RDCK FLOODPLAIN AND STEEP CREEK STUDY

Kokanee Creek

Final
March 31, 2020

BGC Project No.:
0268007

BGC Document No.:
RDCK2-SC-005F

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

BGC ENGINEERING INC. 500-980 Howe Street, Vancouver, BC Canada V6Z 0C8
Tel: 604.684.5900 Fax: 604.684.5909

TABLE OF REVISIONS

ISSUE	DATE	REV	REMARKS
DRAFT	March 10, 2020		Original issue (Drawings 07 not included)
FINAL	March 31, 2020		Final issue.

LIMITATIONS

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

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

EXECUTIVE SUMMARY

The Regional District of Central Kootenay (RDCK) requested that BGC Engineering Inc. (BGC) complete a detailed hydrogeomorphic hazard assessment of Kokanee Creek. Kokanee Creek was chosen as a high priority creek amongst hundreds in the RDCK from a risk perspective because of its comparatively high hazards and perceived consequences from hydrogeomorphic events (debris flows and debris floods). This report provides a comprehensive geomorphological and hydrological background and details the analytical techniques applied to create scenario and composite hazard rating maps for the Kokanee Creek fan-delta. The work presented herein is the foundation for possible future quantitative risk assessments or conceptualization and eventual design and construction of mitigation measures.

Kokanee 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, Duhamel creeks); those by debris flows (Kuskonook Creek); and hybrids (Procter and Redfish creeks). Kokanee Creek is a debris-flood prone creek draining two side-by-side watersheds. Of note is that Kokanee Creek is one of the few fans along the West Arm of Kootenay Lake that is not densely developed with urban housing, especially the central and eastern portion of the fan-delta. However, the eastern fan portions do contain a provincial park and campground.

Two numerical hydro-dynamic models were employed to simulate debris flood hazard scenarios on the fan-delta. The reason for using multiple 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, including bridge blockage scenarios. In addition, BGC applied a bank erosion model that allows estimation of bank erosion for different probabilities. This is especially important for debris floods, which are known to result in sudden and intensive bank recession in a single runoff event. Table E-1 provides key observations derived from the numerical modelling.

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

Process	Key Observations
Clearwater inundation (HEC-RAS results for all return periods)	• Kokanee Creek likely remains in its current channel for return periods up to 50 years. • The Highway 3A bridge has an estimated capacity of 400 m^3/s. So, none of the model scenarios assumed blockage of this structure. However, at the 200 or 500-year return period, water could overtop to the east upstream of the Highway 3A bridge, flow along the highway ditch and pond, possibly leading to highway embankment failures and/or highway breach, scenarios that were not explicitly modeled by BGC. • The 200- and 500-year return period flows that overtop across Highway 3A near the easternmost portion of the fan, flow towards Kootenay Lake inundating the provincial park campground. This is important as the vulnerability of people in tents and mobile homes is higher compared to constructed homes.
Sedimentation	• Given the low gradient of the lowermost reaches of Kokanee Creek, BGC modeled aggradation in the channel downstream of the Highway 3A bridge to simulate the combined effect of high lake levels and high creek flows. • For the 200- and 500-year return period debris floods, it is likely that the Highway 3A bridge could block due to aggradation and flow could divert to the east and across Highway 3A similar to the HEC-RAS clearwater flood results. BGC estimates that event volumes of 90,000 m^3 (200-year) to 120,000 m^3 (500-year) could flow onto the lower fan-delta of Kokanee Creek. • Sedimentation associated with debris floods can occur on the eastern and central fan-delta sector upstream and downstream of the Highway 3A crossing. The average deposition depth across the inundation area could be up to 0.7 m and 0.8 m for the 200- and 500-year debris floods, respectively. • Sedimentation associated with debris floods could reach up to 3 m thickness in the channel and up to 2 m outside the channel, generally on the lower eastern section of the fan in areas of localized depressions.
Bank Erosion	• Bank erosion could lead to slope failures on the western upper fan sector, which could result in impacts to Redfish Campground (Figure 3-5), a parking lot, and possibly adjacent storage buildings (12 Mile Storage) as well as avulsions should the creek be blocked at this location.
Auxiliary Hazards	• As with other debris-flood prone creeks in the study area that end in lakes, during high lake levels there is a substantial chance that the lower portions of Kokanee Creek will build up sediment and avulse east or west of the active channel downstream of Highway 3A. • Given that the modelling results suggest Kokanee Creek will tend to avulse towards the eastern fan portions along the highway ditch, there is an increased chance that the highway will be eroded and become impassable. In some cases, the highway could be overtopped, scoured and a new flow path develop through the highway which could concentrate flows resulting in higher flow velocities and flow depth and hence higher impact forces. This scenario was not modeled. • Bank erosion could lead to slope failures on the western upper fan sector, which could result in impacts to Redfish Campground (Figure 3-5), a parking lot, and possibly adjacent storage buildings (12 Mile Storage) as well as avulsions should the creek be blocked at this location.

The multiple process numerical modelling ensemble approach demonstrates the key hazards and associated risks stem from fan-delta avulsion that may be attributable to exceeding channel capacity, channel aggradation, log jams or bridge failure. An avulsion could result in widespread flooding particularly on the eastern portions of the fan-delta.

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 and debris flow frequencies. It provides a sense of the areas that could possibly be impacted by future events up to the highest modelled 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 land use 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 Kokanee 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 Kokanee Creek fan-delta is subject to very low and low hazards. Moderate and high hazards are confined to the channel of Kokanee Creek.

A review of the NHC/Thurber (1990) study which was a detailed hazard and risk assessment of Kokanee and other creeks in the RDCK, BGC concludes that the hazards and likely (as BGC did not quantify risks) the risks to loss of life are substantially lower than presumed in the NHC/Thurber report. NHC/Thurber did not benefit from lidar topography, detailed numerical modelling, and an additional 30 years of data that have accrued since their study and the present. In absence of such detailed information and analysis, it was likely justified to err on the conservative spectrum.

Several mitigation considerations are provided. They aim primarily to avoid or manage avulsion towards the east and through the Kokanee Creek provincial park. They include erosion protection, deflection berms, added culverts and possibly some land sterilization near the 12 Mile Storage facility. Overall, Kokanee Creek fan-delta is largely still in a natural state, a rare commodity along the Kootenay Lake west arm. This should be maintained as it allows portions of the creek to maneuver freely without resulting in excessive damage to buildings.

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, formation or reactivation of existing large landslides in the watershed that could impound Kokanee Creek, bridge re-design or alteration to the existing berm 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 Kootenay Lake levels could also 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 could 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). Of those, 9 were considered subject to debris floods, and one subject to debris flows as the dominant (i.e. most destructive) hydro-geomorphic hazard. The work focused 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 details the approach used by BGC to conduct a detailed steep creek geohazards assessment and mapping for Kokanee Creek, located approximately 18 km northeast of Nelson, BC in Electoral Area F. The site lies on the north side of the West Arm of Kootenay Lake. In its lower reaches, Kokanee Creek flows on the east side of Crescent Bay, BC, and through Kokanee Creek Provincial Park 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 Kokanee 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.

In addition to this report, BGC is providing a summary report for the entire assessment across different sites, *RDCK Floodplain and Steep Creek Study Summary Report* (BGC, March 31, 2020a) (referred to herein as the “Summary Report”). Readers are encouraged to read the Summary Report to obtain context about the objectives, scope of work, deliverables, and recommendations of the larger study. 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”), which describes the assessment methods applied for this study.

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

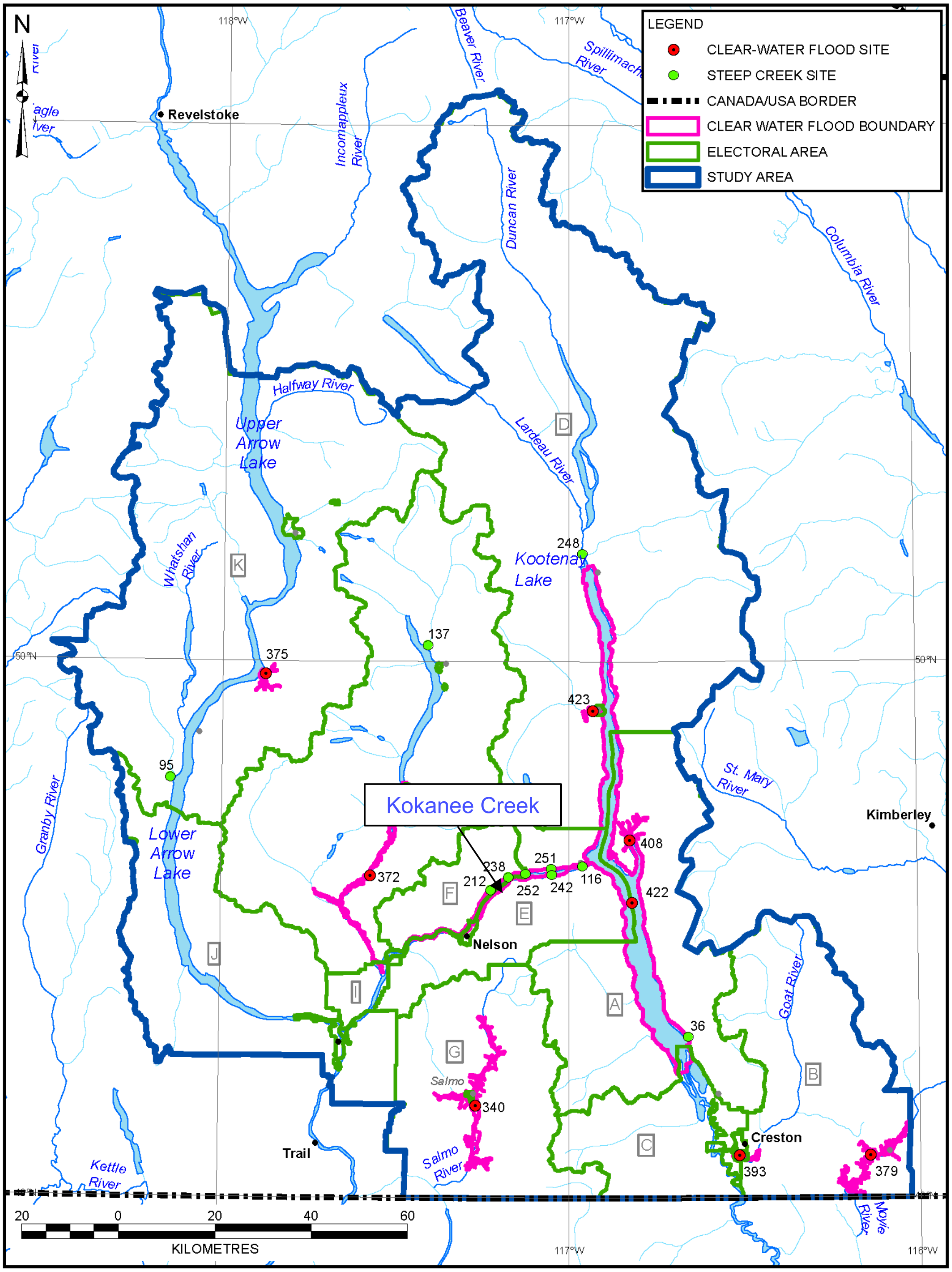


Figure 1-1. Hazard areas prioritized for detailed flood and steep creek mapping. Site labels correspond to hazard identification numbers in Cambio Communities. Kokanee Creek (No. 252) is labelled on the figure.

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 was 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 Kokanee Creek, the scope of work included:

- Characterization of the study area including the regional physiography and hydroclimate, and local geology, steep creek process, and watershed, fan 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) for steep creek flood hazard processes.
- 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 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 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™ web application and as geospatial data provided to RDCK.

This report is best read with access to a BGC web application, Cambio™. 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. A Cambio user guide is provided in the Summary Report (BGC, March 31, 2020a). As outlined in Section 1.1, the report is best read with the Summary Report and Methodology Report (BGC, March 31, 2020b).

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, Junior 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., Hydrotechnical Engineer
- Marc Olivier Trottier, M.A.Sc., P.Eng., Intermediate Hydrotechnical Engineer
- Rob Millar, Ph.D., P.Eng., P.Geo., Principal 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; Jack Park	Lauren Hutchinson; Carie-Ann Lau; Anna Akkerman Melissa Hairabedian
4	Jack Park	Carie-Ann Lau; Lauren Hutchinson
5.1	Lauren Hutchinson	Matthias Jakob
5.2	Melissa Hairabedian	Lauren Hutchinson
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	Sarah Davidson
5.6	Matthias Jakob	Lauren Hutchinson
6.1 – 6.2	Beatrice Collier-Pandya; Lauren Hutchinson	Matthias Jakob
6.3	Melissa Hairabedian;	Lauren Hutchinson
6.4	Matthias Jakob	Lauren Hutchinson
6.5	Gemma Bullard; Beatrice Collier-Pandya	Lauren Hutchinson; Anna Akkerman
6.6	Gemma Bullard	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.

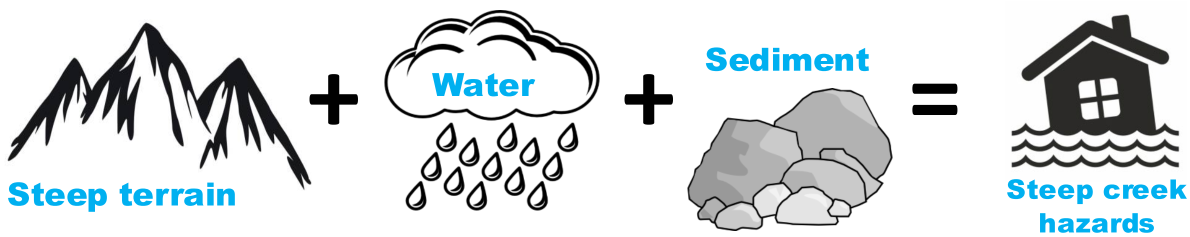


Figure 2-1. Illustration of steep creek hazards.

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.

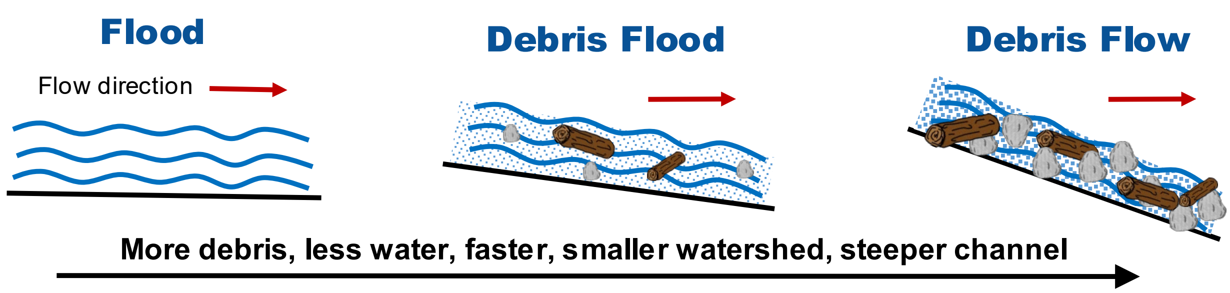


Figure 2-2. Continuum of steep creek hazards.

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.

Kokanee Creek, at the pre-screening level, was assigned to be a clearwater flood-prone creek. However, after completion of fieldwork and desktop analysis, it was reclassified as being subject to debris floods.

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 Jakob and Church (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.

