Results: 95.4 % Probability High Probability Density Range Method (HPD)	
Beta - 532760	**TP-BGC19-EGL-03-GS1**	**2900 +/- 30 BP**	IRMS δ13C: -22.9 o/oo

(78.8%)	**1134 - 1004 cal BC**	**(3083 - 2953 cal BP)**
(16.6%)	**1207 - 1141 cal BC**	**(3156 - 3090 cal BP)**

Submitter Material: Charcoal
Pretreatment: (charred material) acid/alkali/acid
Analyzed Material: Charred material
Analysis Service: AMS-Standard delivery
Percent Modern Carbon: 69.70 +/- 0.26 pMC
Fraction Modern Carbon: 0.6970 +/- 0.0026
D14C: -303.03 +/- 2.60 o/oo
Δ14C: -308.82 +/- 2.60 o/oo(1950:2,019.00)
Measured Radiocarbon Age: (without d13C correction): 2870 +/- 30 BP
Calibration: BetaCal3.21: HPD method: INTCAL13

Results are ISO/IEC-17025:2005 accredited. No sub-contracting or student labor was used in the analyses. All work was done at Beta in 4 in-house NEC accelerator mass spectrometers and 4 Thermo IRMSs. The "Conventional Radiocarbon Age" was calculated using the Libby half-life (5568 years), is corrected for total isotopic fraction and was used for calendar calibration where applicable. The Age is rounded to the nearest 10 years and is reported as radiocarbon years before present (BP), "present" = AD 1950. Results greater than the modern reference are reported as percent modern carbon (pMC). The modern reference standard was 95% the 14C signature of NIST SRM-4990C (oxalic acid). Quoted errors are 1 sigma counting statistics. Calculated sigmas less than 30 BP on the Conventional Radiocarbon Age are conservatively rounded up to 30. d13C values are on the material itself (not the AMS d13C). d13C and d15N values are relative to VPDB-1. References for calendar calibrations are cited at the bottom of calibration graph pages.

Beta Analytic Inc
4985 SW 74 Court
Miami, Florida 33155
Tel: 305-667-5167
Fax: 305-663-0964
info@betalabservices.com

BETA Beta Analytic TESTING LABORATORY

ISO/IEC 17025:2005-Accredited Testing Laboratory

REPORT OF RADIOCARBON DATING ANALYSES

Emily Moase	Report Date: August 16, 2019
BGC Engineering	Material Received: August 01, 2019

Laboratory Number	Sample Code Number	Conventional Radiocarbon Age (BP) or Percent Modern Carbon (pMC) & Stable Isotopes Calendar Calibrated Results: 95.4 % Probability High Probability Density Range Method (HPD)	
Beta - 532761	**TP-BGC19-EGL-04-GS1**	**6760 +/- 30 BP**	IRMS δ13C: -23.7 o/oo

(95.4%) **5717 - 5627 cal BC** **(7666 - 7576 cal BP)**

Submitter Material: Charcoal
Pretreatment: (charred material) acid/alkali/acid
Analyzed Material: Charred material
Analysis Service: AMS-Standard delivery
Percent Modern Carbon: 43.10 +/- 0.16 pMC
Fraction Modern Carbon: 0.4310 +/- 0.0016
D14C: -568.95 +/- 1.61 o/oo
Δ14C: -572.54 +/- 1.61 o/oo(1950:2,019.00)
Measured Radiocarbon Age: (without d13C correction): 6740 +/- 30 BP
Calibration: BetaCal3.21: HPD method: INTCAL13

Results are ISO/IEC-17025:2005 accredited. No sub-contracting or student labor was used in the analyses. All work was done at Beta in 4 in-house NEC accelerator mass spectrometers and 4 Thermo IRMSs. The "Conventional Radiocarbon Age" was calculated using the Libby half-life (5568 years), is corrected for total isotopic fraction and was used for calendar calibration where applicable. The Age is rounded to the nearest 10 years and is reported as radiocarbon years before present (BP), "present" = AD 1950. Results greater than the modern reference are reported as percent modern carbon (pMC). The modern reference standard was 95% the 14C signature of NIST SRM-4990C (oxalic acid). Quoted errors are 1 sigma counting statistics. Calculated sigmas less than 30 BP on the Conventional Radiocarbon Age are conservatively rounded up to 30. d13C values are on the material itself (not the AMS d13C). d13C and d15N values are relative to VPDB-1. References for calendar calibrations are cited at the bottom of calibration graph pages.

Beta Analytic Inc
4985 SW 74 Court
Miami, Florida 33155
Tel: 305-667-5167
Fax: 305-663-0964
info@betalabservices.com

ISO/IEC 17025:2005-Accredited Testing Laboratory

REPORT OF RADIOCARBON DATING ANALYSES

Emily Moase	Report Date: August 16, 2019
BGC Engineering	Material Received: August 01, 2019

Laboratory Number	Sample Code Number	Conventional Radiocarbon Age (BP) or Percent Modern Carbon (pMC) & Stable Isotopes Calendar Calibrated Results: 95.4 % Probability High Probability Density Range Method (HPD)	
Beta - 532762	**TP-BGC19-EGL-04-GS3**	**3920 +/- 30 BP**	IRMS δ13C: -25.4 o/oo

(95.4%) **2480 - 2298 cal BC** **(4429 - 4247 cal BP)**

Submitter Material:	Charcoal
Pretreatment:	(charred material) acid/alkali/acid
Analyzed Material:	Charred material
Analysis Service:	AMS-Standard delivery
Percent Modern Carbon:	61.39 +/- 0.23 pMC
Fraction Modern Carbon:	0.6139 +/- 0.0023
D14C:	-386.14 +/- 2.29 o/oo
Δ14C:	-391.24 +/- 2.29 o/oo(1950:2,019.00)
Measured Radiocarbon Age:	(without d13C correction): 3930 +/- 30 BP
Calibration:	BetaCal3.21: HPD method: INTCAL13

Results are ISO/IEC-17025:2005 accredited. No sub-contracting or student labor was used in the analyses. All work was done at Beta in 4 in-house NEC accelerator mass spectrometers and 4 Thermo IRMSs. The "Conventional Radiocarbon Age" was calculated using the Libby half-life (5568 years), is corrected for total isotopic fraction and was used for calendar calibration where applicable. The Age is rounded to the nearest 10 years and is reported as radiocarbon years before present (BP), "present" = AD 1950. Results greater than the modern reference are reported as percent modern carbon (pMC). The modern reference standard was 95% the 14C signature of NIST SRM-4990C (oxalic acid). Quoted errors are 1 sigma counting statistics. Calculated sigmas less than 30 BP on the Conventional Radiocarbon Age are conservatively rounded up to 30. d13C values are on the material itself (not the AMS d13C). d13C and d15N values are relative to VPDB-1. References for calendar calibrations are cited at the bottom of calibration graph pages.

Beta Analytic Inc
4985 SW 74 Court
Miami, Florida 33155
Tel: 305-667-5167
Fax: 305-663-0964
info@betalabservices.com

Beta Analytic
TESTING LABORATORY

ISO/IEC 17025:2005-Accredited Testing Laboratory

REPORT OF RADIOCARBON DATING ANALYSES

Emily Moase

BGC Engineering

Report Date: August 16, 2019

Material Received: August 01, 2019

Laboratory Number	Sample Code Number	Conventional Radiocarbon Age (BP) or Percent Modern Carbon (pMC) & Stable Isotopes Calendar Calibrated Results: 95.4 % Probability High Probability Density Range Method (HPD)	
Beta - 532763	**BGC19-EGL-Waterline-08**	**4140 +/- 30 BP**	IRMS δ13C: -25.3 o/oo

(95.4%) **2874 - 2621 cal BC** **(4823 - 4570 cal BP)**

Submitter Material: Organics
Pretreatment: (charred material) acid/alkali/acid
Analyzed Material: Charred material
Analysis Service: AMS-Standard delivery
Percent Modern Carbon: 59.73 +/- 0.22 pMC
Fraction Modern Carbon: 0.5973 +/- 0.0022
D14C: -402.73 +/- 2.23 o/oo
Δ14C: -407.69 +/- 2.23 o/oo(1950:2,019.00)
Measured Radiocarbon Age: (without d13C correction): 4150 +/- 30 BP
Calibration: BetaCal3.21: HPD method: INTCAL13

Results are ISO/IEC-17025:2005 accredited. No sub-contracting or student labor was used in the analyses. All work was done at Beta in 4 in-house NEC accelerator mass spectrometers and 4 Thermo IRMSs. The "Conventional Radiocarbon Age" was calculated using the Libby half-life (5568 years), is corrected for total isotopic fraction and was used for calendar calibration where applicable. The Age is rounded to the nearest 10 years and is reported as radiocarbon years before present (BP), "present" = AD 1950. Results greater than the modern reference are reported as percent modern carbon (pMC). The modern reference standard was 95% the 14C signature of NIST SRM-4990C (oxalic acid). Quoted errors are 1 sigma counting statistics. Calculated sigmas less than 30 BP on the Conventional Radiocarbon Age are conservatively rounded up to 30. d13C values are on the material itself (not the AMS d13C). d13C and d15N values are relative to VPDB-1. References for calendar calibrations are cited at the bottom of calibration graph pages.