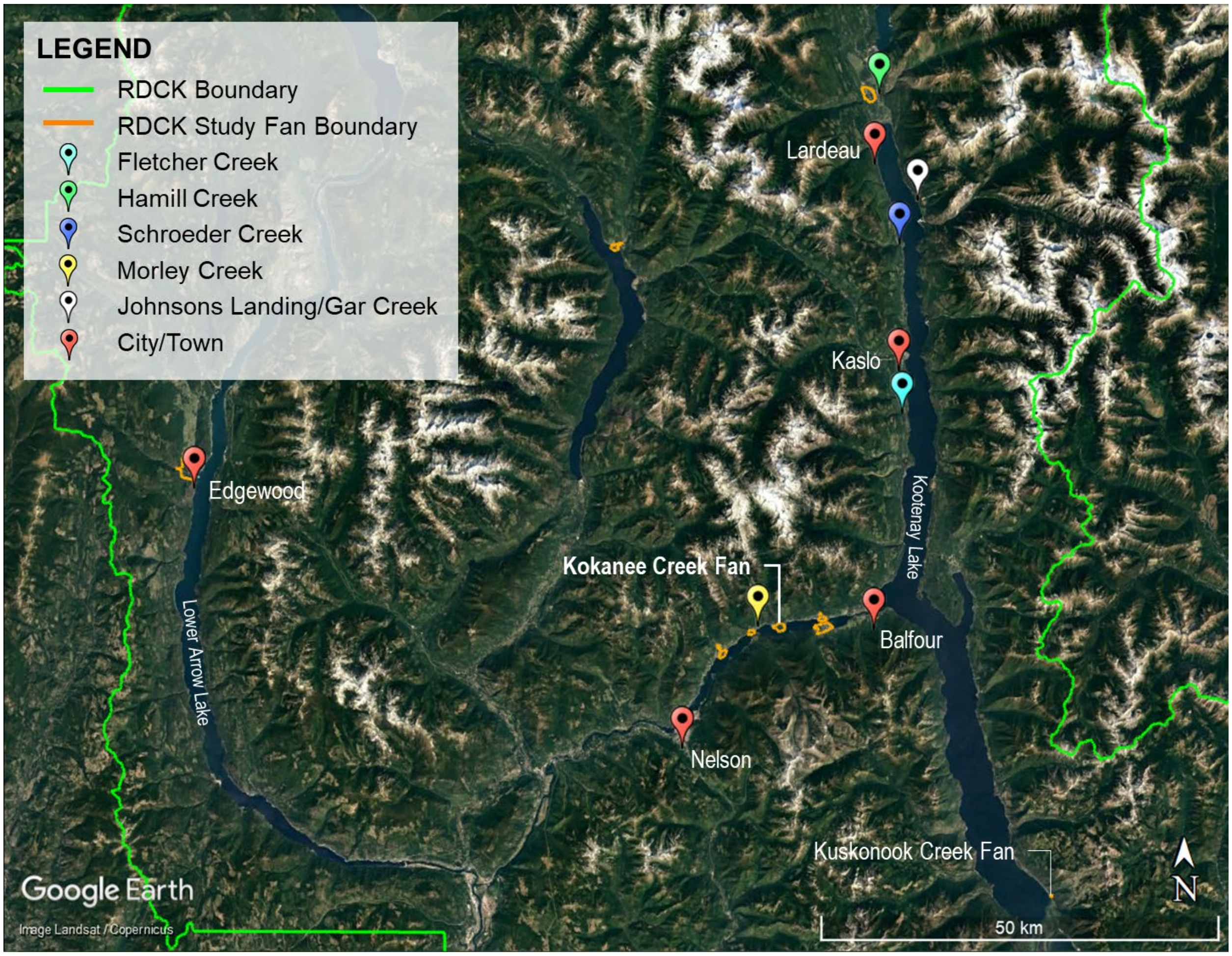


Figure 2-3. Locations of RDCK fans and recent clearwater floods, debris flows, and debris floods (Google Earth Pro, 2016).

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 & 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 modelled Type 2 discharge at the fan 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)
- $Q_{\text{max debris flood (full bed mobilization)}}$; 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.

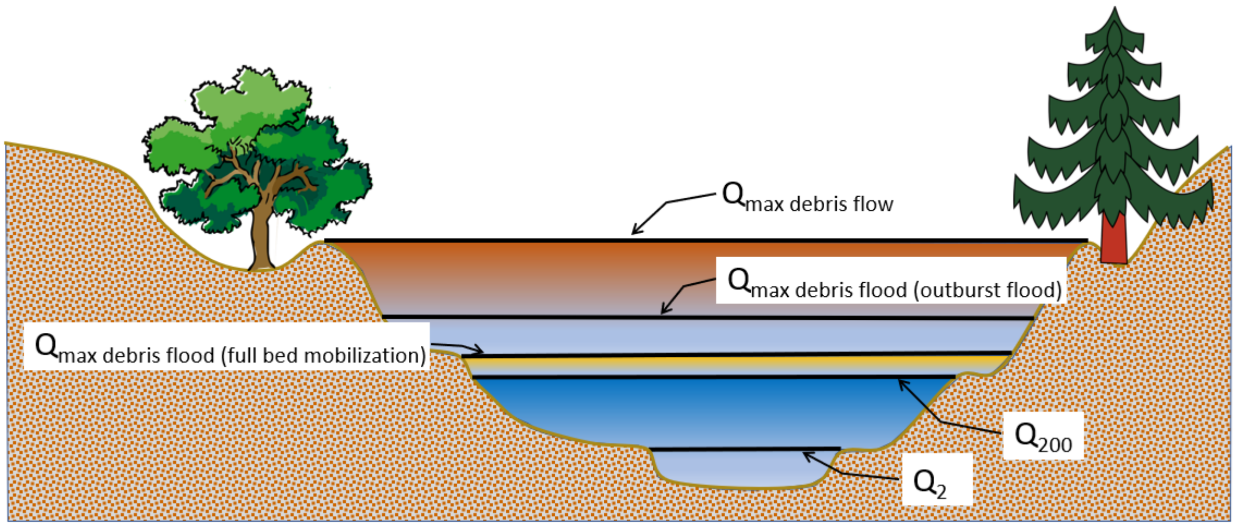


Figure 2-4. Conceptual steep creek channel cross-section showing peak discharge levels for different events. Note that for some outburst floods or debris flows the discharge may well exceed what is shown here.

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.

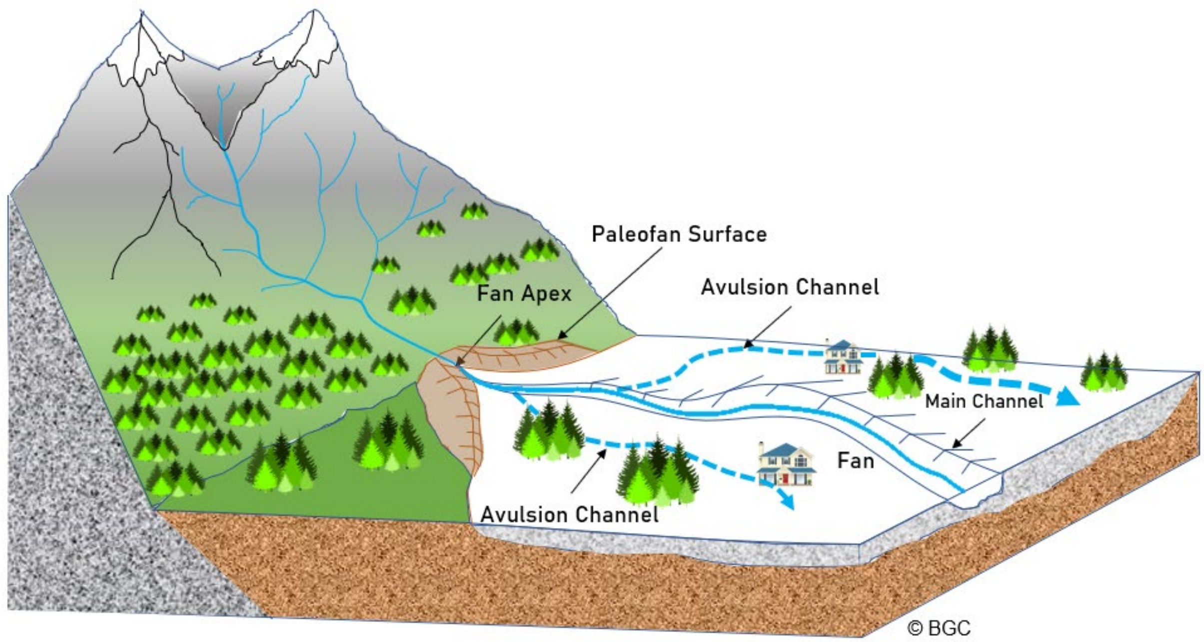


Figure 2-5. Schematic of a steep creek channel with avulsions downstream of the fan apex. Artwork by BGC.

3. STUDY AREA CHARACTERIZATION

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

3.1. Site Visit

Fieldwork on Kokanee Creek was conducted on July 24 and 29, 2019 and on November 20, 2019 by the following BGC personnel: Rob Millar, Anna Akkerman, Marc Olivier Trottier, Beatrice Collier-Pandya, and Hilary Shirra. Field work included channel hikes to look for evidence of high-water marks; assess bank erosion and previous creek alignments; measure grain size diameters (Wolman sampling) at the fan apex, the Highway 3A Bridge and the mouth (Appendix C); and, measure cross-sections at the bridge and other infrastructure crossing locations. Fieldwork focused on the active channel on the fan delta and recent overflow channels as a preliminary steep creek process assessment for Kokanee Creek indicated the dominant process type was clearwater flooding (Stream 1 Study (BGC, March 31, 2019)).[3] The upper watershed was flown by helicopter on July 6, 2019 and numerous photographs were taken for later analysis of major sediment sources to the channel (Appendix B).

3.2. Physiography

Kokanee Creek is located approximately 15 km northeast of Nelson, BC, along the West Arm of Kootenay Lake. The site lies within the Selkirk Mountains, which are a subgroup of the Columbia Mountains in southeastern BC. The watershed falls within the Central Columbia Mountain ecosection of the Northern Columbia Mountains ecoregion, which is drained by numerous streams that flow into Kootenay Lake, the Slocan River, and the Arrow Lake reservoir (Demarchi, 2011). The ecosection is characterized by long, uniformly steep slopes that terminate at sharp ridges and mountain peaks sculpted by cirque glaciers with mostly narrow valleys (Holland, 1976). Precipitation is high in the Central Columbia ecosection (mean annual precipitation of 886 mm), as moisture from coastal areas arrives from the south and west, bringing high humidity and rain in summer, and deep snow in winter (Demarchi, 2011). Typical vegetation includes Western Red Cedar and Western Hemlock trees at lower elevations (from 500 m) and Engelmann Spruce and Subalpine Fir trees along the mid-mountain slopes. The highest peaks in the Central Columbia ecosection reach up to approximately 3,200 m and consist of barren rock.

Drawings 01, 02A show the watershed and fan-delta boundaries of Kokanee Creek on a shaded, bare earth digital elevation model (DEM) created from lidar data. Drawing 03 shows a profile along the creek mainstem and tributaries. Representative photographs of the watershed and fan are provided in Appendix B.

[3] Upon further analysis, it was concluded that Kokanee Creek is also subject to debris floods at return periods in excess of 20 years.

3.3. Geology

3.3.1. Bedrock Geology

The Kokanee Creek watershed is underlain by granodioritic intrusive rocks of the Nelson Batholith, which formed in the Mid-Jurassic Period (Vogl & Simony, 1992). The watershed is situated in the approximately 1500 km^2, northern portion of the batholith, where subvertical to west-dipping foliation has been mapped north of the West Arm of Kootenay Lake (Vogl & Simony, 1992). The Midge Creek and Seeman Creek Faults (Moynihan & Pattison, 2013) are within 5 km of the watershed; however, no faults have been mapped within the watershed itself. Faults often provide preferential surface flow paths and represent locations of structural weakness. Given that no faults were mapped within the Kokanee Watershed, there are no assessed implications of the nearby faults on the present study.

3.3.2. Surficial Geology

Along Kokanee Creek, the surficial material is glaciofluvial in origin, while the West Kokanee Creek tributary is mostly underlain by till (Figure 3-1, Province of British Columbia. (2016)). The valley walls are composed of either till or colluvium overlying bedrock, and the highest ridges are composed of mixed colluvium and bedrock outcrops (Jungen, 1980). The abundant colluvium in the watershed, as well as the rockfall-prone bedrock outcrops, indicate that the watershed is likely largely supply unlimited, which implies a quasi-unlimited amount of sediment available in the watershed to be mobilized during extreme hydroclimatic events. Debris flows 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, they can flow further than debris flows sourced from the coarser-grained colluvium with a largely sandy matrix.

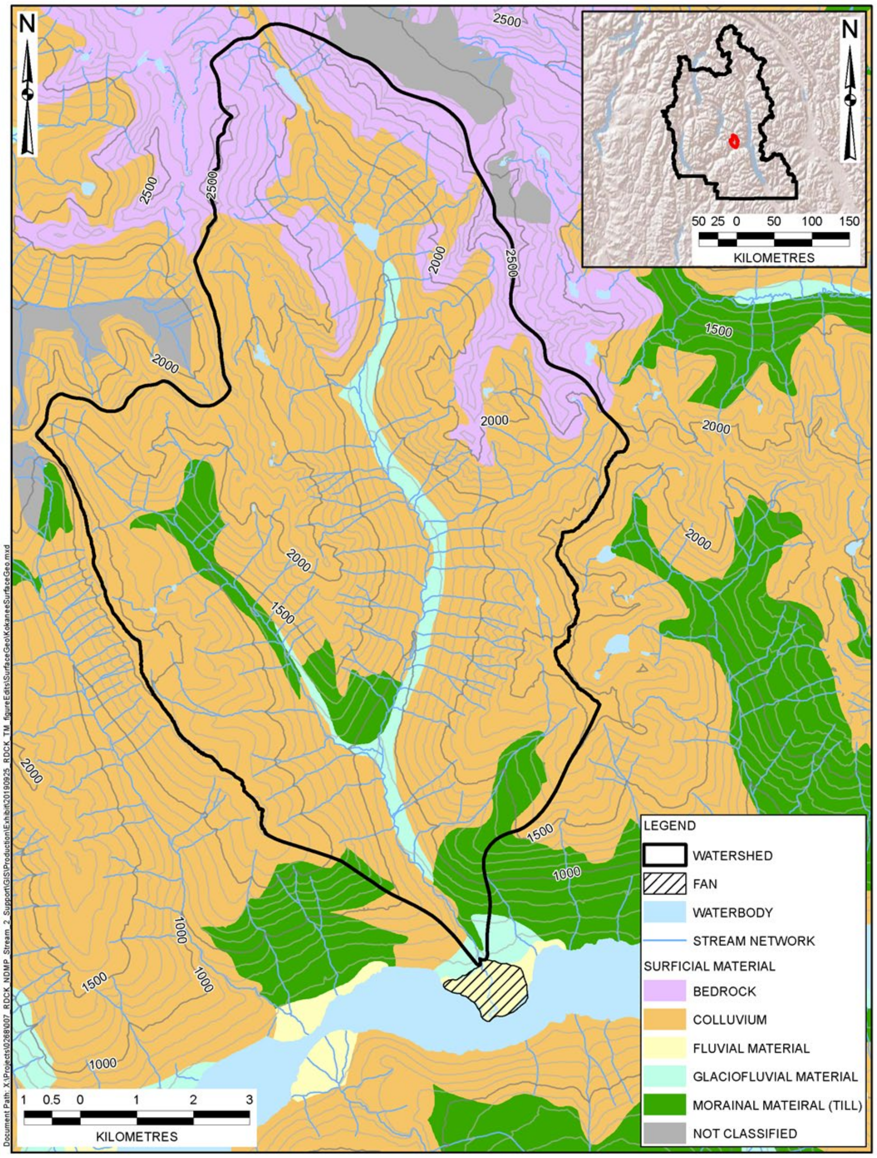


Figure 3-1. Surficial geology of the Kokanee Creek watershed (adapted from Province of BC, 2016).

3.4. Geomorphology

3.4.1. Watershed

Geomorphological analysis of Kokanee Creek included watershed and fan characterization using historical air photos (Drawings 04A and 04B) and lidar supplemented by literature on the regional geology, geologic history and physiography, and a field visit. Drawing 05 shows geomorphic features of the watershed.

The headwaters of Kokanee Creek are the mountainous slopes of Cond Peak and Grays Peak to the east (approximate elevations of 2,800 and 2,750 m) and Mount John Carter and Outlook Mountain to the west (approximate elevations of 2,610 and 2,590 m), with Kokanee Creek ultimately beginning at Kokanee Pass in the north (approximate elevation of 2,520 m). The upper reaches of the watershed are characterized by steep-sided valleys that BGC interprets to contain alpine permafrost environments with frost shattered bedrock based on lidar interpretation. Glacial cirques[4] can be found on the east facing slopes of the upper watershed that contain erodible sediment in talus slopes derived from the bedrock. The steep valley sides are crossed by numerous snow avalanche paths and debris flow tributaries that feed into the Kokanee Creek mainstem (Drawing 05). From the steep sided slopes, the valley transitions into a wide alluvial channel with lakes (Kokanee Lake and Gibson Lake) in the upper reaches (Photo 4, Appendix B). Throughout the watershed, the main channel has cut through glaciofluvial deposits in the valley bottom and truncated tributary debris flow fans thus supplying sediment to the creek. North-south trending lineaments are noted on the eastern-facing slopes within the mid reaches of the watershed (Drawing 05). An approximately 0.15 km^2 deposit from a rock avalanche is noted on the eastern-facing slope approximately 9 km upstream of the fan-delta apex (Photo 5, Appendix B).