BetaCal 3.21

Calibration of Radiocarbon Age to Calendar Years

(High Probability Density Range Method (HPD): INTCAL13)

(Variables: d13C = -22.2 o/oo)

Laboratory number **Beta-532759**

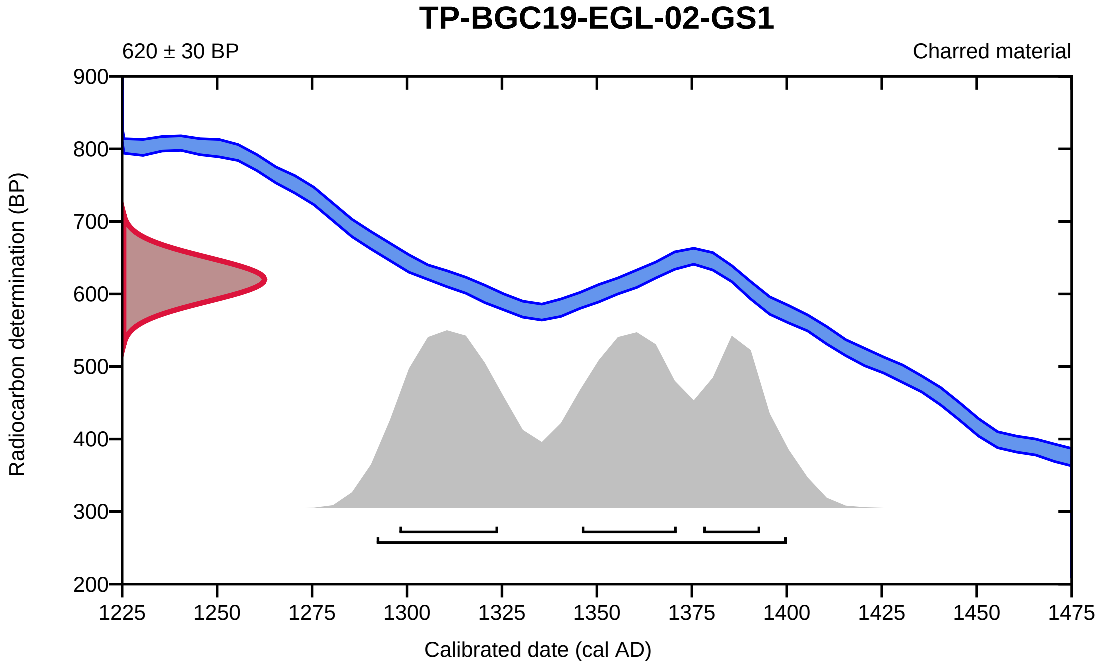
Conventional radiocarbon age **620 ± 30 BP**

95.4% probability

(95.4%)	1292 - 1400 cal AD	(658 - 550 cal BP)

68.2% probability

(26.9%)	1298 - 1324 cal AD	(652 - 626 cal BP)
(26.4%)	1346 - 1371 cal AD	(604 - 579 cal BP)
(14.8%)	1378 - 1393 cal AD	(572 - 557 cal BP)



Database used

INTCAL13

References

References to Probability Method

Bronk Ramsey, C. (2009). Bayesian analysis of radiocarbon dates. Radiocarbon, 51(1), 337-360.

References to Database INTCAL13

Reimer, et.al., 2013, Radiocarbon55(4).

Beta Analytic Radiocarbon Dating Laboratory

4985 S.W. 74th Court, Miami, Florida 33155 • Tel: (305)667-5167 • Fax: (305)663-0964 • Email: beta@radiocarbon.com

BetaCal 3.21

Calibration of Radiocarbon Age to Calendar Years

(High Probability Density Range Method (HPD): INTCAL13)

(Variables: d13C = -22.9 o/oo)

Laboratory number **Beta-532760**

Conventional radiocarbon age **2900 ± 30 BP**

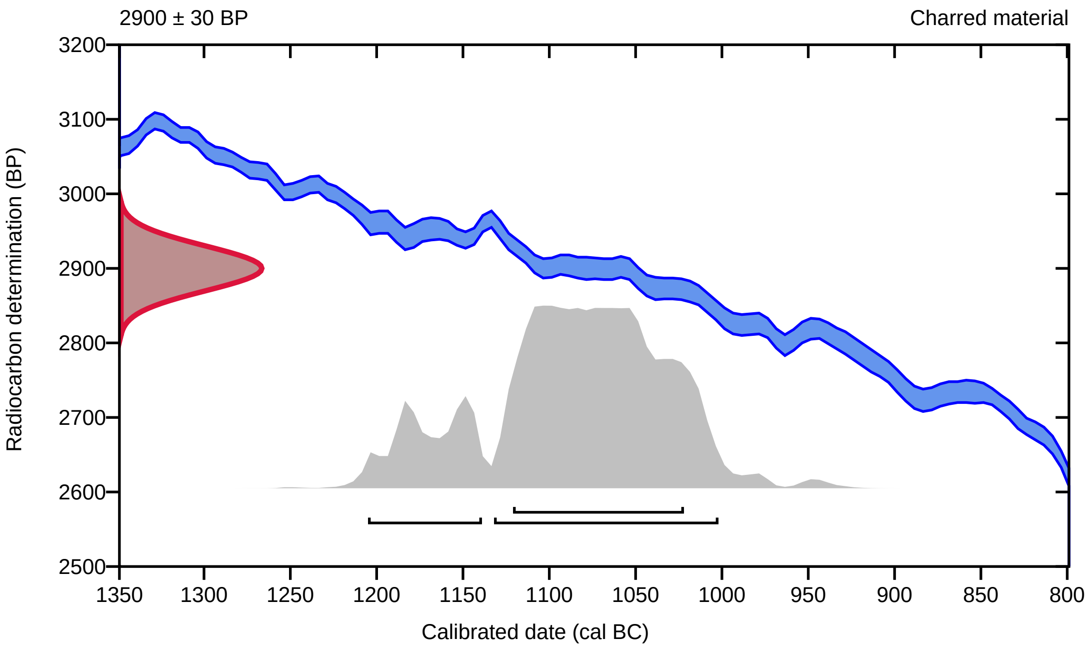
95.4% probability

(78.8%)	1134 - 1004 cal BC	(3083 - 2953 cal BP)
(16.6%)	1207 - 1141 cal BC	(3156 - 3090 cal BP)

68.2% probability

(68.2%)	1123 - 1024 cal BC	(3072 - 2973 cal BP)

TP-BGC19-EGL-03-GS1



Database used

INTCAL13

References

References to Probability Method

Bronk Ramsey, C. (2009). Bayesian analysis of radiocarbon dates. Radiocarbon, 51(1), 337-360.

References to Database INTCAL13

Reimer, et.al., 2013, Radiocarbon55(4).

Beta Analytic Radiocarbon Dating Laboratory

4985 S.W. 74th Court, Miami, Florida 33155 • Tel: (305)667-5167 • Fax: (305)663-0964 • Email: beta@radiocarbon.com

BetaCal 3.21

Calibration of Radiocarbon Age to Calendar Years

(High Probability Density Range Method (HPD): INTCAL13)

(Variables: d13C = -23.7 o/oo)

Laboratory number **Beta-532761**

Conventional radiocarbon age **6760 ± 30 BP**

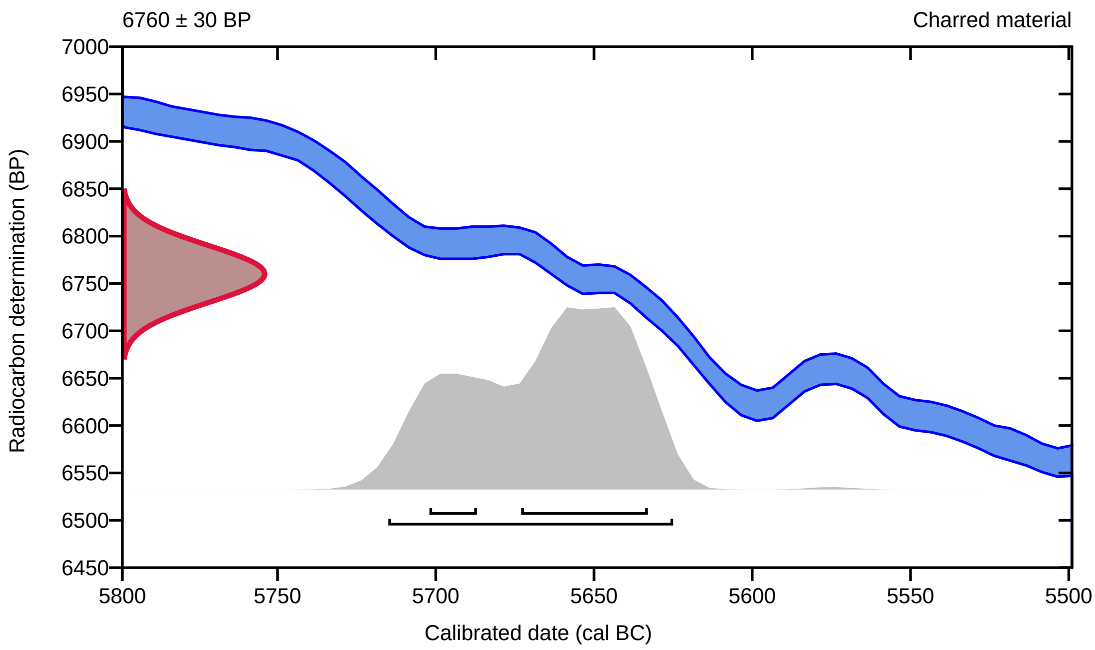
95.4% probability

(95.4%)	5717 - 5627 cal BC	(7666 - 7576 cal BP)

68.2% probability

(54.3%)	5675 - 5635 cal BC	(7624 - 7584 cal BP)
(13.9%)	5704 - 5689 cal BC	(7653 - 7638 cal BP)

TP-BGC19-EGL-04-GS1



Database used

INTCAL13

References

References to Probability Method

Bronk Ramsey, C. (2009). Bayesian analysis of radiocarbon dates. Radiocarbon, 51(1), 337-360.

References to Database INTCAL13

Reimer, et.al., 2013, Radiocarbon55(4).