Kokanee Creek has an average channel gradient of 5% above the fan-delta apex (Drawing 03). Three main tributaries join the creek within the watershed: Sunset, West Kokanee, and Busk creeks. The largest tributary, West Kokanee Creek (Drawing 03), has a large fan (approximately 0.12 km^2) at the confluence into the mainstem of Kokanee Creek, indicating substantial tributary sediment transfer to the mainstem.

Most of the watershed is forested with approximately 5% of the total watershed having been logged since 1900. The logging is concentrated in the lower watershed (Drawing 05), while large portions of the upper watershed are within Kokanee Glacier Provincial Park. Kokanee Creek Provincial Park covers most of the fan-delta and extends upstream from the fan-delta apex for approximately 800 m (Drawings 02A, 02B). Approximately 4% of the watershed area has burned since 1919, with the largest forest fire recorded in 1920 (FLNRORD, 2019a; 2019b).

A conspicuous feature was identified on Busk Creek (Figure 3-2), the tributary to Kokanee Creek closest to the fan apex (Drawings 03, 06). This feature has the appearance of a rapid very large flowslide resulting in a sizable (100,000 m^2) fan in Kokanee Creek which indicates a possible impoundment height of 10 to 20 m. The fan has since been deeply incised by Kokanee Creek. The fan surface is approximately 25 m above the present thalweg. The feature has not been visited in the field as it was detected on lidar after completion of the field component of this study. The materials and geomechanics of the presumed flowslide are unknown. However, in BGC's assessment, this is likely a unique event in the Holocene era as no other signs of a repeat events were found in this or other tributary watershed. It is therefore believed to be outside the return period range considered in this study.

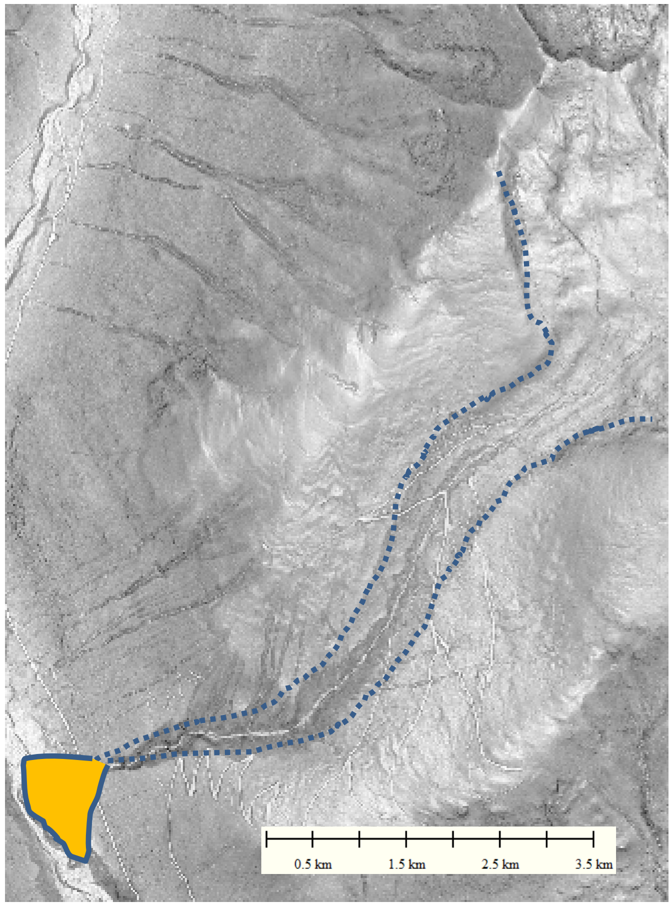


Figure 3-2. Old interpreted flowslide (blue dashed line) on Busk Creek upstream of the Kokanee Creek fan apex.

Table 3-1 summarizes relevant geomorphic characteristics of the Kokanee Creek watershed, which are indicators of the process type and anticipated behaviour of the watershed in response to high runoff. 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 3.4.3). The channel gradient above the fan apex provides an indication of whether transportation of sediment is likely, and the fan gradient approximates the angle where sediment deposition of larger flows from the watershed generally ensues.

Table 3-1. Watershed characteristics of Kokanee Creek.

Characteristic	Value
Watershed area (km^2)	96
Fan-delta area (km^2)	1.21
Active fan-delta area (km^2)[1]	1.24
Maximum watershed elevation (m)	2,800
Minimum watershed elevation (m)	575
Watershed relief (m)	2,225
Melton Ratio[2]	0.23
Average channel gradient of mainstem above fan apex (%)	5
Average channel gradient on fan (%)	4.5
Average fan gradient (%)	11

Notes:
1. Active fan-delta area includes 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.

3.4.2. Kokanee Creek Fan-Delta

An overview of the Kokanee Creek fan is shown in Drawings 02A, 02B, while Drawing 06 shows geomorphic features on the fan. Locations referred to in the text below are labelled on these drawings. The fan areas delineated on the drawings have been interpreted by BGC based on lidar and field data; however, the fan extent beyond the lidar data limits at Kootenay Lake are difficult to define due to changing lake levels.

Kokanee Creek flows south across the fan that extends into the West Arm of Kootenay Lake. The majority of the Kokanee Creek fan is contained within Kokanee Creek Provincial Park with only a small portion of the western fan developed. Kokanee Creek first flows through a confined section immediately downstream of the fan apex where the creek is flanked by a paleofan surface on either side. The paleofan surface formed during a time of different base level and may have been associated with Kootenay Lake being impounded by glaciers disrupting drainage and leading to much higher lake levels than today. Anecdotal evidence points towards glacial-lacustrine sediments at elevations well above the current lake level. In addition, outwash gravels (glacial fluvial sediments) can likely be found flanking the hillsides in the valley. As Kootenay Lake receded to its current level Kokanee Creek eroded into this historical surface and created the modern fan. In lidar, paleochannels and debris lobes near the fan apex are visible but muted, suggesting historical activity on the fan. The channel on the fan is wandering but was dredged and straightened in the 1970s around the Highway 3A bridge and downstream for approximately 400 m (Figure 3-3) (Dohan, 2013; BC Parks, 2019).

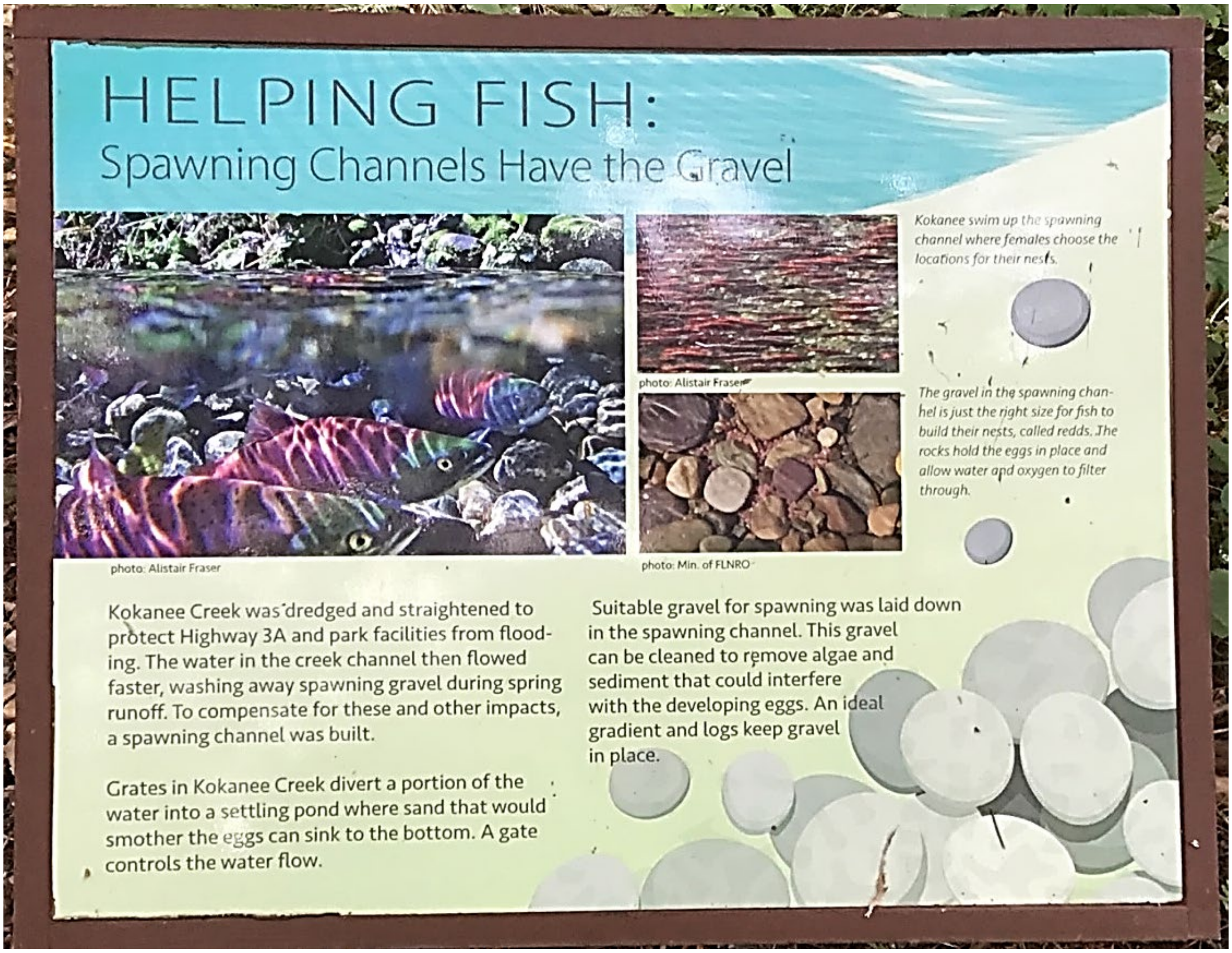


Figure 3-3. Information on dredging and straightening of Kokanee Creek in the 1970s, and the fish spawning channel.

Near the channel outlet into Kootenay Lake the channel is laterally unstable and has changed positions frequently throughout the air photo record. The Kokanee Creek fan-delta was partially submerged due to the raise of lake levels when the Corra Linn Dam (Drawing 06), located southwest of Nelson, began operation in 1938. The dam raised lake levels by approximately 2 m (Touchstone Nelson, 2007) and BGC understands that this level will be maintained. The distal portions of the fan, visible in historical air photos (Section 6.2.2), were flooded by the lake level raise. Lower sections of Kokanee Creek were backwatered (i.e., the creek surface water level is raised by the lake level) by Kootenay Lake during BGC’s July 2019 site visit (Photo 13, Appendix B). Channel morphology, bed material and bank vegetation indicate that the creek is regularly backwatered, and sections of the bank are likely flooded when lake levels are at the high end of the dam’s operating range.

Kokanee Creek fan has a large submerged portion compared to other fans in the West Arm as evident in historical air photos (Drawings 04A and 04B) and Google Earth imagery. This submerged portion appears to have been impacted by wave action which has created dunes and may contribute to aggradation in the channel reach immediately upstream of the outlet.

3.4.3. Steep Creek Process

BGC assessed the potential steep creek process types and hazards on Kokanee 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, Kokanee Creek plots in the zone of floods to debris floods (Figure 3-4). The points shown on the plot are subject to some error and watersheds can be subject to multiple processes at different timescales. For example, it is not possible from this plot to determine if a small tributary near the fan apex could produce a debris flow that reaches the fan apex or travels beyond. For this reason, it is important to consider additional evidence to supplement the assessment of process type.

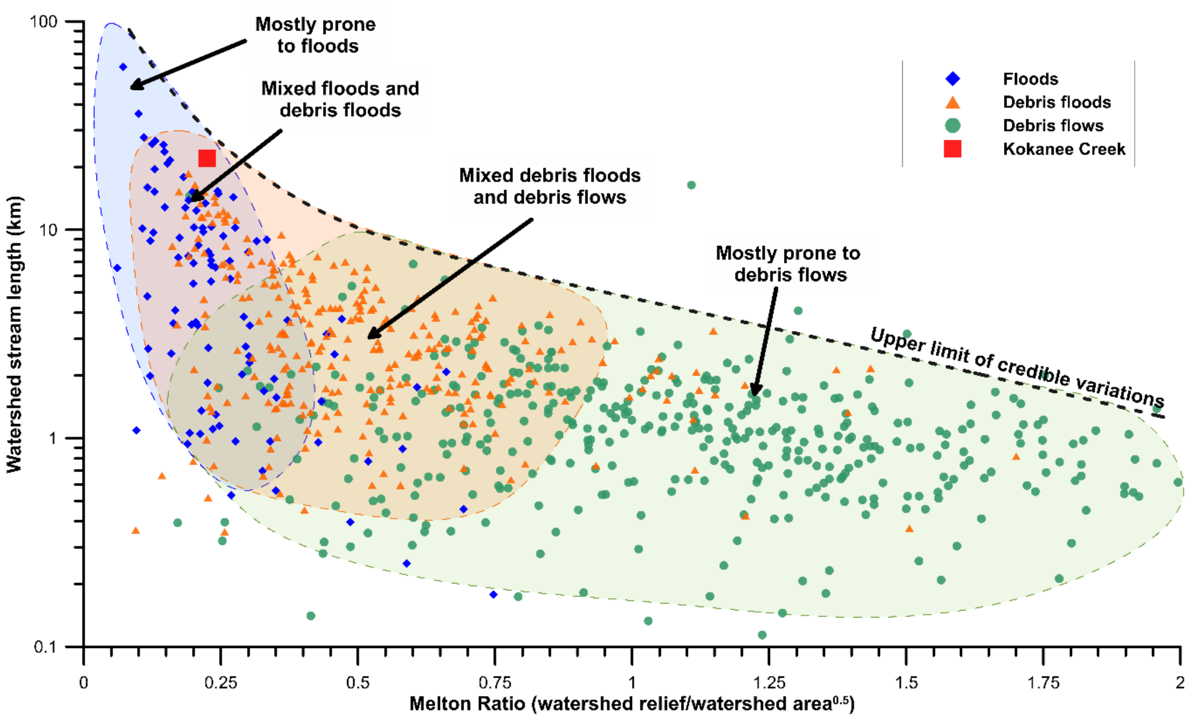


Figure 3-4. Tendency of creeks to produce floods, debris floods and debris flows, as a function of Melton Ratio and stream length (data from Holm et al., 2016 and Lau, 2017). See Table 3-1 for Kokanee Creek watershed data.

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. See Section 6.1 for further details on selection of hydrogeomorphic process for hazard analysis.

3.5. Existing Development

Development on the Kokanee Creek fan-delta comprises a small community east of Crescent Bay and the western fan-delta boundary (Drawings 02A, 02B). Petroleum infrastructure transects mainly along Highway 3A on the mid-fan, and electrical infrastructure across the fan apex. The majority of the eastern side of Kokanee Creek is occupied by Kokanee Creek Provincial Park, which includes multiple campgrounds and trails. An additional campground is located northwest of the Highway 3A bridge (Redfish Campground, Figure 3-5). West of Redfish Campground there are industrial buildings associated with the storage facility, 12 Mile Storage.

Figure 3-5. Kokanee Creek Provincial Park campgrounds.

The 2016 census does not have a population estimate for Crescent Bay and instead groups the community into the RDCK electoral area (Statistics Canada, 2016). The estimated total improvement value of parcels intersecting the Kokanee Creek fan based on the 2018 BC Assessment Data is $17,081,300 (BGC, March 31, 2019).