Beta Analytic Radiocarbon Dating Laboratory

4985 S.W. 74th Court, Miami, Florida 33155 • Tel: (305)667-5167 • Fax: (305)663-0964 • Email: beta@radiocarbon.com

BetaCal 3.21

Calibration of Radiocarbon Age to Calendar Years

(High Probability Density Range Method (HPD): INTCAL13)

(Variables: d13C = -25.4 o/oo)

Laboratory number **Beta-532762**

Conventional radiocarbon age **3920 ± 30 BP**

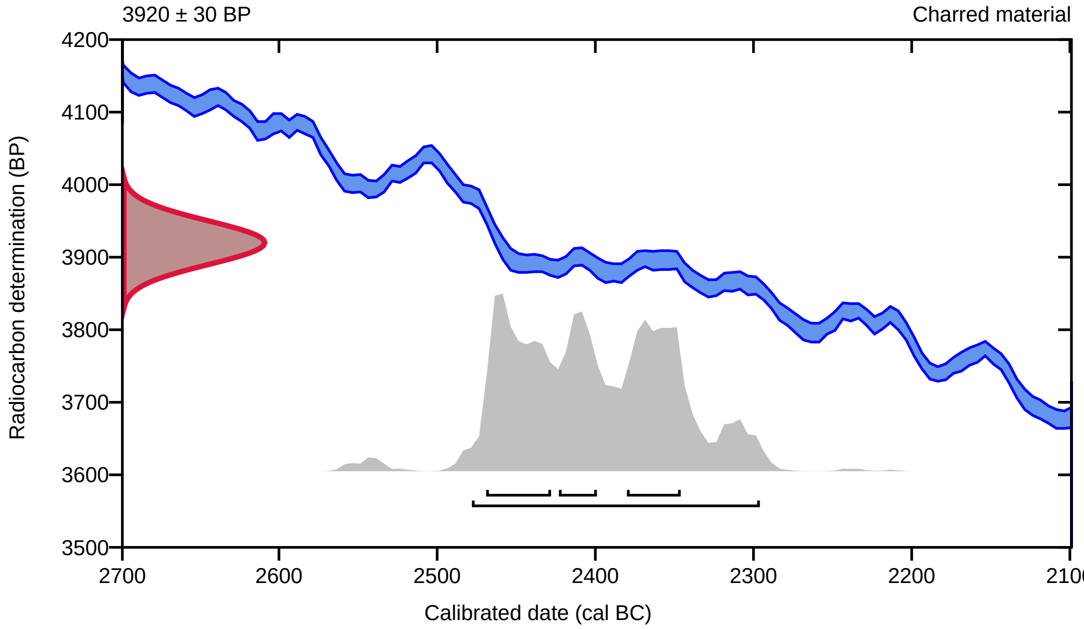
95.4% probability

(95.4%)	2480 - 2298 cal BC	(4429 - 4247 cal BP)

68.2% probability

(28.6%)	2471 - 2430 cal BC	(4420 - 4379 cal BP)
(23.4%)	2382 - 2348 cal BC	(4331 - 4297 cal BP)
(16.2%)	2425 - 2401 cal BC	(4374 - 4350 cal BP)

TP-BGC19-EGL-04-GS3



Database used

INTCAL13

References

References to Probability Method

Bronk Ramsey, C. (2009). Bayesian analysis of radiocarbon dates. Radiocarbon, 51(1), 337-360.

References to Database INTCAL13

Reimer, et.al., 2013, Radiocarbon55(4).

Beta Analytic Radiocarbon Dating Laboratory

4985 S.W. 74th Court, Miami, Florida 33155 • Tel: (305)667-5167 • Fax: (305)663-0964 • Email: beta@radiocarbon.com

BetaCal 3.21

Calibration of Radiocarbon Age to Calendar Years

(High Probability Density Range Method (HPD): INTCAL13)

(Variables: d13C = -25.3 o/oo)

Laboratory number **Beta-532763**

Conventional radiocarbon age **4140 ± 30 BP**

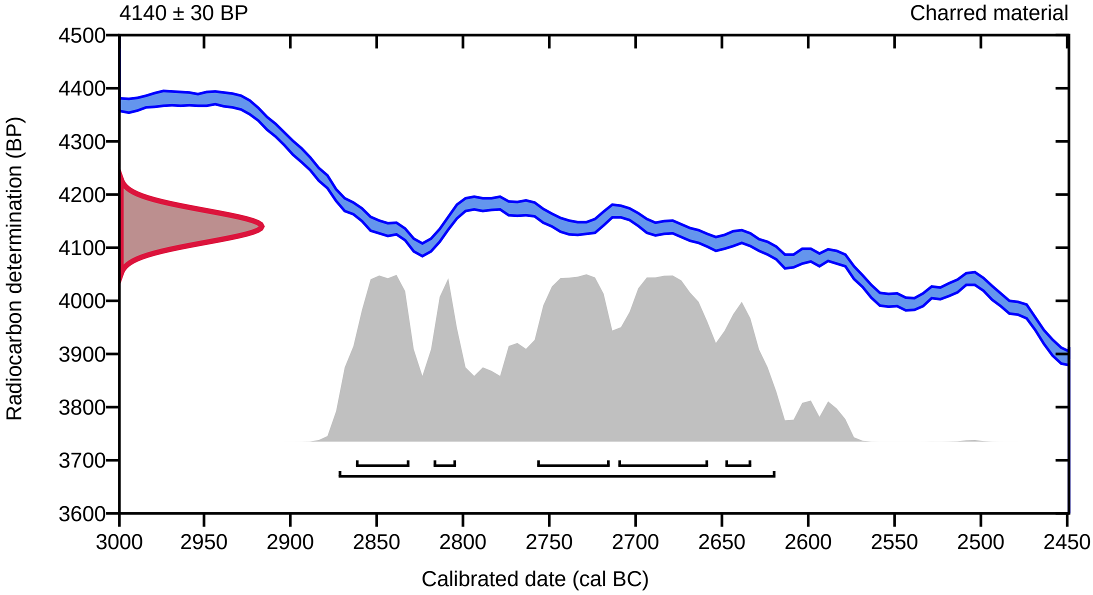
95.4% probability

(95.4%)	2874 - 2621 cal BC	(4823 - 4570 cal BP)

68.2% probability

(23.2%)	2712 - 2660 cal BC	(4661 - 4609 cal BP)
(19.6%)	2759 - 2717 cal BC	(4708 - 4666 cal BP)
(14%)	2864 - 2833 cal BC	(4813 - 4782 cal BP)
(5.9%)	2650 - 2635 cal BC	(4599 - 4584 cal BP)
(5.5%)	2819 - 2806 cal BC	(4768 - 4755 cal BP)

BGC19-EGL-Waterline-08



Database used

INTCAL13

References

References to Probability Method

Bronk Ramsey, C. (2009). Bayesian analysis of radiocarbon dates. Radiocarbon, 51(1), 337-360.

References to Database INTCAL13

Reimer, et.al., 2013, Radiocarbon55(4).

Beta Analytic Radiocarbon Dating Laboratory

4985 S.W. 74th Court, Miami, Florida 33155 • Tel: (305)667-5167 • Fax: (305)663-0964 • Email: beta@radiocarbon.com

Beta Analytic Inc
4985 SW 74 Court
Miami, Florida 33155
Tel: 305-667-5167
Fax: 305-663-0964
info@betalabservices.com

ISO/IEC 17025:2005-Accredited Testing Laboratory

Quality Assurance Report

This report provides the results of reference materials used to validate radiocarbon analyses prior to reporting. Known-value reference materials were analyzed quasi-simultaneously with the unknowns. Results are reported as expected values vs measured values. Reported values are calculated relative to NIST SRM-4990B and corrected for isotopic fractionation. Results are reported using the direct analytical measure percent modern carbon (pMC) with one relative standard deviation. Agreement between expected and measured values is taken as being within 2 sigma agreement (error x 2) to account for total laboratory error.

Report Date: August 19, 2019
Submitter: Ms. Emily Moase

QA MEASUREMENTS

Reference 1

Expected Value:	0.42 +/- 0.04
Measured Value:	0.42 +/- 0.03 pMC
Agreement:	Accepted

Reference 2

Expected Value:	129.41 +/- 0.06 pMC
Measured Value:	129.39 +/- 0.40 pMC
Agreement:	Accepted

Reference 3

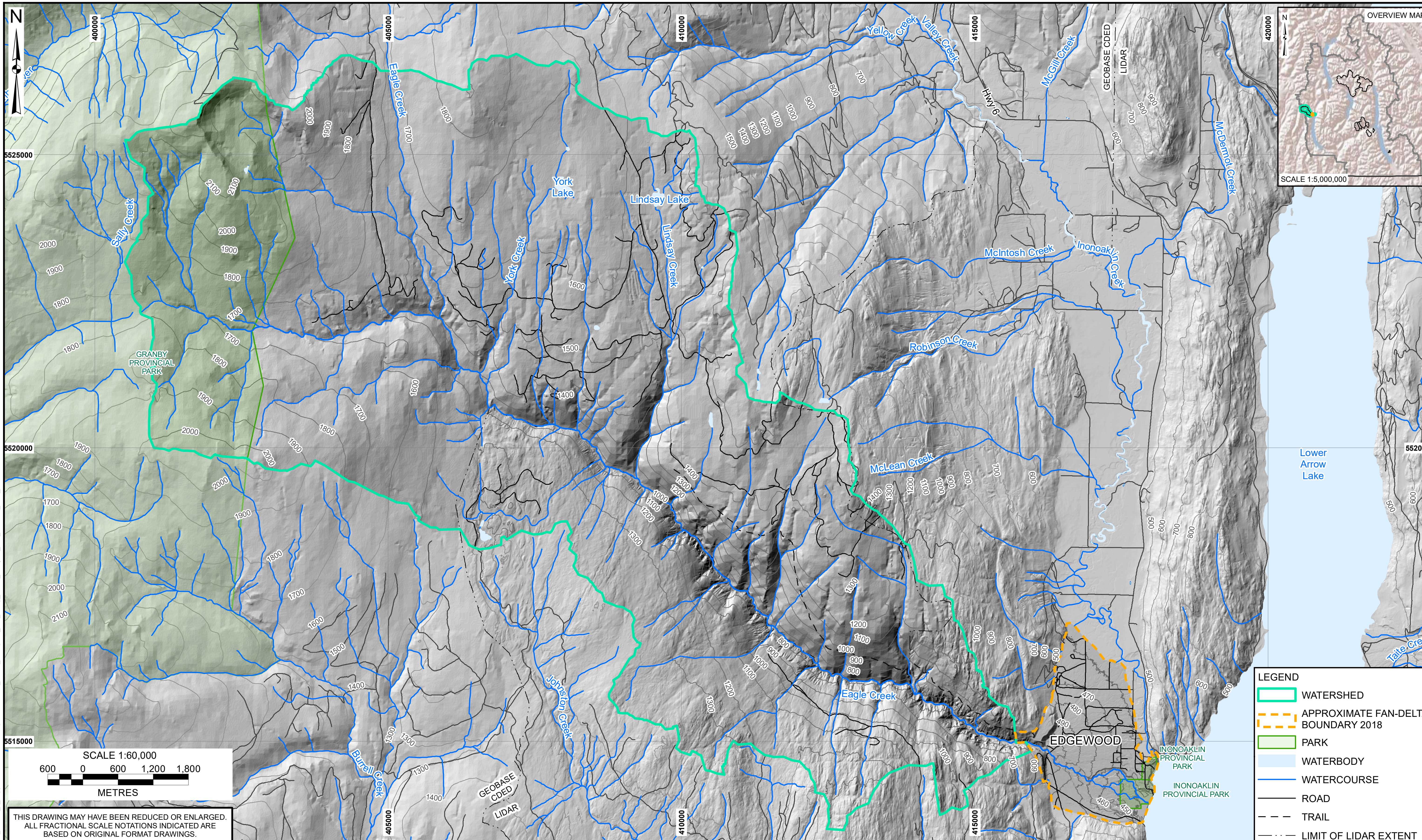
Expected Value:	96.69 +/- 0.50 pMC
Measured Value:	96.98 +/- 0.29 pMC
Agreement:	Accepted

COMMENT: All measurements passed acceptance tests.