3.5.1. Bridges

Bridge locations are shown on Drawings 02A, 02B. Kokanee Creek passes under two bridge structures on the fan-delta: a Pedestrian Bridge and Kokanee Highway Bridge (Table 3-2, Figure 3-6). The Pedestrian Bridge, approximately 220 m downstream of the Kokanee Highway Bridge, is not included in the public dataset (Government of British Columbia, 2020b). There are also two small pedestrian bridges over the fish spawning channel. The upstream bridge is located in line with the Pedestrian Bridge, while the downstream bridge is located approximately 150 m downstream of the Pedestrian Bridge (Drawings 02A, 02B). Both bridges over the spawning channel are approximately 40 m east of the main channel. These bridges were not considered in our modelling scenarios, as they do not cross the active Kokanee Creek channel.

Table 3-2. Estimated dimensions of bridge crossings on Kokanee Creek fan-delta.

Bridge	Span (m)	Height Above Channel Center (m)	Notes
Kokanee Highway Bridge	29	3	Highway 3A, 2-lane road. Bank protection on the downstream side on both right and left banks.
Pedestrian Bridge	26.7	1.7	Downstream of Kokanee Highway Bridge. Channel center closer to the right bank. Gravel bar in the middle likely from pier of an old bridge.

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

A) Standing on the upstream right bank of Kokanee Highway Bridge, looking east.

B) On downstream left bank looking upstream at the downstream face of Kokanee Highway Bridge.

C) Standing on Kokanee Highway Bridge, looking south and downstream of the creek. Pedestrian Bridge visible downstream (top of the photo).

D) Standing on the upstream right bank looking at the upstream face of the Pedestrian Bridge.

Figure 3-6. Bridge structures encountered on Kokanee Creek fan during BGC's field work in July 2019. Refer to Drawings 02A, 02B for locations.

3.5.2. Flood Protection Structures

Kokanee Creek was dredged and straightened in the 1970s to protect Highway 3A and the park facilities from flooding (Dohan, 2013 and BC Parks, 2019). Field observations indicate that the dredged material was placed along both banks for flood protection from approximately 200 m upstream of the Kokanee Highway Bridge to approximately 400 m upstream of Kootenay Lake. There are two designated flood protection structures along the banks of Kokanee Creek upstream of the Kokanee Highway Bridge (KKN-FP-01 and KKN-FP-02) and two structures BGC identified during site visits downstream of the bridge (KKN-FP-03 and KKN-FP-04). Figure 3-7 summarizes these structures and the locations are shown on Drawings 02A, 02B. The exact lengths and locations of KKN-FP-03 and KKN-FP-04 were not mapped in the field and approximate extents are shown on Drawings 02A, 02B. KKN-FP-01 is located on the right bank (Figure 3-7a), approximately 100 m upstream the Kokanee Highway Bridge and consists of bank protection over an approximate distance of 120 m. KKN-FP-02 is an approximately 1 to 1.5 m high riprapped dike located immediately upstream of the Kokanee Highway Bridge on the left bank that extends approximately 140 m upstream. A small breach or a low point (by 0.5 to 1 m compared to the dike height) along KKN-FP-02 was noted by BGC approximately 90 m upstream of the bridge (Figure 3-7b).

Downstream of Kokanee Highway Bridge both banks have varying degrees of bank protection. KKN-FP-03 is an approximate 1 to 1.5 m high berm[4] that extends on the right bank from the Kokanee Highway Bridge to approximately 200 m downstream of the Pedestrian Bridge. A low spot along KKN-FP-03 was noted approximately 30 m downstream of the Pedestrian Bridge (Figure 3-7c, Drawings 02A, 02B). The material forming KKN-FP-03 appears similar to channel material (rounded cobbles and boulders, 0.2 to 0.5 m in diameter) and was likely placed during dredging and straightening of the channel. The fourth flood protection structure, KKN-FP-04, was noted on the left bank from the Kokanee Highway Bridge and extending to the outlet of the Fish Spawning Channel. The lower section of KKN-FP-04 has been riprapped (angular boulders, approximately 0.5 to 1.0 m in diameter) from approximately 150 m downstream of the Pedestrian Footbridge (Figure 3-7d, Drawings 02A, 02B) to the outlet of the Fish Spawning Channel (Figure 3-7e). The upstream portion of KKN-FP-04 is composed of material similar to KKN-FP-03.

KKN-FP-05 is located on the right bank of Kokanee Creek upstream of the section that appears to be dredged and straightened. KKN-FP-05 is an approximately 10 to 15 m long, 2 to 2.5 m high berm constructed of rounded cobbles and boulders up to 0.4 m in diameter (Figure 3-7f). The purpose of this berm is not entirely clear, but it could provide bank stability for vehicle access for the nearby water license point of diversion.

[4] In this report, a berm refers to a non-engineered dike designed to protect against erosion and high water levels.

Table 3-3. Attributes of Kokanee Creek flood protection works.

Attribute	Flood Protection Structure				
BGC ID	KKN-FP-01	KKN-FP-02	KKN-FP-03	KKN-FP-04	KKN-FP-05
Source[1,2]	iMapBC	iMapBC[3]	BGC Field Observation	BGC Field Observation	BGC Field Observation
Type	Protection	Dike	Berm	Berm	Berm
Orphan (Y/N)[4]	Y	Y	-	-	-
Comments	Rounded boulders (D_{50} = ~0.5 m)	Berm, thick vegetation c/w trees to 100 cm		Ends at the outlet of the fish spawning channel	Edge of storage container property. Rounded boulders (D_{50} = ~0.4 m)
Survey Year(s)	2003	2003	-	-	-
Erosion Protection Side	Right	Left	Right	Left	Right
Length (m)	119	138	-	-	-

Notes:
1. iMapBC data downloaded from Flood Protection Structural Works layer on February 26, 2020.
2. BGC Field Observation made on July 24, 2019.
3. Two or more contiguous segments.
4. Only the structures within iMapBC data were classified as orphan structures.

A) On the left bank looking across Kokanee Creek at KKN-FP-01.

B) On the left bank looking east at the low point along KKN-FP-02, approximately 90 m upstream of the Highway Bridge.

C) In the avulsion channel looking east at the low point in KKN-FP-03. Kokanee Creek runs behind the trees.

D) On the right bank looking east and downstream at KKN-FP-04.

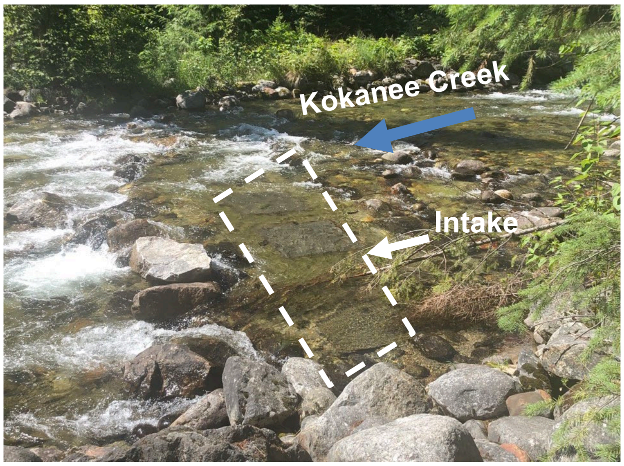
E) On the left bank of the Fish Spawning Channel outlet looking north at the end of KKN-FP-04 riprap.

F) On the left bank looking across Kokanee Creek at KKN-FP-05 berm.

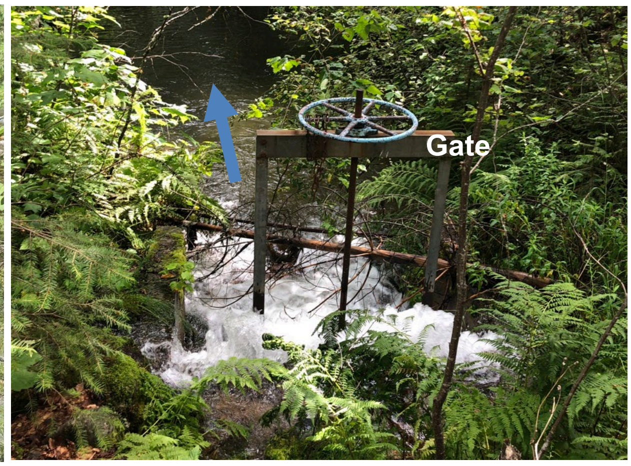
Figure 3-7. Flood protection measures encountered on Kokanee Creek fan during BGC's field work in July 2019. Refer to Drawings 02A, 02B for locations.

3.5.3. Other Structures

A 330 m long fish spawning channel (Drawings 02A, 02B) was built in 1985 approximately 100 m downstream of the Kokanee Highway Bridge and runs along the eastern side of Kokanee Creek. Water enters the fish spawning channel through an intake embedded below the Kokanee bed and covered with a grate (Figure 3-8a). The intake flow is controlled by a gate at the head of the spawning channel (Figure 3-8b). Downstream of the gate, the channel flows over a weir (Figure 3-8c) and into spawning habitat (Figure 3-8d).



A) On the left bank, looking west at the Fish Spawning Channel intake in Kokanee Creek.



B) On trail, looking south and downstream at gate controlling flow into the Fish Spawning Channel.

C) On the left bank looking south-west and downstream at weir and staff gauge for measuring flow in Fish Spawning Channel.

D) On the left bank of the Fish Spawning Channel looking south and downstream at the bridge just upstream of channel outlet.

Figure 3-8. Fish Spawning Channel observations during BGC's field work in July 2019.

3.6. Hydroclimatic Conditions

3.6.1. Existing Conditions

Climate normal data were obtained from Environment and Climate Change Canada's Kaslo station (600 m), located approximately 35 km north of the Kokanee Creek outlet (Environment and Climate Change Canada, n.d.). Daily precipitation and temperature data are available from 1894 to 2015 at this station. Figure 3-9 shows the average monthly temperature and precipitation for this station from the 1981 to 2010 climate normals. Mean annual precipitation (rain and snow) is 886 mm (Table 3-4), and monthly precipitation peaks in November with an average of 113 mm.

The measured precipitation at the Kaslo station is lower than the precipitation in the Kokanee Creek watershed, where the mountaintops extend more than 1600 m above Kootenay Lake. This is due to orographic effects, which occur when an air mass is forced up over rising terrain from lower elevations. As it gains altitude it quickly cools down, the water vapour condenses (forming clouds), ultimately resulting in precipitation.

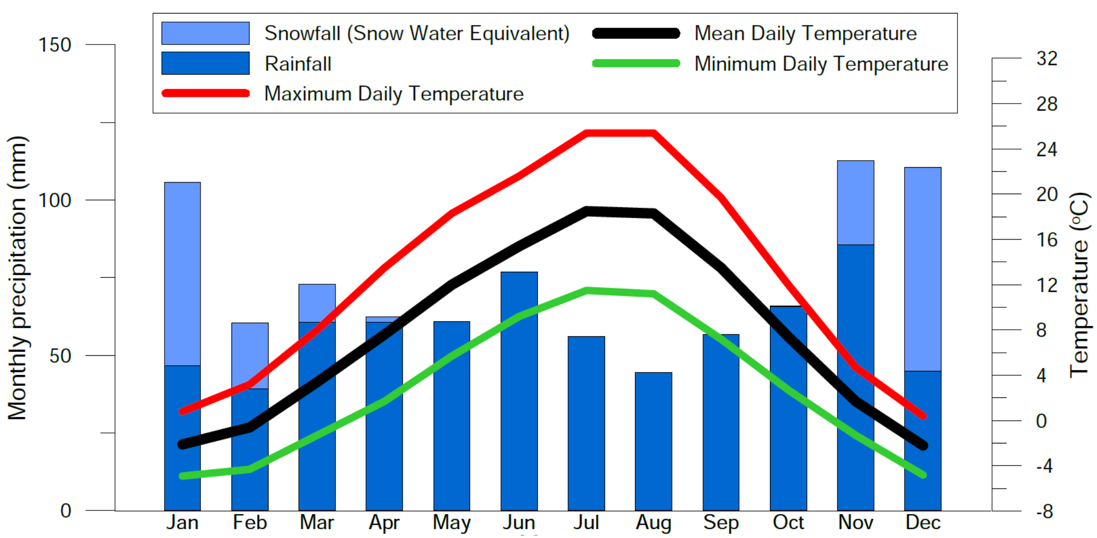


Figure 3-9. Climate normal data for Kaslo station from 1981 to 2010.

Table 3-4. Annual total of climate normal data for Kaslo station from 1981 to 2010.

Variable	Annual Total	Percent of total annual precipitation (%)
Rainfall (mm)	698	79
Snowfall (cm)	188	21
Precipitation (mm)	886	100

To understand the regional distribution of precipitation and snowfall patterns and supplement the data from the Kaslo station, BGC obtained climate 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 watershed is 1405 mm, varying as a function of elevation. The same trend is evident in precipitation as snow (PAS) over the watershed where the annual average is 839 mm. PAS increases with elevation; therefore, Kokanee Creek watershed accumulates greater precipitation falling as snow compared to the Kaslo station.

3.6.2. Climate Change Impacts

The watershed lies within the Central Columbia Mountain ecosection of the Northern Columbia Mountains ecoregion. 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 & Quick., 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 historical (average for the 1961 to 1990 period) mean annual temperature (MAT) in the Kokanee Creek watershed is projected to increase from 2.0ºC to 5.5ºC by 2050 (average for the 2041 to 2070 period). MAP is projected to increase from a historical value of 1405 mm to 1490 mm by 2050, while PAS is projected to decrease from a historical value of 839 mm to 577 mm by 2050 in the Kokanee Creek watershed. Projected change in climate variables from historical conditions for the Kokanee Creek watershed are presented in Table 3-5.

Changes in discharge 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; Farjad et al., 2016). Peak flows may increase or decrease depending on the watershed characteristics and the balance of temperature and precipitation changes in the future.

Table 3-5. Projected change (RCP 8.5, 2050) from historical conditions (1961 to 1990) for the Kokanee Creek watershed (Wang et. al, 2016).

Climate Variable	Projected Change
Mean Annual Temperature (MAT)	+3.5 ºC
Mean Annual Precipitation (MAP)	+84 mm
Precipitation as Snow (PAS)	-262 mm

4. SITE HISTORY

4.1. Introduction

Kokanee Creek flows through Kokanee Creek Provincial Park and into Kootenay Lake at Kokanee Point. Residents have lived on the fan-delta since the late 1800s. BGC notes that the community has been previously named “Crescent Bay” and the creek has also been referred to as “Yuill Creek”. Historically, the Kokanee Creek watershed was explored and developed for mineral exploration and mining. A large portion of the upper watershed is part of the Kokanee Glacier Provincial Park.

Historic mining activity at Molly Gibson Mine dates back to at least 1896. Molly Gibson Mine is located on the west facing slopes upslope of Gibson Lake in the upper Kokanee Creek watershed. The mine is accessed via the Kokanee-Busk FSR (Drawing 01). Mining activity continued under different companies in fits and starts until 1967 (Ministry of Energy, Mines and Petroleum Resources, 1988).

4.2. Document Review

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

- Archival records from the BC Archives and Nelson Touchstone Museum.
- 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).
- Research articles.
- Historical flood and landslide events from the following sources:
    - Social media and online media reports
    - Septer (2007)
    - DriveBC historical events (2009 to 2017)
    - Canadian Disaster Database (Public Safety Canada, n.d.)
    - MFLNRORD.
- Historical wildfire perimeters (MFLNRORD, n.d.).
- Cutblock perimeters (MFLNRORD, n.d.)

BGC’s review of the NHC/Thurber (1990) study is not aimed as a critique but rather a brief summary of the findings. The different methodologies used by that study and this one are discussed, as the former is frequently quoted by practitioners working on single lot hazard assessments.

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

Year	Month/Day	Source	Purpose
1990	April	Northwest Hydraulic Consultants Ltd. and Thurber Consultants Ltd.	Hazard Assessment
1998	February	Klohn Crippen Consultants Ltd.	Terrain Stability Inventory
2011	March	N/A[1]	Precondition for Site-specific Exemption

Note:
1. Incomplete application notice, as the applicant did not provide an engineer's report.

4.2.1. NHC/Thurber (1990)

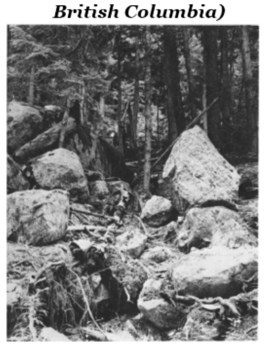
In 1990, a detailed report was authored by a team of Northwest Hydraulic Consultants Ltd (NHC) and Thurber Consultants (Thurber), titled: Alluvial Fan Hazard Assessment, Regional District of Central Kootenay Electoral Area "E" & "F". This assessment included Duhamel, Sitkum, Kokanee, Redfish, Harrop, Procter, Laird, and Narrows creeks. Except for the latter two (Laird and Narrows), those same creeks were prioritized for detailed study by BGC. A detailed comparison of the NHC/Thurber study with the present work is included in Section 6.7.2.

4.3. Historic Timeline

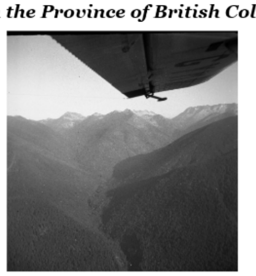
Figure 4-1 provides a timeline summary of floods and mitigation history for Kokanee Creek. For location references, refer to Drawings 01, 02A, 02B. The historical event inventory is assumed to be incomplete, but the information contained within it can be used to identify the location of past geohazards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

- One notable hydrogeomorphic event was recorded in 1968. BGC notes that other hydrogeomorphic events were observed in the air photo record (between 1929 and 1939, and between 1939 and 1945) and others may have occurred that may not be documented by the available records.
- NHC/Thurber (1990) noted the presence of large boulders near the fan apex, suggesting a pre-historic large debris flood or debris flow event.
- The channel location on the fan has been relatively stable upstream of the highway bridge, and more unstable near the mouth of the channel at Kootenay Lake.
- Logging has taken place in the lower watershed and on the West Kokanee Creek tributary.
- Water levels at the toe of the fan are influenced by reservoir levels on Kootenay Lake.

Avalanche path in Kokanee Creek watershed, 1980 (Copyright Province of British Columbia. All rights reserved. Reproduced with permission from the Province of British Columbia)



Bouldery deposits in Kokanee Creek watershed, 1980 (Copyright Province of British Columbia. All rights reserved. Reproduced with permission from the Province of British Columbia)



Looking up Kokanee Creek from the air above the West Arm of Kootenay, September 1963 (Photo by John D. Smith, Courtesy of Touchstones Nelson: Museum of Art and History, 1996.008.046)

Geohazard History

1983 - Flooding with minor erosion/shifting

1968 - Flood on Kokanee Creek caused the creek to flow over the bank on the north side of the highway, through the park road and camp sites

1958 - Airphotos show creek occupying several channels at mouth

1939 to 1945 - Avulsion channel east of main channel evident in the air photo record

1929 to 1939 - Fresh sediment visible in the air photos in the channel from fan apex to outlet

1920 - Two lightning-caused wildfires burned approximately 400 ha in the upper watershed

1908 - Legal surveys show single channel at lake outlet

December 1902 - Snow slide at the Molly Gibson Mine (northeastern watershed) caused nine fatalities

1880s - West Arm drainage areas burned in search of mineral deposits

Mitigation

Late 1960s to early 1970s - Resident notes of Ministry of Highways excavating sediments out of the stream and placing them on the side of the creek for approximately 500 m to 600 m along the creek.

1955 - Kokanee Highway Bridge constructed

Development

2018 - Viewing platform constructed over Kokanee Creek spawning channel

Mid 1990s to mid 2010s - Logging in lower watershed and West Kokanee Creek tributary

Mid 1980s - Logging in lower watershed

1985 - 330-m long fish spawning channel (Drawing 02) was built approximately 100 m downstream of the Kokanee Highway Bridge

1970s - Kokanee Creek was dredged and straightened to protect Highway 3A and the park facilities from flooding

Late 1960s to early 1970s - Logging in watershed

1955 - Kokanee Creek Provincial Park on alluvial fan is established

1938 - Corra Linn Dam activated downstream of Kokanee Creek on Kootenay River.

1922 - Kokanee Glacier Provincial Park in upper watershed is established

1899 - Sleigh road constructed connecting the Ten Mile wagon road and Kokanee

1896 - Kokanee Creek, also known as Yuill Creek, was so named by October 1896 and a townsite called Kokanee was laid out at its head, adjoining the Molly Gibson Mine (northeastern watershed)

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

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

Figure 4-1. Summary of recorded geohazard, mitigation, and development history at Kokanee 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). The method applied to Kuskonook Creek (Table 1-1) is for debris flow prone steep creeks. This section summarizes the overall workflow as well as any specific deviations from the steep creek methodology applied at Kokanee Creek. Figure 5-1 shows the workflow to develop frequency-magnitude (F-M) relationships for Kokanee Creek and other flood and debris flood prone creeks in the RDCK.

In comparison to Figure 5-1, the field investigation at Kokanee Creek did not include test trenching or dendrogeomorphology.

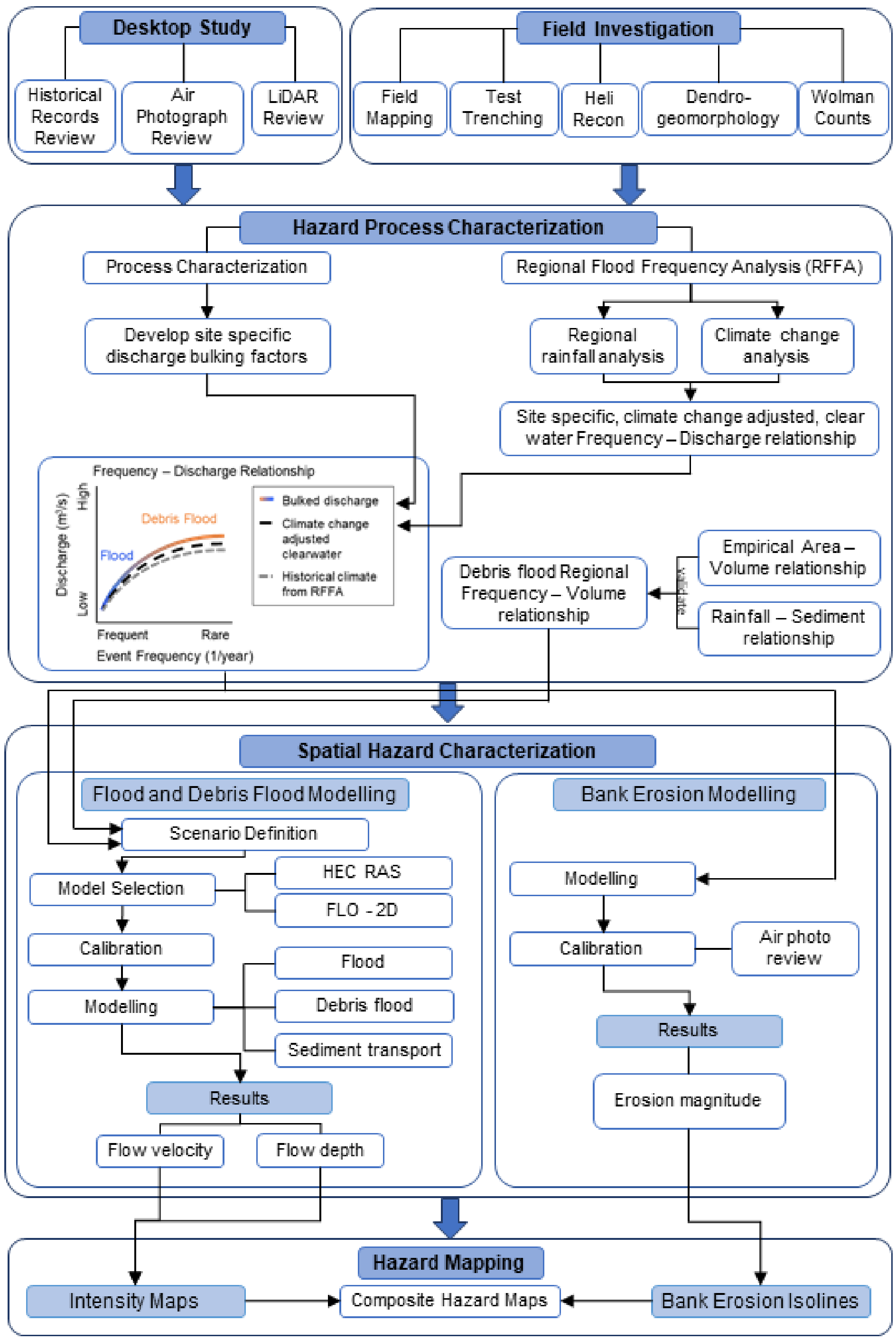


Figure 5-1. Flood and debris flood prone steep creeks workflow used for developing frequency-magnitude relationships, modelling, and preparing hazard maps.

5.1. Debris Flood Frequency Assessment – Air Photo Interpretation

At Kokanee Creek, air photo interpretation was used to estimate debris-flood frequencies. Air photos dated between 1929 and 2017 were examined for evidence of past sediment transport events on Kokanee 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 (Section 4.3).

5.2. Peak Discharge Estimates

5.2.1. Clearwater Peak Discharge Estimation

There are no hydrometric stations on Kokanee Creek, therefore peak discharges (flood quantiles) were estimated using a regional flood frequency analysis (Regional FFA). The regionalization of floods procedure was completed using the index-flood method. For this project, 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 Kokanee Creek is determined from watershed characteristics. The index-flood was estimated using a regional and provincially based ensemble of multiple regression models. Based on its watershed characteristics, the Kokanee Creek watershed was assigned to the '4 East hydrologic region for watersheds less than 500 km^2'. 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 Kokanee 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 and precipitation 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 (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[5], 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).

BGC assessed Kokanee Creek for the 20-, 50-, 200-, and 500-year return periods. At these return periods, the dominant hydrogeomorphic process was identified as debris flood based on stream morphometrics and site observations (Section 6.1). Because the debris-flood events will carry sediment and woody debris, the climate adjusted clearwater discharges need 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 runout 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 applied in addition to the numerical model (Jakob et al., 2016; Jakob et al., submitted). The inundation areas were then divided by the predicted sediment volumes to arrive at likely average deposition depths across the inundated areas. 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 Kokanee 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 hydraulic 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.

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

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). Different Manning's n values were used between the HEC-RAS and FLO-2D models as during modelling execution each model treats roughness in a different way; further details are provided in Section 2 of the Methodology Report. The impacts of Kootenay Lake level on the communities bordering the lake are investigated in the Kootenay Lake Flood Impact Analysis (BGC, January 15, 2020). Because Kootenay Lake level is regulated by dam operation, high flows in Kokanee Creek may not be concurrent with high lake levels. Additionally, water levels drop along the West Arm from Kootenay Lake to Corra Linn Dam. For the purpose of modelling fluvial conditions at Kootenay Lake level of 534.6 was assumed

Table 5-1. Summary of numerical modelling inputs.

Variable	HEC-RAS	FLO-2D
Topographic Input	Lidar (2017)	Lidar (2017)
Grid cells	Variable (2- 10 m)	5 m
Manning' n	0.08 (channel), 0.02 (main roads), 0.1 (fan)	0.06 (channel), 0.02 (main roads), 0.1 (fan)
Upstream boundary condition	Steady Flow (Q_{20})	Steady Flow (Q_{50}, Q_{200} and Q_{500})
Downstream boundary condition	Steady stage at Kootenay Lake (534.6 m)	

Note: The downstream boundary condition is Intermediate scenario between BC Hydro's minimum and maximum flood scenarios; and above the approximate peak recorded reservoir level (July 4, 2012) since commissioning of the Libby Dam (BGC, January 15, 2020).

BGC attempted to simulate the process with sediment transport modes in FLO-2D but those yielded results not considered credible. Instead, BGC chose to infill the channel for the 200- and 500-year return period events modelled in FLO-2D by 1 m to reflect anticipated aggradation in the lower reach of the channel. This was done for Kokanee Creek because the lowermost channel is of particularly low gradient (< 1%) and thus subject to backwatering and sedimentation due to a reduced water surface slope during high lake levels. The effect of backwatering can also occur on other creeks in the study area discharging into Kootenay Lake, but is believed to be potentially severe at Kokanee Creek.

A series of modelling scenarios were developed for Kokanee Creek as presented in Appendix E. 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 Kokanee Creek, the following flood protection structures were assumed eroded away for all modelled return periods: KKN-FP-01 and KKN-FP-02.

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 six creek cross-sections between the fan 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 Kokanee Creek: debris flood model result maps and a composite hazard rating map. The model result 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. Debris Flood and Debris Flow Model Result Maps

Model result maps display the following, for each scenario considered:

1. The hazard intensity and extent of inundated areas from both HEC-RAS and FLO-2D modelling.
2. Areas of sediment deposition extracted from FLO-2D modelling.
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:

$$IIF = v^2 \times \rho_f \times d_f \times P(H) \qquad \text{[Eq. 5-1]}$$

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 5-1and $P(H)$ 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 5-1 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 maps. 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 for some creeks.

Figure 5-2 displays a wider range of return periods and intensities than are relevant to debris flood hazards on Kokanee 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					

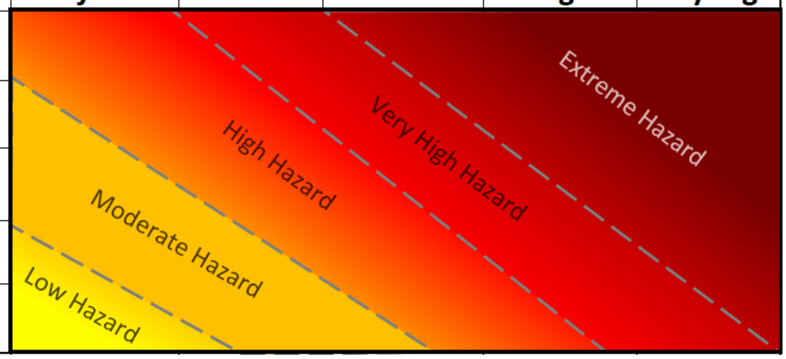


Figure 5-2. Simplified geohazard impact intensity frequency matrix.

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 and the loss(es) associated with an event scale with impact force. 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 *IIF* 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. Hydrogeomorphic Process Characterization

Figure 3-4 indicates that Kokanee Creek is prone to floods and debris floods. This result is consistent with the following evidence:

- The average channel gradient above the fan apex is 5% (Drawing 03), which is insufficient for sustained debris flow transport. The average channel gradient on the major tributaries is 17.5% on Sunset Creek, 8% on West Kokanee Creek, and 17.5% on Busk Creek. The gradient of Busk Creek is pertinent as it is assessed to have the potential for debris flows that transition to debris floods (Type 2) upstream of the Kokanee Creek fan-delta during 200- and 500-year return periods.
- The average fan gradient of 11% is typical of creeks prone to debris floods.
- The west side of the fan is dissected by a number of small, shallow avulsion channels, which are more typical of debris flood rather than debris-flow activity (Drawing 06).
- Accounts of previous flood events and analysis of historic air photos (see Section 4.3) are consistent with flood and debris-flood activity due to associated erosion and observed movement of sediment in air photos.

Together, this evidence indicates that Kokanee Creek is subject to supply-unlimited Type 1 debris floods for lower return periods (20- and 50-year). For higher return periods (200- and 500-year), Type 2 debris floods are considered the dominant process.

Should there be a large stand-replacing moderate to high intensity fire in the watershed, Type 3 debris floods are also conceivable, as moderate and high severity wildfires increase the likelihood and magnitude of tributary debris flows. Due to their higher magnitude, debris flows that are a result of forest fires are substantially more likely to impound Kokanee Creek and form a temporary landslide dam followed by an outbreak flood. This potential scenario ought to be considered in the context of a detailed post-fire hazard assessment which BGC has not attempted. A discussion of wildfire impacts on debris floods is included in Section 6.4.2.

6.2. Debris Flood Frequency Assessment – Air Photo Interpretation

Results of the debris flood F-M assessment are presented in this section. As noted above, Kokanee Creek is believed to be subject to supply-unlimited Type 1 debris floods for lower return periods (20- and 50-year) and Type 2 debris floods for higher return periods (200- and 500-year).

At least three notable hydrogeomorphic events have occurred since 1929 as identified from the air photo interpretation. 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 the pre-1939 and 1960's events are likely Type 1 debris floods due to the observed patterns of erosion and sediment deposition.

The deposition areas delineated from the air photos were combined with the Scheidl and Rickenmann (2010) debris flood area-volume relationship to estimate event volumes (Section 2 of the Methodology Report (BGC, March 31, 2020b)). Sediment deposition depths back calculated from the Scheidl and Rickenmann (2010) equation give an average depth of 0.5 to 0.7 m for the two events delineated from air photos.