Validation: R.E. Digital signature on file

Date: August 19, 2019

DRAWINGS



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 - EAGLE CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2018, AND GEOBASE CDED. CONTOUR INTERVAL IS 100 m AND 10 m ON FAN.
4. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM BASED ON LIDAR DATED 2018. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL FLOODING.
5. PARKS DATA FROM GOVERNMENT OF BC. ROADS DATA FROM BC DIGITAL ROAD ATLAS.
6. PROJECTION IS NAD 1983 UTM ZONE 11N.
7. 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:	1:60,000
DATE:	MAR 2020
DRAWN:	LL
CHECKED:	JJHP
APPROVED:	MJ

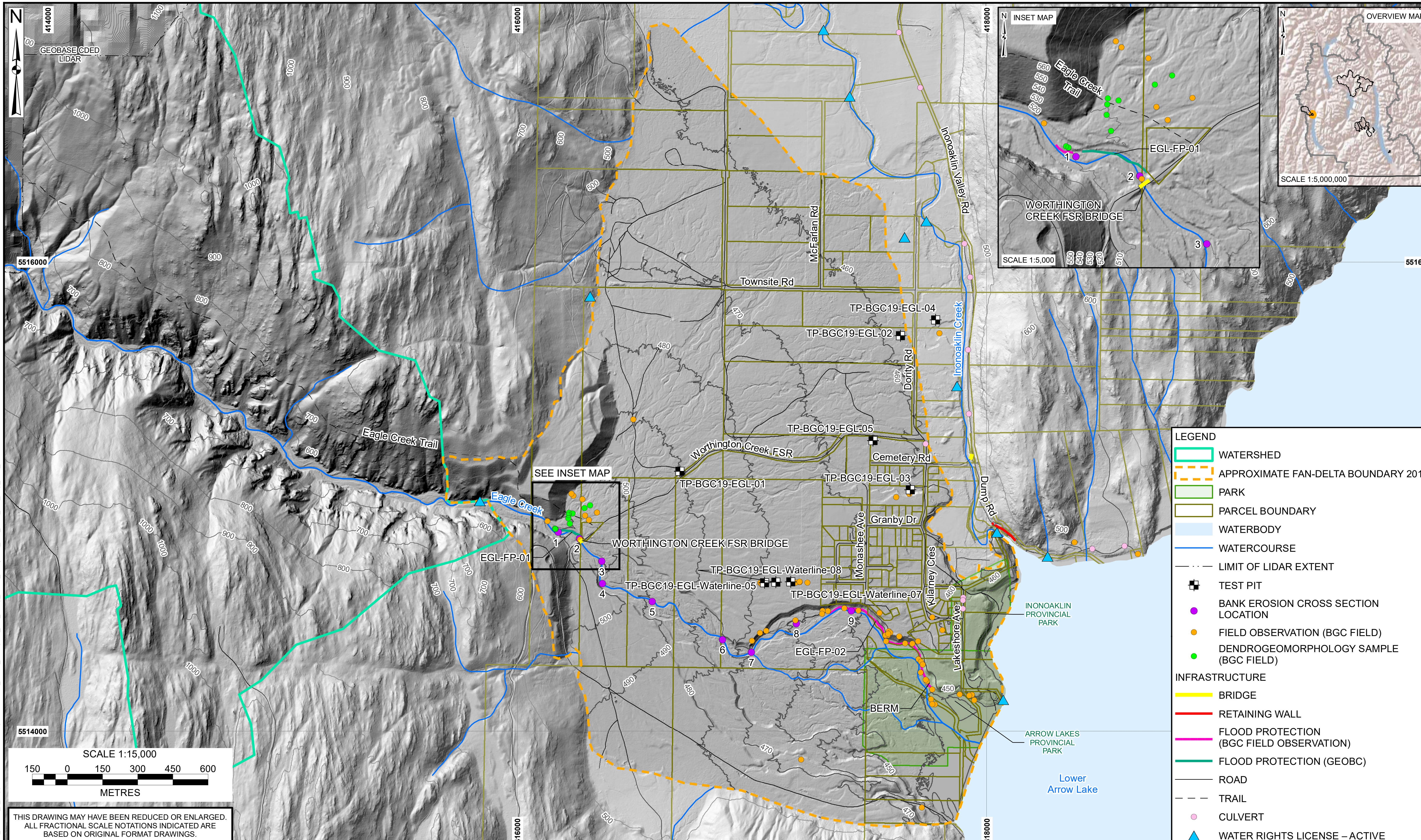
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE: EAGLE CREEK SITE LOCATION MAP

PROJECT No.:	DWG No:
0268007	01



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 - EAGLE CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK, DATED 2018. CONTOUR INTERVAL IS 100 m AND 10 m ON FAN.
4. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM BASED ON LIDAR DATED 2018. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL FLOODING.
5. WATER DATA FROM CANVEC, UPDATED BASED ON BGC FIELD OBSERVATIONS, WHERE APPLICABLE. CULVERT LOCATIONS FROM BC MINISTRY OF TRANSPORTATION. FLOOD PROTECTION DATA FROM GEOBC AND BGC FIELD OBSERVATIONS (APPROXIMATE). ROADS DATA FROM BC DIGITAL ROAD ATLAS. WATER RIGHTS LICENSE DATA FROM GEOBC. PARCELS FROM PARCELMAP BC. PARKS DATA FROM GOVERNMENT OF BC.
6. PROJECTION IS NAD 1983 UTM ZONE 11N.
7. 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:	1:15,000
DATE:	MAR 2020
DRAWN:	LL
CHECKED:	JJHP
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

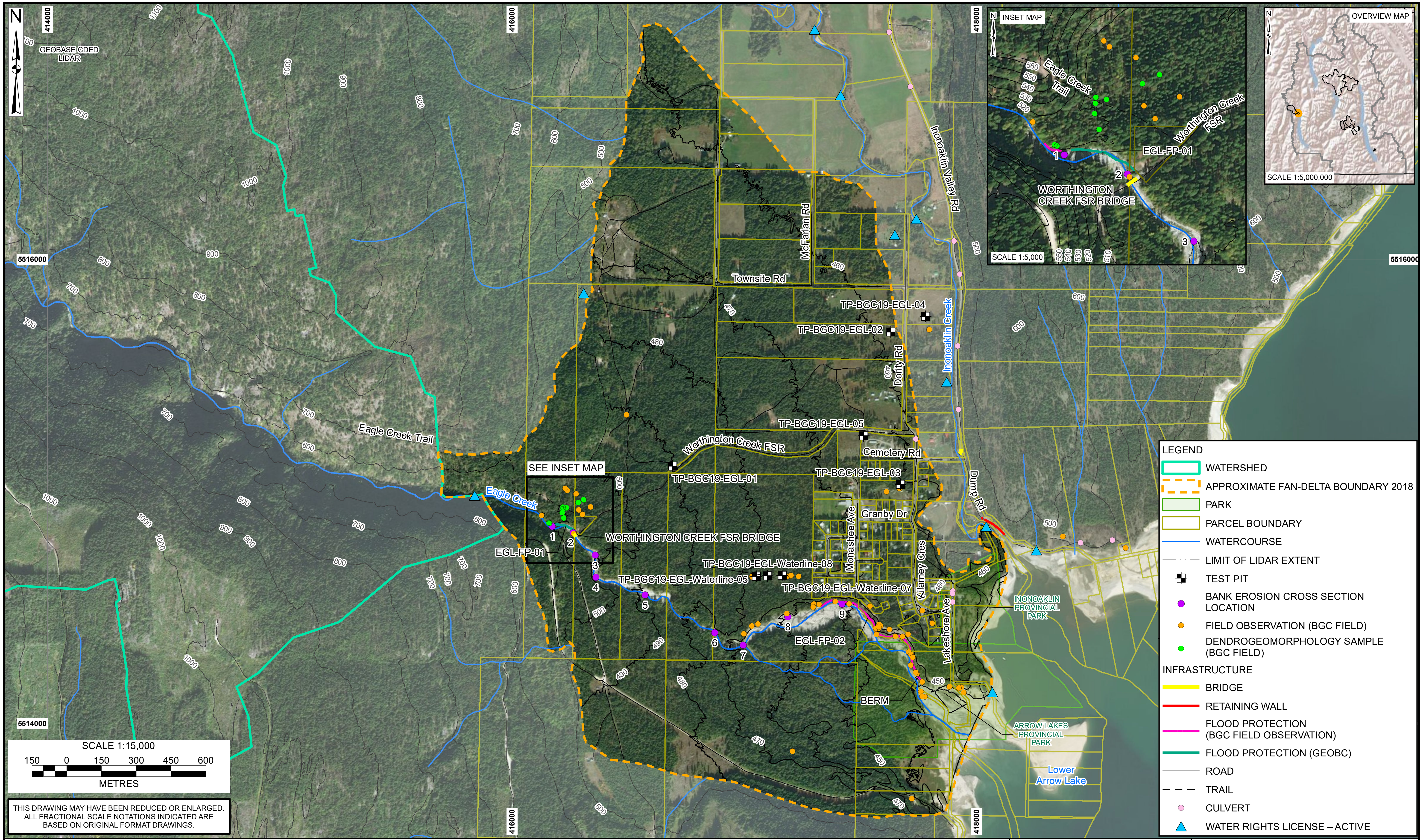
PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE: EAGLE CREEK FAN-DELTA SITE MAP