Table 6-1. Summary of Kokanee Creek sediment transport events in air photo record (1929-2017).

Event Year[1]	Air Photo Year	Deposition Area (m^2)	Estimated Event Volume (m^3)	Event Characteristics
1929 - 1939	1939	76,700	51,000	Fresh sediment deposited in channel from fan apex to distal fan.
1939 - 1945	1945	N/A	N/A	Poorly defined avulsion channel east of main channel.
1968	1968	45,000	23,000	Fresh sediment deposited from fan apex to channel outlet. Deposition in secondary channel west of main channel in the distal fan.

Note:
1. Event year interpreted from air photo dates and historical records. Where the exact date is unknown, the decade or time period between successive air photos is indicated.

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. Results of the analysis are presented in Figure 6-1 and Table 6-2. With respect to these results, the reader should note the following:

- Because there are no hydrometric stations on Kokanee Creek, non-adjusted peak discharges (flood quantiles) were estimated using a Regional FFA. The regional index-flood model was selected because it produced slightly higher peak discharges than the provincial model.
- The historic peak discharge estimates were adjusted by 20% to account for the projected impacts of climate change as per Section 4 of the Methodology Report (BGC, March 31, 2020b).
- The climate-adjusted, bulked peak discharges were used in the numerical modelling.

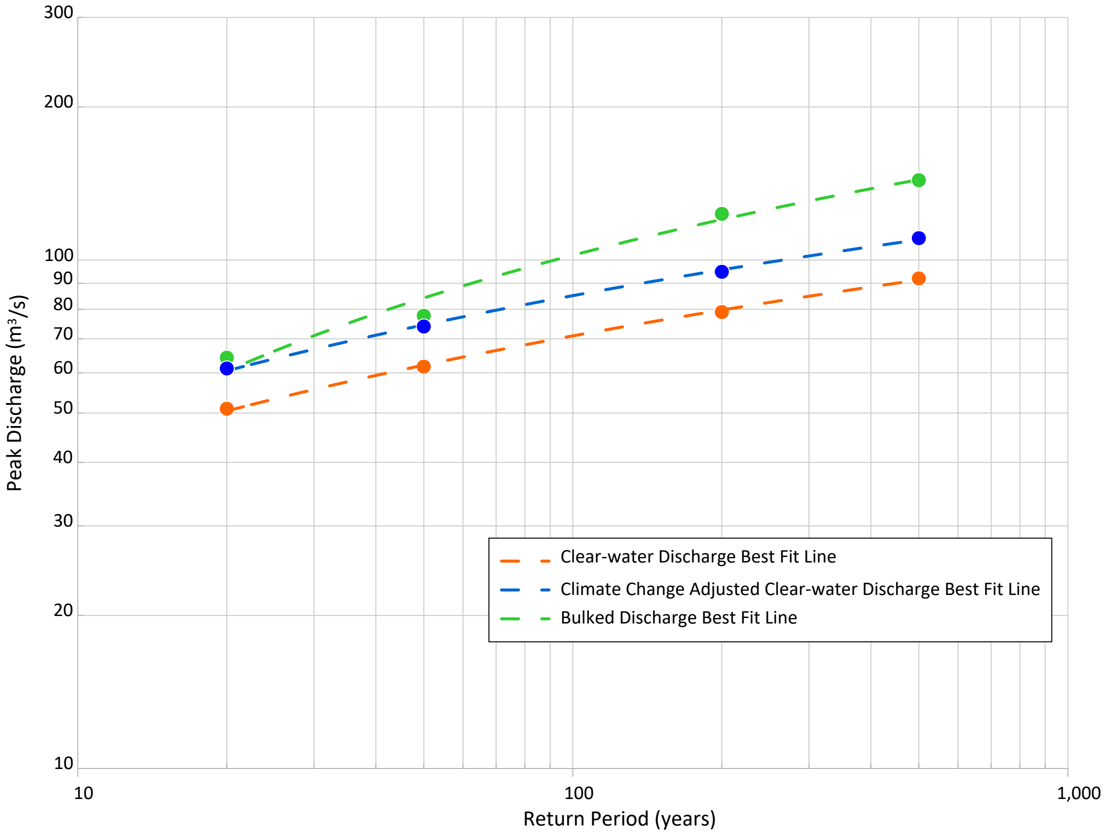


Figure 6-1. Frequency-discharge relationship for Kokanee Creek.

Table 6-2. Bulking factors for each return period's peak discharge and justification.

Return Period (years)	AEP	Historical Peak Discharge (m^3/s)	Climate-adjusted Peak Discharge (m^3/s)	Bulking Factor	Bulked Peak Discharge (m^3/s)	Key Considerations	
						Debris Flood Type	Comments
2	0.5	25	30	1.0		n/a	Flood
20	0.05	50	60	1.05	60	1	Few active landslides in lower 20% of watershed
50	0.02	60	70	1.05	80	1	Similar landslide activity to 20-year event
200	0.005	80	100	1.3	120	2	Debris flow tributary entering from Busk Creek approximately 2 km upstream of fan apex (Drawing 05) is interpreted to have the potential for debris flow to debris flood transition. Given the comparatively low gradient of Kokanee Creek, this bulking factor may be high, but in light of no direct measurements was chosen conservatively.
500	0.002	90	110	1.3	140	2	Similar debris flow tributary activity to 200-year event.

Note:

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

6.4. Frequency-Volume Relationship

6.4.1. General

BGC used several independent approaches to create a frequency-volume relationship for Kokanee Creek. These included air photo analysis of sediment deposits, an empirical sediment transport equation (Rickenmann, 2001), and application of regional relationships for fan area – sediment volume and watershed area – sediment volume (Jakob et al., 2016; Jakob et al., submitted). The different methods were compared, as described below.

Debris volume results from the air photo analysis are shown in Table 6-1 and the results of the regional relationship and Rickenmann sediment transport equation are shown in Table 6-3. The estimated event volumes from the air photo record correspond with the 20-year return period or smaller volumes determined from the regional relationship. The volume estimates from the Rickenmann (2001) empirical equation are not credible given that events greater than 80,000 m^3 do not appear in the air photo record and are approximately twice those obtained from the regional F-M analysis. This overestimate could be attributable to either BGC's hydrographs not being representative, or the critical discharge being underestimated (Section 2 of Methodology Report (BGC, March 31, 2020b)). Therefore, for numerical modelling, the regional relationships were applied as they appear to provide more reasonable results.

These sediment volumes for the 20- and 50- year return period events are associated with Type 1 debris floods, while the sediment volumes for the 200- and 500- year return period events are associated with Type 2 debris floods.

Table 6-3. Summary of event volumes for each return period based on the regional frequency-volume curve.

Return Period (years)	Event Volume (m^3)	
	Regional Frequency Volume	Rickenmann (2001)
20	57,000	120,000
50	73,000	150,000
200	98,000	197,000
500	114,000	233,000

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 an increase in the 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. Factors to consider in assessing the impacts of forest fires on hydrogeomorphic response include:

- The elevation of the fires in the watersheds is important as it could either increase peak discharges through melt at higher elevation occurring simultaneously with lower elevation, or vice versa, in which case a wildfire may have little effect on the frequency and magnitude of runoff.
- 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 Kokanee Creek watershed, especially for large moderate to high burn severity wildfires.

6.5. Numerical Debris Flood and Debris Flow Modelling

A summary of the key observations from the debris flood modelling is included in Table 6-4. The model scenario results are presented in Cambio Communities and a representative example is included as a static map in Drawing 07.

A Cambio user guide is included in the Summary Report (BGC, March 31, 2020a).

Table 6-4. Summary of modelling results.

Process	Key Observations
Clearwater inundation (HEC-RAS results for all return periods)	• Kokanee Creek likely remains in its current channel for return periods up to 50 years. • The Highway 3A bridge has an estimated capacity of 400 m^3/s. So, none of the model scenarios assumed blockage of this structure. However, at the 200 or 500-year return period, water could overtop to the east upstream of the Highway 3A bridge, flow along the highway ditch and pond, possibly leading to highway embankment failures and/or highway breach, scenarios that were not explicitly modeled by BGC. The 200 and 500-year return period flows that overtop across Highway 3A near the easternmost portion of the fan flow towards Kootenay Lake inundating the provincial park campground. This is important as the vulnerability of people in tents and mobile homes is higher compared to constructed homes. Flow depth could exceed 1 m in some locations and flow velocities range from 1 to 2 m/s.
Sedimentation	• Given the low gradient of the lowermost reaches of Kokanee Creek, BGC modeled 1 m aggradation in the channel downstream of the Highway 3A bridge to simulate the combined effect of high lake levels and high creek flows. • For the 200-year and 500-year return period debris floods, it is likely that the Highway 3A bridge could block due to aggradation and flow could divert to the east and across Highway 3A similar to the HEC-RAS clearwater flood results. BGC estimates that event volumes of 90,000 m^3 (200-year) to 120,000 m^3 (500-year) could flow onto the lower fan-delta of Kokanee Creek. • Sedimentation associated with debris floods can occur on the eastern and central fan-delta sector upstream and downstream of the Highway 3A crossing. The average deposition depth across the inundation area could be up to 0.5 to 0.7 m for the 200-year and between 0.6 and 0.8 m for the 500-year debris floods. • Sedimentation associated with debris floods could reach up to 3 m thickness in the channel and up to 2 m outside the channel, generally on the lower eastern section of the fan in areas of localized depressions.
Auxiliary Hazards	• As with other debris-flood prone creeks in the study area that end in lakes, during high lake levels there is a substantial chance that the lower portions of Kokanee Creek will build up sediment and avulse east or west of the active channel downstream of Highway 3A. • Given that the modelling results suggest Kokanee Creek will tend to avulse towards the eastern fan portions along the highway ditch, there is an increased chance that the highway will be eroded and become impassable. In some cases, the highway could be overtopped, scoured and a new flow path develop through the highway which could concentrate flows resulting in higher flow velocities and flow depth and hence higher impact forces. This scenario was not modeled. • Bank erosion could lead to slope failures on the western upper fan sector, which could result in impacts to Redfish Campground (Figure 3-5), a parking lot, and possibly adjacent storage buildings (12 Mile Storage) as well as avulsions should the creek be blocked at this location.

6.6. Bank Erosion Assessment

The air photo assessment compared available air photos from 1945 to 2006 to determine the historical changes in channel width at the six cross-sections considered in the bank erosion assessment (Drawings 02A, 02B). Table 6-5 summarizes the maximum channel width change measured between successive pairs of air photos and the cross-section at which it was observed. The maximum observed change in channel width between two successive air photos on Kokanee Creek was 14 m, between 1981 and 1988 at cross-section 6. To provide context for these values, the average current bankfull width is 18 m at the cross sections analyzed. 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 would be less than 5 m.

Table 6-5. 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)
1945-1952	2	2
1952-1958	4	3
1958-1968	3	3
1968-1974	7	4
1974-1981	3	2
1981-1988	14	6
1988-1997	11	6
1997-2000	2	1
2000-2006	5	5

A summary of the bank erosion model results by return period is outlined in Table 6-6. 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 6-6. Summary of bank erosion model results by return period.

Return Period (years)	Minimum Erosion (m)	Average Erosion (m)	Maximum Erosion (m)
20	0	6	19
50	0	7	20
200	0	28	62
500	8	66	97

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). Erosion peaks at different cross sections depending on the return period considered, but it generally higher in the upper reaches and lower near the mouth.

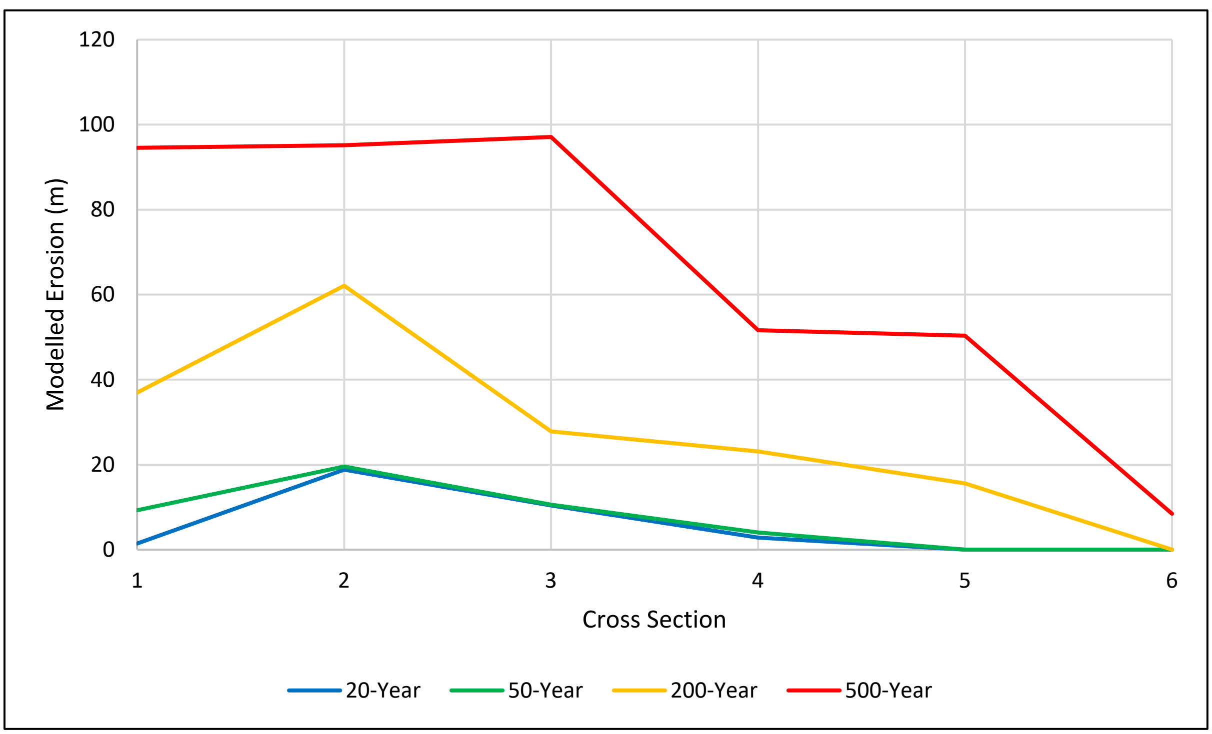


Figure 6-2. Kokanee Creek 50th percentile bank erosion model results at each cross-section.

The topography is high relative to the channel elevation along much of the right (west) side of the creek, with the exception of the downstream-most cross-section (cross-section 6). As a result, the likely erosion ranges from 17% to 50% of the full modeled erosion (Figure 6-2) for cross-sections 1 to 5 along the right bank. The topography is lower along the left (east) bank throughout the fan, with the likely erosion ranging from 50% to 100% of the modelled erosion.

All return periods have the potential to impact the bridge abutments at the Highway 3A crossing. However, the likely erosion corridor is not predicted to reach any other infrastructure identified in Drawings 02A, 02B for the 500-year event. The potential/improbable erosion corridor for the 500-year event intersects the 12 Mile Storage facility immediately north of Highway 3A (Drawings 02A, 02B).

6.7. Hazard Mapping

Debris flood model result maps for different return periods and bridge blockage scenarios as presented in Cambio Communities and a representative example is included in Drawing 07. Drawing 08 provides a composite hazard rating map showing the maximum extent of all hazard scenarios.

6.7.1. Composite Hazard Rating Map

As noted in Section 5.6.2, hazard rating zones 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 approximately half of the active fan-delta of Kokanee Creek is located within the yellow (low) hazard zone. It is mostly confined to the eastern fan sector which is lower lying and affected through redirected flow along the highway ditch and eventual overtopping. The orange (moderate) and red (high) hazard zones are confined to the channel and near-lake avulsion zones outside of current development. The dotted zones indicate areas that will likely be inundated with sediment to depths of less than 1 m outside the active channel and up to approximately 3 m in the active channel.

6.7.2. Comparison with NHC/Thurber (1990)

As outlined in Section 4.2.1, a detailed study of creeks on the Kootenay Lake West Arm was completed in 1990 by NHC/Thurber. The NHC/Thurber (1990) study is highlighted and discussed separately as it is the key detailed study now being superseded by this report.

6.7.2.1. Methodological Differences

The NHC/Thurber (1990) assessment considered debris torrents[6], avulsions or channel shifts, and inundation. For each fan investigated, hazard areas were codified between 0 (lowest hazard)

[6] In the NHC/Thurber (1990) report, debris torrent is used to describe a debris flow and is sometimes used interchangeably with debris flood. Section 2 and Appendix A provide definitions of these terms as used in this report.

and 5 (highest hazard). However, since NHC/Thurber (1990) also included loss of life consequences as a second dimension in their hazard mapping, their hazard maps provided information on relative levels of risk. Specific risk zones were defined as those where individual life loss risk exceeds or falls below specified values. Areas with a hazard (risk) code of 3 or higher were interpreted to have a significant threat to loss of life defined as the annual probability of death of a select individual of > 1:20,000. Figure 6-3 shows the NHC/Thurber risk map for Kokanee Creek.

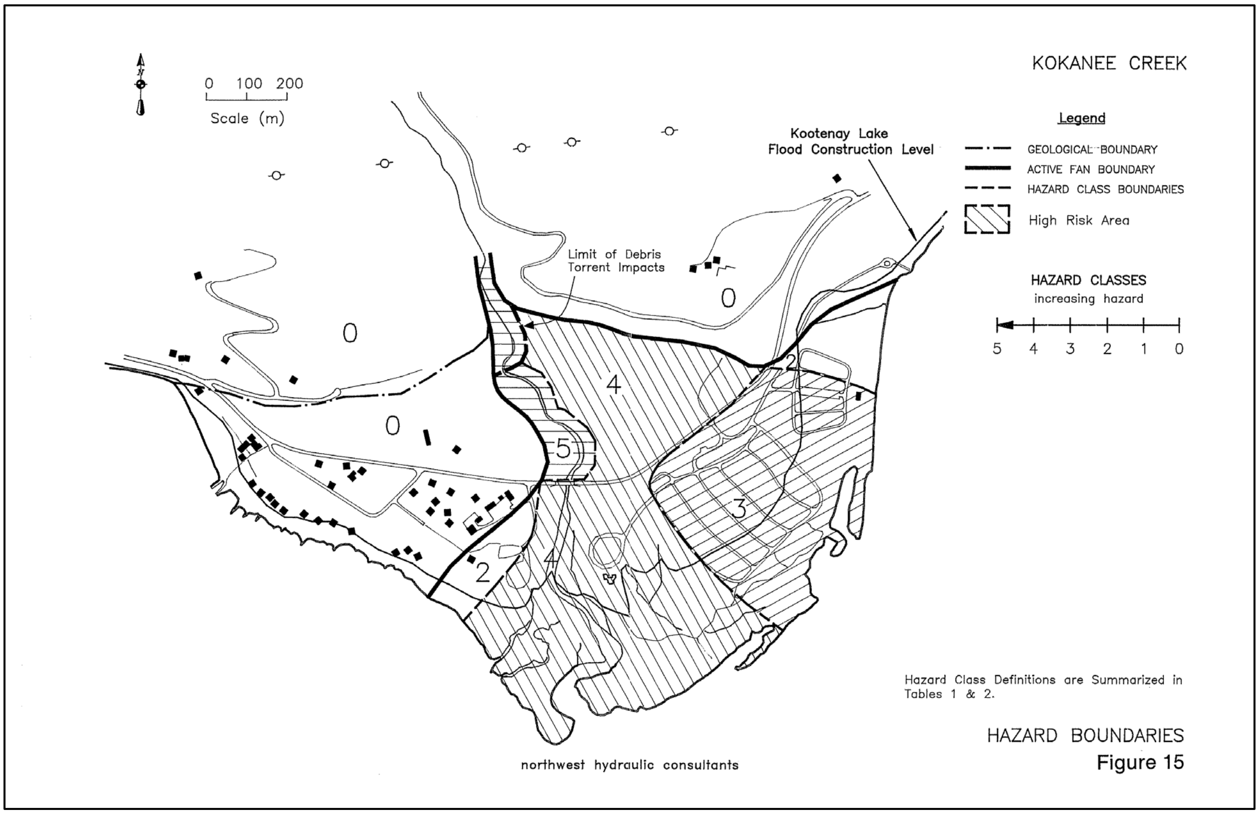


Figure 6-3. NHC/Thurber's (1990) Kokanee Creek individual life risk map. Class 4 and 5 imply individual life loss risk values exceeding 1:10,000. Class 3 1:10,000 to 1:20,000. Class 0, 1 and 2 < 1:20,000.

This section compares BGC's and NHC/Thurber's approaches because the hazard maps of the two reports differ significantly with NHC/Thurber's hazard levels being generally much higher than those of BGC. The principal differences are highlighted in Table 6-7. For convenience, NHC/Thurber (1990) is abbreviated in Table 6-7 to N/T.

Table 6-7. Method comparison between NHC/Thurber (1990) and this report (BGC, 2020).

Technique/Data	NHC/Thurber (1990)	BGC (2020)	Comment
Process	Debris torrents (debris flows and debris floods)	Debris floods	BGC did not encounter evidence for debris flows on the fans at the return periods considered
Process Severity	Classification into debris floods, indirect and direct impacts	Impact quantified and independent of process	BGC (2020) is a more comparable and transparent approach to evaluate impact intensity
Topography	2 m contours	Lidar DEM	Substantially higher resolution in BGC (2020)
Fan activity designation	Into “active” and “inactive”	Into “paleofans” and “active”	Given the better DEM resolution, BGC’s classification is a refinement to N/T
Return Periods Considered	<100, 100-1000, >1000	20, 50, 200, 500	Return periods greater than 500 years are associated with very high uncertainties and were thus not included in BGC (2020)
Frequency Estimates	Historical air photos, maps, records, watershed characteristics	As N/T, but also 30 years more historical data, flood and debris flood frequency analysis.	Substantially greater effort by BGC (2020) compared to N/T, thus higher confidence in BGC (2020)
Magnitude Estimates	Relative assessments of sediment supply, hydraulic modelling of clearwater flows in main channels	Three types of sediment transport calculations: regional F-M sediment volume relationships, an empirical sediment transport equation and air photo interpretation	Substantially greater effort by BGC (2020) compared to N/T, thus higher confidence in BGC (2020)
Probability of Avulsion	Method by Dawdy (1979) to determine probability of avulsion based on historical information and geomorphology	Numerical modelling-assisted with assumptions of bridge and/or culvert blockages at critical locations based on capacity exceedances	Lesser reliance on expert judgement for BGC (2020) and hence more replicable and transparent than N/T.
Impact Intensity	Based on flow velocity and depth*. Note that those were estimated, not modelled.	Based on modelled flow velocity, depth and fluid density	The key difference is the association of given impact intensity groupings to severity of impact.
Hazard Mapping	Classification into 5 groups based on hazard type, frequency and severity	Based on frequency and impact force (severity) including bank erosion	More transparent approach based on numerical modelling rather than pure expert judgement
Risk to Loss of Life	Calculated via standard probability of loss of life for an individual formula	No loss of life risk calculations	In N/T, risk to loss of life calculations were reported under hazard mapping. Risk and hazard are distinctly different. BGC’s (2020) did not attempt to calculate risk to loss of life.

* See Table 6-8

Table 6-8. Comparison of NHC/Thurber (1990) and this report (BGC, 2020) hazard mapping methods. Note that the categories of flow depth and flow velocity of NHC/Thurber (1990) do not exactly match the impact force as determined by BGC (2020).

NHC/Thurber (1990)			BGC (2020)	
Flow Depth (m)	Flow Velocity (m/s)	Severity	Impact Force (kN/m)	Severity
< 0.5	1.5-2	Low, lives rarely threatened, little structural damage	< 1	Slow flowing shallow and deep water with little or no debris. High likelihood of water damage. Potentially dangerous to people in buildings, in areas with high water depths
0.5 to 1.0	1.5-2	Moderate, threshold conditions which can result in loss of life and structural damage	1-10	(1-3): Mostly slow flowing shallow or deep flow with minor debris. High likelihood of sedimentation and water damage. Potentially dangerous to people in buildings, or in areas with higher water depths. (3-10): Potentially fast flowing but mostly shallow water with debris. Moderate likelihood of building damage and high likelihood of major sediment and/or water damage. Potentially dangerous to people on the first floor or in the basement of buildings without elevated concrete footings
>1	>2	High, considerable potential of loss of life, significant structural damage	10-100	Fast flowing and debris. High likelihood of structural building damage and severe sediment and water damage. Dangerous to people on the first floor or in the basement of buildings. Replacement of unreinforced buildings likely required.
			>100	Fast flowing debris. High likelihood of severe structural building damage and severe sediment damage. Unreinforced building replacement required. Very dangerous to people in buildings irrespective of floor.

6.7.2.2. Kokanee Creek Specifics

NHC/Thurber (1990) identified a natural debris levee consisting of boulders up to 3 m in height near the fan apex. They interpret the presence of this feature as evidence of “ancient debris torrent deposits.” BGC did not observe this feature during the July 2019 site visit and instead noted the presence of large boulders mid-channel near the fan apex and steep channel banks. Further evidence described as poorly graded material resembling debris torrent deposits was observed by NHC/Thurber in the creek banks approximately 200 m downstream of the fan apex. NHC/Thurber noted that of the steep creeks investigated (Duhamel, Sitkum, Redfish, Laird, Harrop, Narrows, Procter, and Kokanee), Kokanee appeared to be the most active in terms of bedload transport. Although NHC/Thurber identified potential avulsion locations at the fan apex and upstream of the highway bridge, the dearth of past avulsions was interpreted to indicate that the probability of an avulsion at these locations was low. The hazard classification at Kokanee Creek was highest in the proximal fan and along the main channel with elevated hazard on the entirety of the west side of the fan. In total 65% of the fan was classified as hazard code 3, 4, or 5.

6.7.2.3. Summary

After careful review of the NHC/Thurber (1990) work, BGC concludes that the hazards and likely risks to loss of life are substantially lower than estimated by NHC/Thurber as determined through BGC's assessment. The main reason for this discrepancy is that NHC/Thurber did not benefit from lidar topography, detailed numerical modelling, and an additional 30 years of data that have accrued since their study and the present. In absence of such detailed information and analysis, it was likely justified to be conservative in the designation of hazard zones. BGC believes that the current work is a credible representation of hazards on Kokanee Creek up to the 500-year return period scenarios considered.

7. SUMMARY AND RECOMMENDATIONS

7.1. Introduction

This report provides a detailed hazard assessment of the Kokanee Creek fan-delta. Kokanee Creek was chosen as a high priority creek amongst hundreds in the RDCK due to its comparatively high risk as estimated during the prioritization level. 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 Kokanee Creek.

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

7.2. Summary

7.2.1. Air Photo Interpretation

Air photo interpretation was 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:

- At least three notable hydrogeomorphic events have occurred since 1929. BGC interprets that the pre-1939 and 1968 events are likely Type 1 debris flood events due to the erosion and observed movement of sediment in air photos.
- Kokanee Creek was dredged and straightened in the 1970s downstream of Highway 3A
- Prior to 1979, there were multiple channel outlets in the distal fan
- There was one large flowslide on Busk Creek, the eastern tributary (Drawings 03, 06) during some unknown time in the Holocene era. It left a sizable (100,000 m^2) fan which indicates a possible impoundment height of 10 to 20 m. This event was not further investigated as it is believed to lie outside the return period range considered by BGC. However, debris flows originating on Busk Creek are interpreted to have the potential to develop into Type 2 debris floods on Kokanee Creek and were modelled for the 200- and 500-year return periods.

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 challenging 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 Kokanee Creek range from 60 m^3/s (20-year flood) to 110 m^3/s (500-year flood).

- Sediment bulking factors of 1.05 (5% 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 as BGC classified Kokanee Creek as being subject to debris floods.
- Consideration of climate change and sediment bulking increase the clearwater discharge estimate from 50 to 60 m^3/s for the 20-year debris flood, and from 90 to 140 m^3/s for the 500-year event.

7.2.3. Frequency-Magnitude Relationships

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

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

Return Period (years)	Adjusted Peak Discharge (m^3/s)
20	60
50	80
200	120
500	140

7.2.4. Numerical Flood and Debris Flood Modelling

Two numerical models were employed to simulate the chosen hazard scenarios on the Kokanee 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 6-4 provides key observations derived from the numerical modelling.

The multiple process numerical modelling ensemble approach demonstrates that the key hazards and associated risks at Kokanee Creek stem from avulsions mid-fan due to sediment transportation and avulsions upstream of the highway as the main channel is over capacity and dikes will most likely be eroded at higher return periods.

7.2.5. Bank Erosion Assessment

Debris floods can be highly erosive and may undercut unstable banks. BGC modeled bank erosion associated with a range of return period. The model was calibrated based on an air photo analysis by comparing the predicted 50-year erosion to the maximum erosion measured on the fan. The key findings from the bank erosion assessment are:

- Total bank erosion (both channel sides) is predicted to range between a maximum of 19 m for a 20-year debris flood event to approximately 97 m for a 500-year return period debris flood.
- The likely erosion on the higher elevation west (right) side of the creek is less than 50% of the full modeled erosion throughout most of the fan. The likely erosion ranges from 50% to 100% of the full modeled erosion on the lower elevation east (left) side of the creek.

- Erosion has the potential to impact the Highway 3A bridge at all return periods, but the likely and potential/improbable erosion corridors do not intersect any other infrastructure.

7.2.6. Hazard Mapping

Model results are cartographically expressed in two ways:

- The individual debris flood model results are captured through an index of impact force that combines flow velocity, bulk density and flow depth flow path. These maps are useful for assessments of development proposals and emergency planning. A representative example from the 200-year return period is included on Drawing 07.
- A composite hazard rating map (impact intensity frequency 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 and is included as Drawing 08.

Both the individual debris flood model results and the composite hazard rating map serve as decision-making tools to guide subdivision and other development permit approvals. Details on how to translate the hazard map into tangible land use decisions will be developed collaboratively between the RDCK and BGC.

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 Kokanee Creek represent a snapshot in time. Future changes to the Kokanee Creek watershed or fan including the following may warrant re-assessment and/or re-modelling:

- Future fan development
- Substantial flood or debris flood events
- Development of large landslides in the watershed with the potential to impound Kokanee Creek
- Bridge re-design
- Substantial changes to Kootenay Lake levels
- Significant wildfire events in the watershed
- Expansion of the existing provincial park campground
- Major earthworks within the active portion of the fan-delta.

The assumptions made on changes in runoff due to climate change and sediment bulking, while not unreasonable, are not infallible and will likely need to be updated occasionally as scientific understanding of climate impacts on hydrogeomorphic 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. Similarly, high bank landslides triggered by bank erosion can divert the creek into pre-existing paleochannels or scour can create new channels. 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 Kokanee 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 Kokanee 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:

1. Stopping organic and mineral debris near the fan apex to avoid downstream aggradation and concordant avulsions. Note that this strategy, while being effective, is expensive and requires regular maintenance. Stream downcutting downstream of the structure can be avoided by allowing some grains to pass through the structure. This will also be beneficial for downstream fish habitat.
2. Most creeks on fans and fan-deltas tend to be wide and laterally unstable. Forcing the creek in between berms flanking the creek is undesirable. Deepening the channel through excavation will invariably be followed by infill causing a cycle of expensive and disruptive gravel excavations. This is being done at the Resort Municipality of Whistler on Fitzsimmons Creek at a cost of several hundred thousand dollars per year. Instead, setback berms that provide maximum room for the creek to shift and build up sediment is preferred. On Kokanee Creek fan-delta, setback berms paralleling the 50th percentile likely bank erosion corridor (500-year return period lines shown on Drawing 08) would not significantly infringe on properties with existing development and may be a viable option to consider, though could be prohibitively expensive.

Kokanee Creek fan-delta hosts the fourth highest value of assets of the steep creek fan-deltas studied in detail (Table 1-1); however, the majority of the development is on the west side of the fan where the hazard rating is "very low" (Drawing 08). In addition to the residential, commercial and recreational (campgrounds) developments on the Kokanee fan-delta, Highway 3A transects mid-fan and anticipated impacts of the steep creek processes investigated in this study include overtopping, sedimentation, and the potential for highway embankment failures at upper return periods. As many floods occur in late spring or early summer, it is possible that the campground would be occupied.

The following are site-specific mitigation considerations. These are not prioritized, and additional options may emerge during future mitigation option analyses. These considerations are conceptual only and their feasibility has not been assessed by BGC. They are coded by letters in Figure 7-1 and described in Table 7-2

Table 7-2. Preliminary, conceptual-level, site specific mitigation options for Kokanee Creek. Note that none of the options have been examined in detail.