PROJECT No.: 0268007

DWG No: 02A

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191018_RDCK_Floodplain_and_Steep_Creek_Study\02A_Fan_Delta_Site_Map_DDP_EAGLE.mxd



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 - EAGLE CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK, DATED 2018. CONTOUR INTERVAL IS 100 m AND 10 m ON FAN. IMAGERY FROM WORLD_IMAGERY_BASEMAP.
4. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM BASED ON LIDAR DATED 2018. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL FLOODING.
5. WATER DATA FROM CANVEC, UPDATED BASED ON BGC FIELD OBSERVATIONS, WHERE APPLICABLE. CULVERT LOCATIONS FROM BC MINISTRY OF TRANSPORTATION. FLOOD PROTECTION DATA FROM GEOBC AND BGC FIELD OBSERVATIONS (APPROXIMATE). ROADS DATA FROM BC DIGITAL ROAD ATLAS. WATER RIGHTS LICENSE DATA FROM GEOBC. PARCELS FROM PARCELMAP BC. PARKS DATA FROM GOVERNMENT OF BC.
6. PROJECTION IS NAD 1983 UTM ZONE 11N.
7. 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:	1:15,000
DATE:	MAR 2020
DRAWN:	LL
CHECKED:	JJHP
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

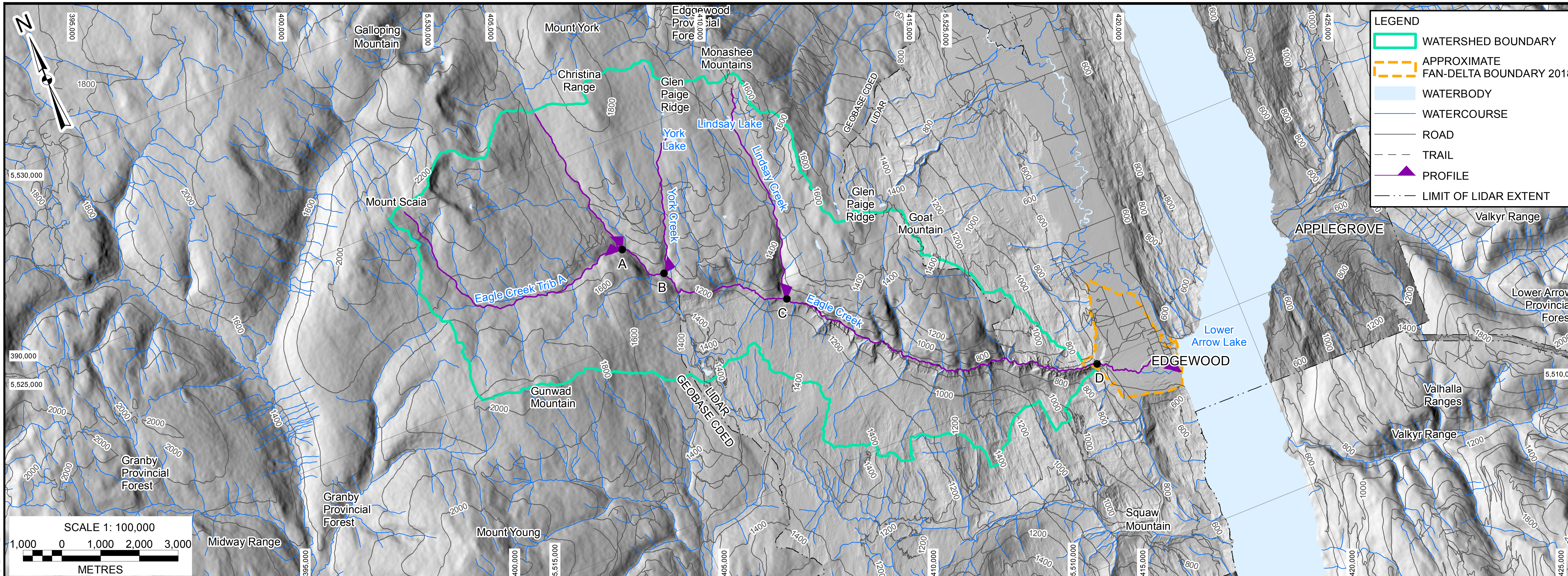
CLIENT:

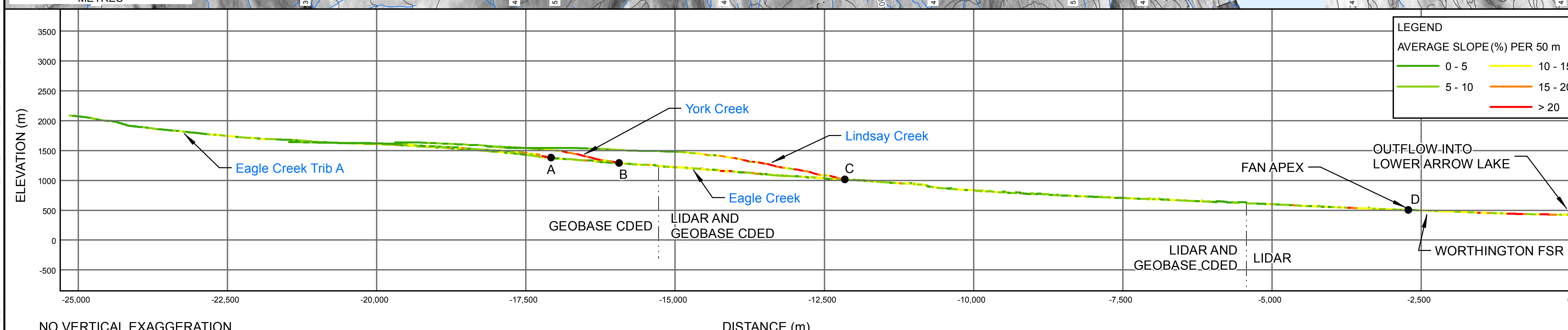
PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE: EAGLE CREEK FAN-DELTA SITE MAP

PROJECT No.:	DWG No:
0268007	02B

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191018_RDCK_Floodplain_and_Steep_Creek_Study\02B_Fan_Delta_Site_Map_DDP_EAGLE.mxd





PROFILE

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 – EAGLE CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK AND GEOBASE CDED, DATED 2018 AND 2013, RESPECTIVELY.
4. THE WATERSHED AND FAN BOUNDARES AS DRAWN ARE APPROXIMATE AND DELINEATE THE LANDFORM BASED ON LIDAR DATED 2018. THE BOUNDARIES SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DO THEY SHOW THE SPATIAL EXTENT OF POTENTIAL FLOODING.
5. WATERSHED BOUNDARIES DELINEATED FROM BGC'S RIVER NETWORK TOOLS, WATERBODIES SOURCED FROM CANVEC, WATERCOURSES SOURCED FROM BGC'S RIVER NETWORK TOOLS AND CANVEC, ROADS AND TRAILS SOURCED FROM GEOBC DIGITAL ROAD ATLAS.
6. ELEVATION PROFILE SHOWS DISTANCE RELATIVE TO THE CREEK OUTLET ON X-AXIS AND ELEVATION DERIVED FROM THE BASE TOPOGRAPHIC DATA ON Y-AXIS
7. PROJECTION IS NAD 1983 UTM ZONE 11N.
8. 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 OF OR RELIANCE UPON 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:	1:100,000
DATE:	MAR 2020
DRAWN:	STT
CHECKED:	JJHP, LCH
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

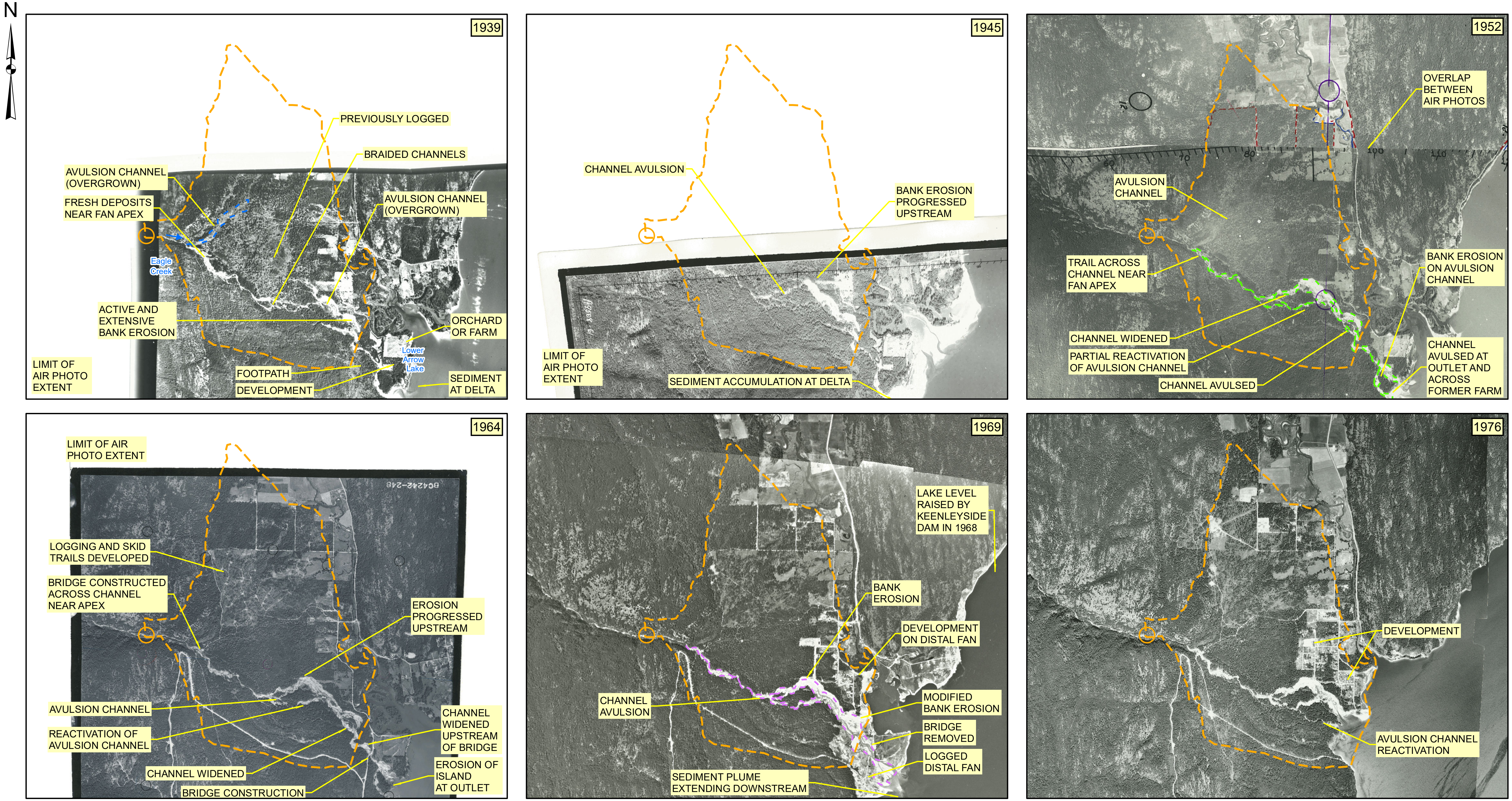
PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE: EAGLE CREEK PROFILE

PROJECT No.: 0268007

DWG No: 03

X:\Projects\0268007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191018_RDCK_Floodplain_and_Steep_Creek_Study\Profile\03_Eagle_Creek_Profile.mxd



SCALE 1:40,000

200 0 200 400 600

METRES

THIS DRAWING MAY HAVE BEEN REDUCED OR ENLARGED. ALL FRACTIONAL SCALE NOTATIONS INDICATED ARE BASED ON ORIGINAL FORMAT DRAWINGS.

LEGEND

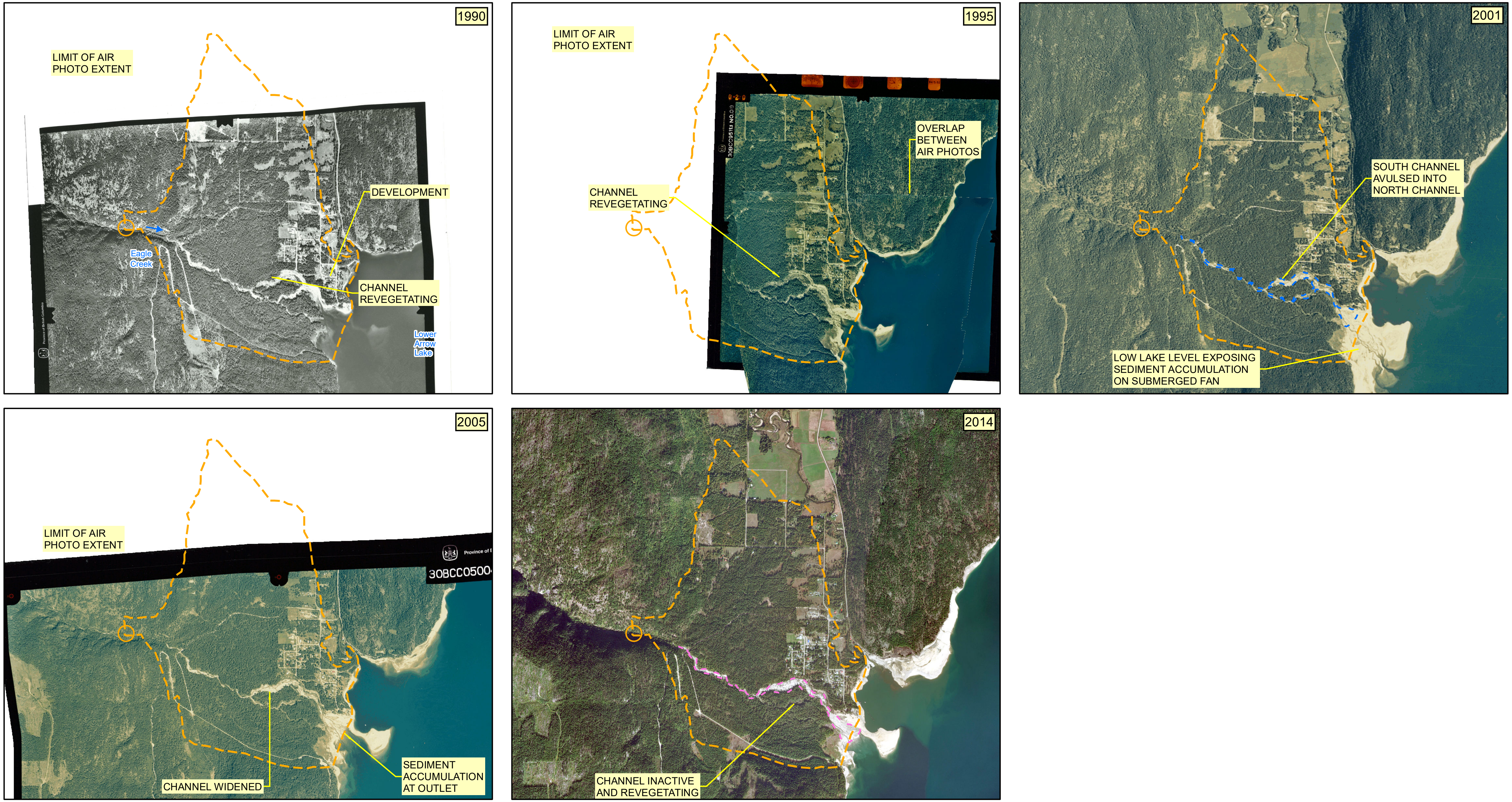
- APPROXIMATE FAN-DELTA BOUNDARY 2018
- FAN APEX
- APPROXIMATE EXTENT OF 1894 EVENT
- APPROXIMATE EXTENT OF 1948 EVENT
- APPROXIMATE EXTENT OF 1968 EVENT

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "STEEP CREEK HAZARD AND RISK ASSESSMENT - EAGLE CREEK", AND DATED FEBRUARY 2020.
3. BASE TOPOGRAPHIC DATA BASED ON AIR PHOTOS PROVIDED BY BC AIR PHOTO LIBRARY AND NATIONAL AIR PHOTO LIBRARY.
4. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM BASED ON LIDAR DATED 2018. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL FLOODING.
5. AIR PHOTO FROM YEAR 1951 WAS MARKED ON PHYSICAL COPIES PRIOR TO BGC'S AIR PHOTO INTERPRETATION.
6. BANK EROSION INDICATES DISCERNIBLE EROSION FROM PREVIOUS IMAGE.
7. COORDINATE SYSTEM IS UTM ZONE 11 NAD 1983. VERTICAL DATUM IS UNKNOWN.
8. 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: 1:40,000	BGC ENGINEERING INC. AN APPLIED EARTH SCIENCES COMPANY	PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY	
DATE: MAR 2020		TITLE: EAGLE CREEK AIR PHOTO COMPARISON	
DRAWN: MIB, LL	CLIENT:		
CHECKED: JJHP, LCH	REGIONAL DISTRICT OF CENTRAL KOOTENAY	PROJECT No.: 0268007	DWG No: 04A
APPROVED: MJ			

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20190716_RDCK_Airphoto_Comparison\Air Photo Map 6 panels.mxd

N



SCALE 1:40,000

200 0 200 400 600

METRES

THIS DRAWING MAY HAVE BEEN REDUCED OR ENLARGED. ALL FRACTIONAL SCALE NOTATIONS INDICATED ARE BASED ON ORIGINAL FORMAT DRAWINGS.

LEGEND

- APPROXIMATE FAN-DELTA BOUNDARY 2018
- FAN APEX
- APPROXIMATE EXTENT OF 1997 EVENT
- APPROXIMATE EXTENT OF 2013 EVENT

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "STEEP CREEK HAZARD AND RISK ASSESSMENT - EAGLE CREEK", AND DATED FEBRUARY 2020.
3. BASE TOPOGRAPHIC DATA BASED ON AIR PHOTOS PROVIDED BY BC AIR PHOTO LIBRARY AND NATIONAL AIR PHOTO LIBRARY.
4. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM BASED ON LIDAR DATED 2018. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL FLOODING.
5. COORDINATE SYSTEM IS UTM ZONE 11 NAD 1983. VERTICAL DATUM IS UNKNOWN.
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:	1:40,000
DATE:	MAR 2020
DRAWN:	MIB, LL
CHECKED:	JJHP, LCH
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

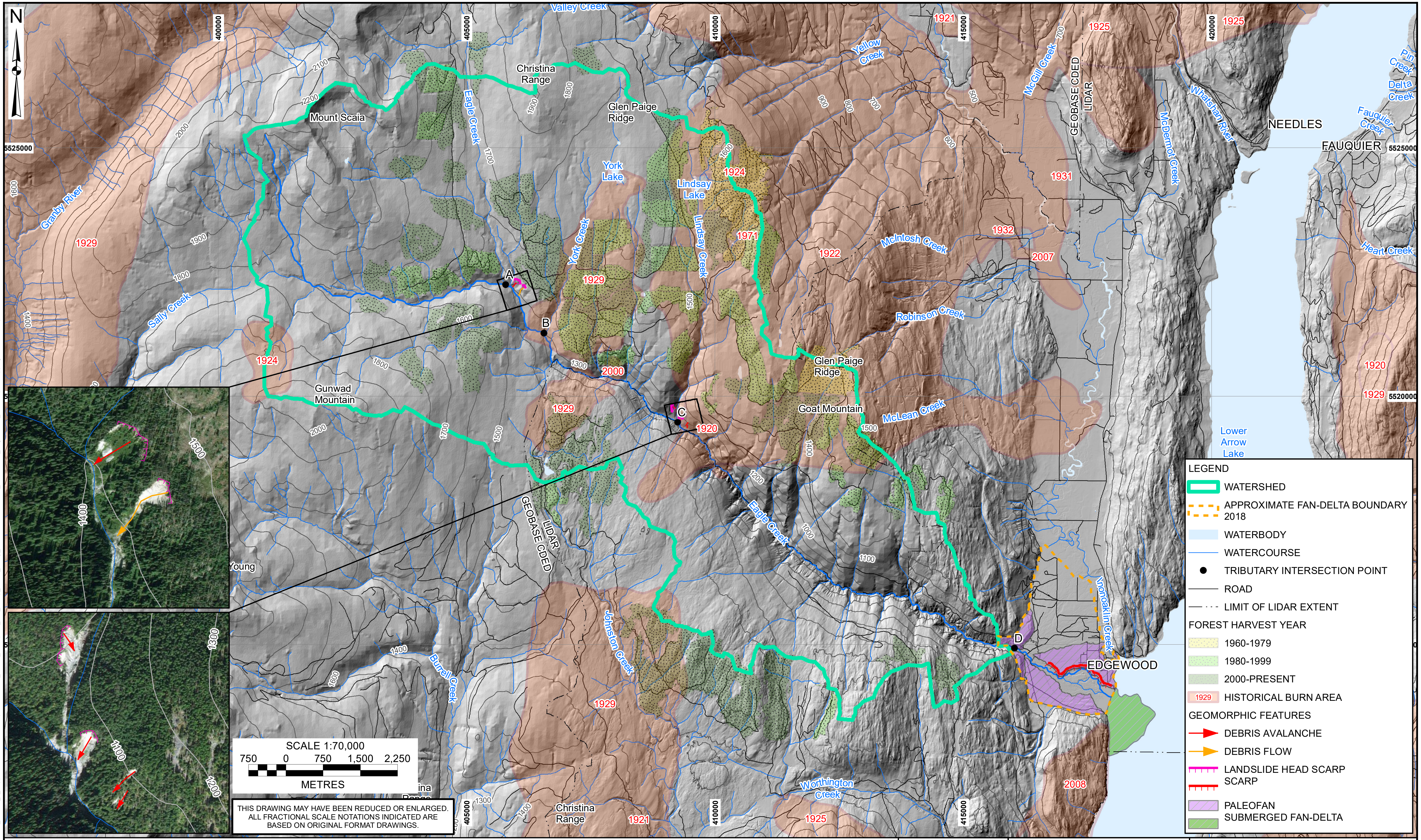
PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE: EAGLE CREEK AIR PHOTO COMPARISON

PROJECT No.: 0268007

DWG No: 04B

X:\Projects\0268007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20190716_RDCK_Airphoto_Comparison\Air Photo Map 6 panels.mxd



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 - EAGLE CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2018, AND GEOBASE CDED. CONTOUR INTERVAL IS 100m.
4. INSET BASE IMAGERY DATED 2014 AND PROVIDED BY ESRI GLOBAL IMAGERY SERVICE.
5. THE WATERSHED AND FAN-DELTA BOUNDARY AS DRAWN ARE APPROXIMATE AND DELINEATE THE LANDFORMS BASED ON LIDAR DATED 2018. THE BOUNDARIES SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DO THEY SHOW THE SPATIAL EXTENT OF POTENTIAL FLOODING.
6. HISTORICAL CUT BLOCK DATA FROM GEOBC DATASET DATED 2019 AND ONLY REPRESENTATIVE OF AREAS THAT INTERSECT WATERSHED BOUNDARY. HISTORICAL BURN AREA FROM GEOBC DATASET DATED 2019. ROADS DATA FROM BC DIGITAL ROADS ATLAS.
7. PROJECTION IS NAD 1983 UTM ZONE 11N.
8. 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:	1:70,000
DATE:	MAR 2020
DRAWN:	MW
CHECKED:	JJHP
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

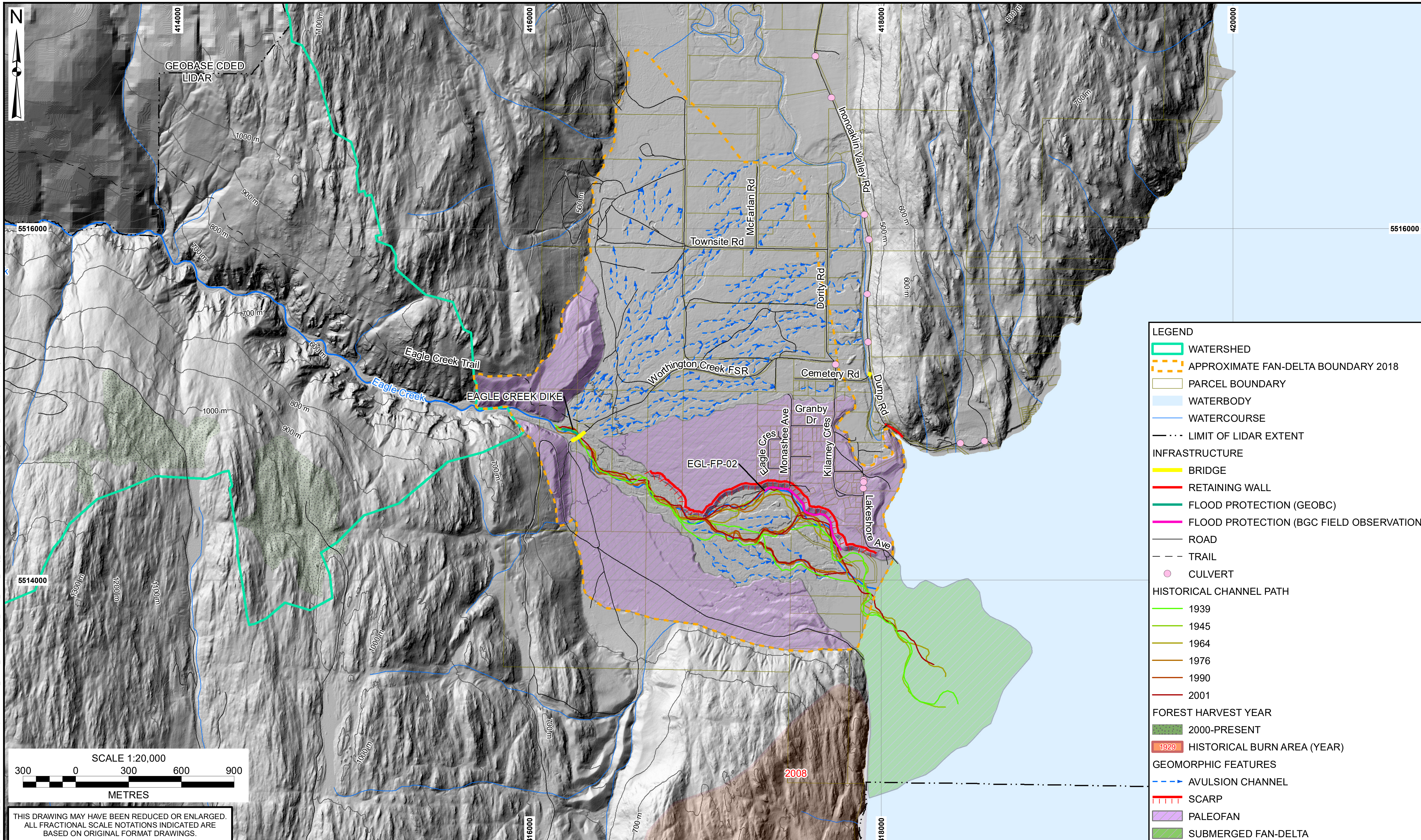
CLIENT: REGIONAL DISTRICT CENTRAL KOOTENAY

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY EAGLE CREEK

TITLE: WATERSHED GEOMORPHOLOGY

PROJECT No.:	DWG No.:
0268007	05

X:\Projects\0268007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191112_RDCK_Floodplain_and_Steep_Creek_Study_STEEPCREEK\FINAL_COPIES\05_EagleCreek_GeomorphicMapping.mxd Date: April 8, 2020 Time: 10:00 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 - EAGLE CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2018, AND GEOBASE CDED. CONTOUR INTERVAL IS 100m.
4. THE WATERSHED AND FAN-DELTA BOUNDARY AS DRAWN ARE APPROXIMATE AND DELINEATE THE LANDFORMS BASED ON LIDAR DATED 2018. THE BOUNDARIES SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DO THEY SHOW THE SPATIAL EXTENT OF POTENTIAL FLOODING.
5. HISTORICAL CUT BLOCK DATA FROM GEOBC DATASET DATED 2019 AND ONLY REPRESENTATIVE OF AREAS THAT INTERSECT WATERSHED BOUNDARY. HISTORICAL BURN AREA FROM GEOBC DATASET DATED 2019. ROADS DATA FROM BC DIGITAL ATLAS. PARCELS FROM PARCELMAP BC. RETAINING WALL FROM MINISTRY OF TRANSPORTATION DATASET DATED 2012.
6. PROJECTION IS NAD 1983 UTM ZONE 11N.
7. 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:	JJHP
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: REGIONAL DISTRICT CENTRAL KOOTENAY

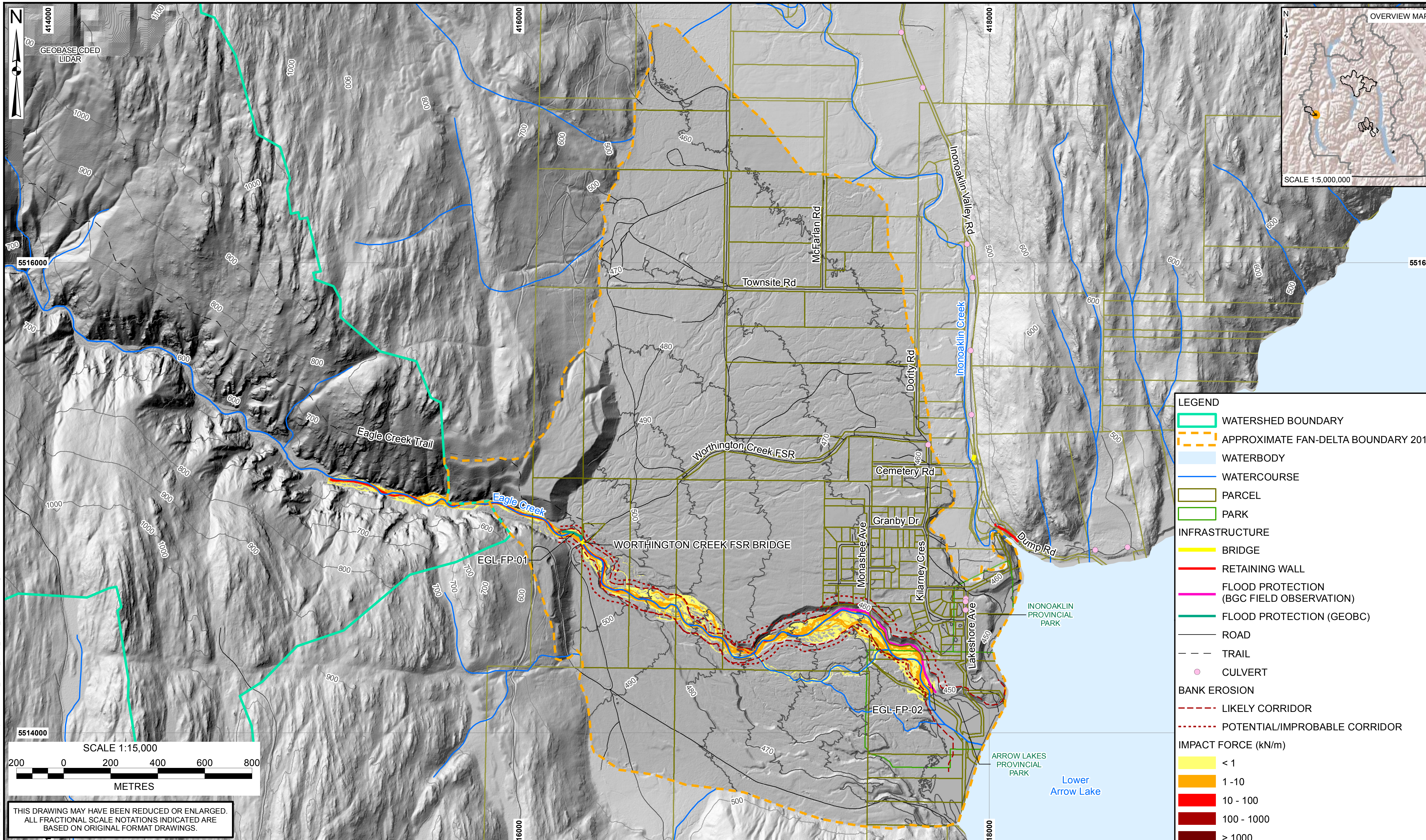
PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY EAGLE CREEK

TITLE: FAN-DELTA GEOMORPHOLOGY

PROJECT No.: 0268007

DWG No: 06

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191112_RDCK_Floodplain_and_Steep_Creek_Study_STEEPCREEK\FINAL_COPIES\06_EagleCreek_GeomorphicMapping\Fan.mxd Date: April 8, 2020 Time: 10:45 AM



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 REPORTS TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY - EAGLE CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK, DATED 2018. CONTOUR INTERVAL IS 100 m AND 10 m ON FAN.
4. MODELLED BANK EROSION IS SHOWN AS A LIKELY CORRIDOR (DIVIDED BETWEEN CHANNEL BANKS BASED ON CHANNEL GEOMETRY) AND POTENTIAL/IMPROBABLE CORRDIOR (APPLIED EQUALLY TO BOTH BANKS).
5. ROADS DATA FROM BC DIGITAL ROAD ATLAS. BANK PROTECTION FROM GEOBC AND BGC FIELD OBSERVATIONS. PARCEL MAP FROM PARCELMAP BC.
6. SCENARIO MAP SHOWS CLEARWATER IMPACT FORCE BASED ON HEC-RAS MODEL RESULTS FOR THE 200-YEAR RETURN PERIOD COMPLETED BY BGC. THIS IS A REPRESENTATIVE MAP AND DOES NOT SHOW THE FULL SUITE OF MODELLED SCENARIOS. SCENARIO DETAILS ARE OUTLINED IN BGC REPORT.
7. THIS MAP REPRESENTS A SNAPSHOT IN TIME. FUTURE CHANGES (DEVELOPMENT, DEBRIS FLOOD MITIGATION, GEOHAZARD EVENTS) MAY WARRANT RE-DRAWING OF CERTAIN AREAS.
8. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS UNKNOWN.
9. 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:	1:15,000
DATE:	MAR 2020
DRAWN:	LL, MIB, STT
CHECKED:	LCH
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

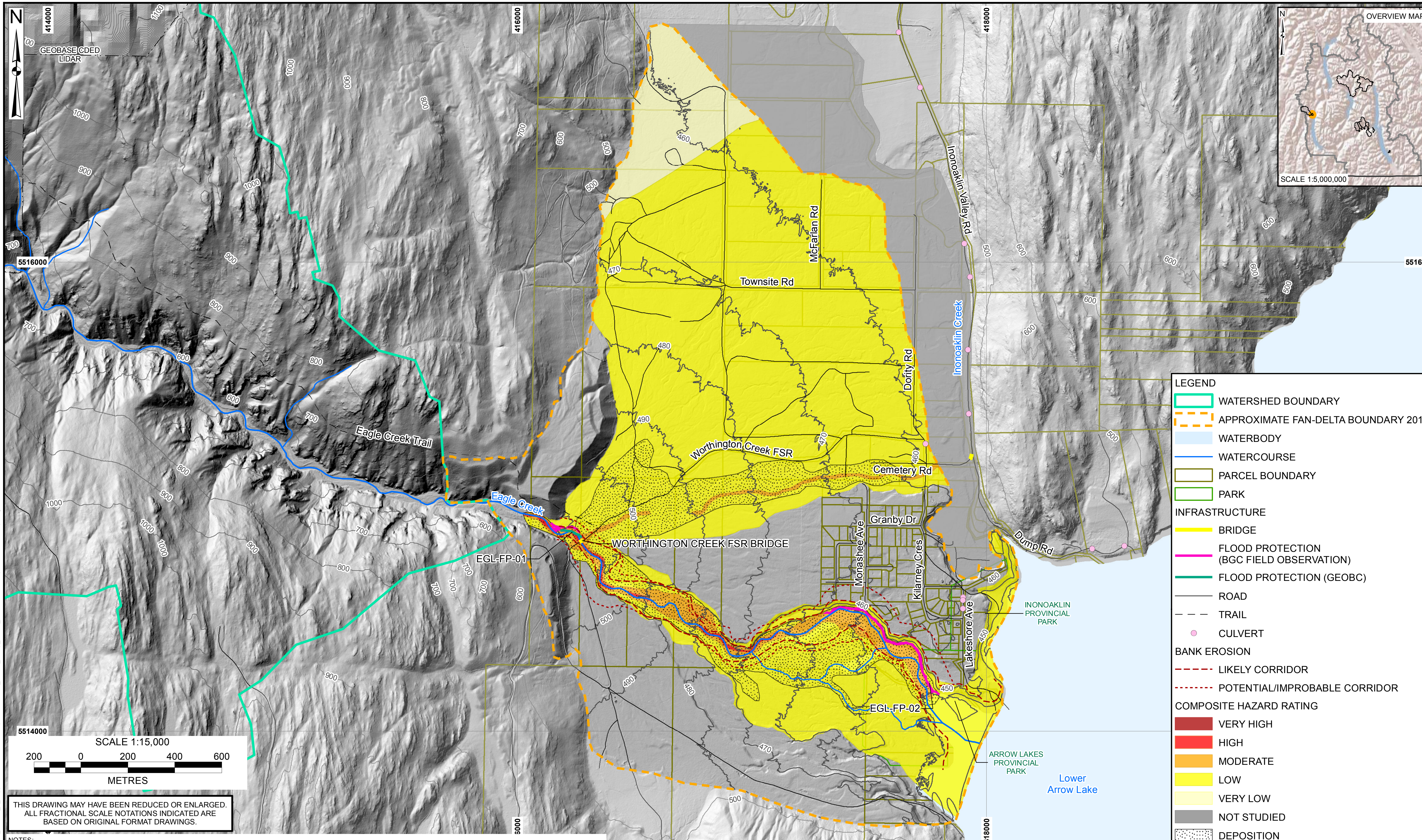
PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE: EAGLE CREEK 200 YEAR MODEL SCENARIO EGL-3a

PROJECT No.: 0268007

DWG No: 07

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20200207_RDCK_Steep_Creek_Hazards\07 Eagle Creek 200 Year Model Scenario.mxd



NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORTS TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY - EAGLE CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK, DATED 2018. CONTOUR INTERVAL IS 100 m AND 10 m ON FAN. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM BASED ON LIDAR DATED 2018.
4. COMPOSITE HAZARD RATINGS PORTRAYED ON THIS DRAWING ONLY REPRESENT HAZARDS STUDIED WITHIN THE FAN-DELTA BOUNDARY.
5. SURFACE FLOW ON PALEO SURFACES WITHIN THE FAN-DELTA BOUNDARY HAVE NOT BEEN ASSESSED IN THIS STUDY.
6. MODELLED BANK EROSION IS SHOWN AS A LIKELY CORRIDOR (DIVIDED BETWEEN CHANNEL BANKS BASED ON CHANNEL GEOMETRY) AND POTENTIAL/IMPROBABLE CORRDIOR (APPLIED EQUALLY TO BOTH BANKS).
7. THIS MAP REPRESENTS A SNAPSHOT IN TIME. FUTURE CHANGES (DEVELOPMENT, DEBRIS FLOOD MITIGATION, GEOHAZARD EVENTS) MAY WARRANT RE-DRAWING OF CERTAIN AREAS.
8. BUILDING FOOTPRINTS DIGITIZED BY BGC. CULVERT LOCATIONS FROM BC MINISTRY OF TRANSPORTATION. PARKS DATA FROM GOVERNMENT OF BC. ROADS DATA FROM BC DIGITAL ROAD ATLAS. RAILWAY DATA FROM GEOBASE NATIONAL RAILWAY NETWORK. ELECTRICAL, PETROLEUM, COMMUNICATION AND WATER INFRASTRUCTURE FROM INTEGRATED CADASTRAL INFORMATION SOCIETY. BANK PROTECTION FROM GEOBC AND BGC FIELD OBSERVATIONS. PARCEL MAP FROM PARCELMAP BC.
9. PROJECTION IS NAD 1983 UTM ZONE 11N.
10. 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:	1:15,000
DATE:	MAR 2020
DRAWN:	STT, LL, MIB
CHECKED:	LCH
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: REGIONAL DISTRICT CENTRAL KOOTENAY

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE: EAGLE CREEK
COMPOSITE HAZARD RATING MAP

PROJECT No.:	DWG No:
0268007	08

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20200207_RDCK_Steep_Creek_Hazards\08 Composite Hazard Map Eagle.mxd