Option	Description	Effect on Steep Creek Hazard Reduction
a	Armoured setback deflection berm along the eastern side of Kokanee Creek upstream of Highway 3A.	Concentration of flow underneath the Highway 3A bridge to prevent flow avulsion towards the eastern fan segments
b	Installation of one or more culvert(s) underneath the eastern portion of Highway 3A and construction of a downstream drainage channel potentially with setback berms.	Creation of safe location for flow to pass underneath Highway 3A and downstream to the Kootenay Lake outlet in the event of flow avulsion east of the highway bridge.
c	Installation of riprap on upstream side of Highway 3A embankment.	Erosion protection and prevention of flows outflanking the highway bridge.
d	Bank protection to prevent destabilization of the west Kokanee Creek bank in the upper fan.	Erosion protection and prevention of flows affecting the Mile 12 storage facilities.
e	Re-naturalization of the area immediately west of the creek allowing bank retreat.	Removal of elements at risk in the immediate vicinity of the creek channel reduces the risk to the Mile 12 storage facility parking lot.

In addition to the mitigation options outlined above, development should be actively discouraged on the central and eastern fan portions – those fan segments should be maintained in their natural state. As shown in the composite hazard rating map, the western fan portions are characterized by very low hazard zones that may be suitable for future development upon further study including modelling of highway breach scenarios.

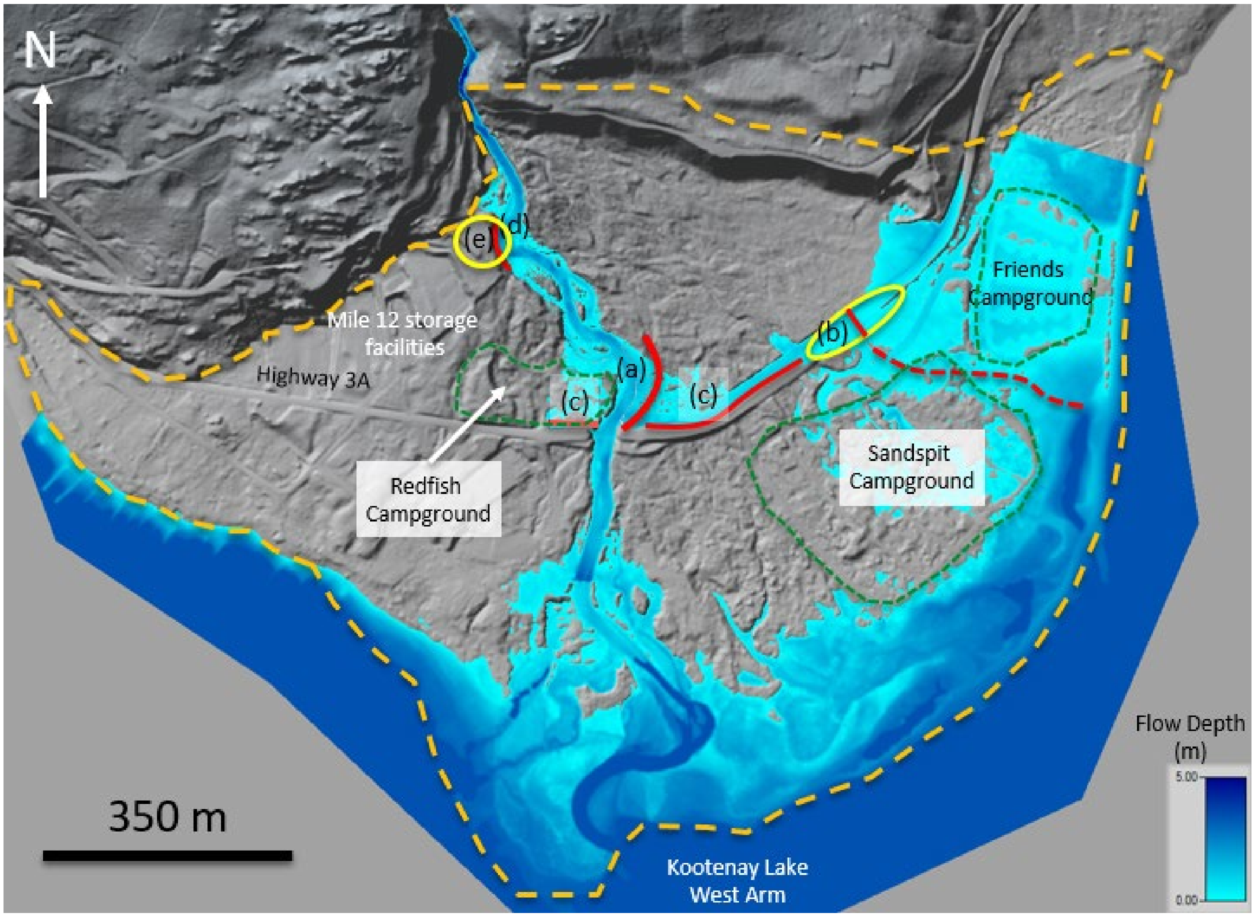


Figure 7-1. Mitigation considerations described in this section for a 500-year return period HEC-RAS model showing inundation depths. Note these are not a complete listing of all mitigation options and serve to illustrate the descriptions above. This figure should not be used for decision making nor design of mitigation works.

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

Anna Akkerman, B.A.Sc., P.Eng.
Senior Hydrotechnical Engineer

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

Reviewed by:

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

KH/MJ/mp/mm

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

REFERENCES

11 projects aided for fish, wildlife. (1981, August 20). *Times-Colonist*, p. 6.

Apex Geoscience Consultants Ltd. (2016, April). *Kokanee Creek hydrogeomorphic assessment* [Report]. Prepared for Kalesnikoff Lumber Co. Ltd.

Apex Geoscience Consultants Ltd. (2017, January 15). Response to email from Tyler Hodgkinson from January 13, 2017. Prepared for Kalesnikoff Lumber Co. Ltd.

BC Parks (n.d.). *Helping fish: Spawning channels have the gravel* [Interpretive signage]. Kokanee Creek Provincial Park, BC. Viewed 24 July 2019.

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. (January 15, 2020). *Kootenay Lake Flood Impact Analysis* [Report]. Prepared for Regional District of Central Kootenay.

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

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

Boivin, J. (2019, June 13). West Kootenay afternoon storms spark fires. *Nelson Star*. Retrieved from https://www.nelsonstar.com/

Boyer, D. & Jordan, P. (2001). November 1999 fall storm: Kootenay region. Changing Water Environments: Research and Practice. CWRA BC Branch conference proceedings. May 8-11, 2001, Whistler, BC.

British Columbia Minister of Highways and Public Works. (1936). *Report for the fiscal year 1935/36*. Victoria, BC: Author.

British Columbia Minister of Highways and Public Works. (1976). *Report for the fiscal year 1975/76*. Victoria, BC: Author.

British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD). (2019, December 17). *Fire Perimeters - Historical* [GIS Data]. Retrieved from https://catalogue.data.gov.bc.ca/dataset/fire-perimeters-historical

Cui, Y., Miller, D., Schiarizza, P., and Diakow, L.J. (2017). *British Columbia digital geology*. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Open File 2017-8, 9p.

Davidson, D. (2002, August 26). Valhalla Park fire burning wild. *Nelson Daily News*, p. 1.

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

Deverney Engineering Services Ltd. (2009, September 30). *Natural Hazard Assessment, Lot 2, Plan 8398, D.L. 1313, Kootenay Land District, 286 Harrop Ferry Road, Balfour, BC* [Precondition for Subdivision]. Prepared for David Dever and Abigail Dever.

Deverney Engineering Services Ltd. (2010, September 12). *Natural Hazard Assessment, Lot A, Plan 7634, DL 1313, Kootenay Land District, 6103 Highway 3A, Balfour, BC* [Precondition for Building Permit]. Prepared for Barry Riehl.

Deverney Engineering Services Ltd. (2011, June 17). *Natural Hazard Assessment and Building Setback Variance Application, Lot A, Plan NEP89540, DL 1313, Kootenay Land District, 6126 Pippers Lane, Nelson, BC* [Precondition for Building Permit]. Prepared for Michael McGillvrey and Janet McGillvrey.

Dohan, N. (2013, September 12). It takes a tribe to raise a kokanee. *Nelson Star*. Retrieved from http://nelsonstar.com

Environment and Climate Change Canada. (n.d.). *Canadian Climate Normals 1981-2010 Station Data – Kaslo* [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=kaslo&searchMethod=contains&txtCentralLatMin=0&txtCentralLatSec=0&txtCentralLongMin=0&txtCentralLongSec=0&stnID=1124&dispBack=1

Government of British Columbia. (2020a). *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.

Government of British Columbia. (2020b). *Flood Protection Works – Appurtenant Structures.* Internet webpage. URL last accessed February, 2020: https://catalogue.data.gov.bc.ca/dataset/4639cc3d-93dd-4ff2-ae77-0aae4f3cd588

Green, K.C. & Alila, Y. (2012). A paradigm shift in understanding and quantifying the effects of forest harvesting on floods in snow environments. *Water Resources Research, 48*(10), W10503. https://doi.org/10.1029/2012WR012449

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

Integrated Hydropedology Ltd. (2003, July 22). *Proposed second house on Parcel A, (SC U3340), Plan 5239, L.L. 1313 KD* [Precondition for Building Permit]. Prepared for Ben Martin and Debbie Gail Jervis-Legate.

Intermountain Engineering & Surveying Ltd. (2003, June 13). *Report Pursuant to Floodplain Management By-Law No. 1000, 1993* [Precondition for Building Permit]. Prepared for Regional District of Central Kootenay.

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.

Jakob, M. McDougall, S., Bale, S., Friele, P. (2016, October). Regional debris-flow and debris-flood frequency-magnitude curves. GeoVancouver 2016. Paper presented at the meeting of the Canadian Geotechnical Society, Vancouver, British Columbia.

Jakob, M., Mark, E., McDougall, S., Friele, P., Lau, C.-A., & Bale, S. (submitted). Regional debris-flow and debris-flood frequency-magnitude curves. Submitted to Earth Surface Processes and Landforms.

Jordan, P. (2001). Sediment budgets in the Nelson Forest Region. In D.A.A. Toews and S. Chatwin (Eds). *Watershed Assessment in the Southern Interior of British Columbia*: Workshop Proceedings March 9 - 10, 2000. Penticton B.C. Canada. B.C. Min. For. Working Paper 57.

Jordan, P. (2006). The use of sediment budget concepts to assess the impact on watersheds of forestry operations in the southern interior of British Columbia. *Geomorphology ,79*(1-2), 27-44. https://doi.org/10.1016/j.geomorph.2005.09.019

Jungen, J.R. (1980). *Soil resources of the Nelson map area (82F)* [RAB Bulletin 20, British Columbia Soil Survey Report No. 28]. Kelowna, BC: British Columbia Ministry of Environment, Resource Analysis Branch.

Klohn-Crippen Consultants Ltd. (1998, February 23). *Terrain Stability Inventory: Alluvial and Debris Torrent Fans Kootenay Region* [Report]. Prepared for the Ministry of Environment, Lands and Parks.

Klohn Crippen Consultants Ltd. (2004, July 21). *Flood Hazard Assessment Kokanee Creek Property* [Precondition for Building Permit]. Prepared for Robert Osler Haggar.

Lasca Group Technical Services Ltd. (2015, February 15). *6160 Kokanee Road – Alluvial Fan Flood Hazard Assessment Report* [Precondition for Building Permit]. Prepared for Patrice Mauro and Joseph Mauro.

Local and personal. (1925, August 28). *The Creston Review*, p. 8.

Ministry of Energy, Mines and Petroleum Resources. (1988). *MINFILE Record Summary, MINFILE No 082FNW121.* Retrieved from https://minfile.gov.bc.ca/Summary.aspx?minfilno=082FNW121

Moynihan, D.P. & Pattison, D.R.M. (2013, April 3). Barrovian metamorphism in the central Kootenay Arc, British Columbia: Petrology and isograd geometry. *Canadian Journal of Earth Sciences, 50,* 769-794. http://dx.doi.org/10.1139/cjes-2012-0083

Navigable Waters' Protection Act. (1925, May 22). *The Creston Review*, p. 4.

Northwest Hydraulic Consultants Ltd. and Thurber Consultants Ltd. (1990, April). *Alluvial Fan Hazard Assessment: Regional District of Central Kootenay Electoral Area "E" & "F"* [Report]. Prepared for Regional District of Central Kootenay.

Perdue Geotechnical Services Ltd. (2016, July 21). *Kokanee Creek Alluvial Fan Hazard Assessment Lot 9, Plan NEP5817, District Lot 1313, Kootenay District* [Precondition for Building Permit]. Prepared for Simone Michelle Campbell.

Province of British Columbia. (2016). Terrestrial Ecosystem Information (TEI) Spatial Data - Dist_Pkg_NonPEM_Cariboo_Okanagan_Kootenay2016.zip. Data available from the British Columbia Ministry of Environment, Ecosystem Information Section at: http://www.env.gov.bc.ca/esd/distdata/ecosystems/TEI/TEI_Data/2016-09-14.

Rickenmann, D. (2001). Comparison of bed load transport in torrents and gravel bed streams. *Water Resources Research, 37*(12), 3295-3305. https://doi.org/10.1029/2001WR000319

Schafer, T. (2012, June 7). Rainfall warning adds to flood concerns. *Trail Times*, p. 1.

Schafer, T. (2012, June 25). West Kootenay weather turns deadly. *Trail Times*, p. 3.

Scheidl, C. & Rickenmann, D. (2010). Empirical prediction of debris-flow mobility and deposition fans. *Earth Surface Processes and Landforms, 35*(2), 157-173. https://doi.org/10.1002/esp.1897

Schnorbus, M. & Alila, Y. (2004). Forest harvesting impacts on the peak flow regime in the Columbia Mountains of southeastern British Columbia: An investigation using long-term numerical modeling. *Water Resources Research, 40*(5). https://doi.org/10.1029/2003WR002918

Spawning creek saved by preservation fund. (1979, August 18). *The Vancouver Sun*, p. B12.

Touchstone Nelson, Museum of Art and history. (2007). Corra Linn Dam, Kootenay River [Web page]. Retrieved from https://web.archive.org/web/20111004041631/http://virtualmuseum.ca/Exhibitions/Hydro/en/dams/?action=corralinn

Vogl, J.J. & Simony, P.S. (1992). *The southern tail of the Nelson batholith, southeast British Columbia: emplacement and deformation along a terrane accretion zone.* Retrieved from http://users.clas.ufl.edu/jvogl/Vogl_Simony_Nelson.pdf

Whitaker, A., Alila, Y., Beckers, J., & Toews, D. (2003). Application of the distributed hydrology soil vegetation model to Kokanee Creek, British Columbia: model evaluation using internal catchment data. *Hydrological Processes, 17*(2), 199-224. https://doi.org/10.1002/hyp.1119

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.

Overview photo taken during helicopter overflight looking north at Kokanee Creek. The outlet into Kootenay Lake is visible. Photo: BGC, July 6, 2019.

Photo 2.

Overview photo taken during helicopter overflight looking north at the Kokanee Creek fan with Hwy 3A (left to right) running across Kokanee Creek. Photo: BGC, July 6, 2019.

Photo 3.

Overview photo taken during helicopter overflight looking north at the Kokanee Creek Fan with Hwy 3A (left to right) running across Kokanee Creek. A portion of the Kokanee Creek watershed is visible. Photo: BGC, July 6, 2019.

Photo 4.

Overview photo taken during helicopter overflight looking south at Kokanee Creek, approximately 14 km upstream of the outlet to Kootenay Lake. Photo: BGC, July 6, 2019.

Photo 5.

Overview photo taken during helicopter overflight looking down (west at the top) at the lower Kokanee Creek watershed, approximately 8 km upstream of the fan apex. Kokanee Glacier Road is visible, as well as the site of a potential debris avalanche (orange) to the west of the creek. Photo: BGC, July 6, 2019.

Photo 6.

Overview photo taken during helicopter overflight looking down (north is up) at the lower Kokanee Creek watershed, approximately 6 km upstream of the fan apex. Photo: BGC, July 6, 2019.

Photo 7.

Looking downstream (south) at boulders on the left bank of Kokanee Creek, approximately 250 m upstream of the Hwy 3A bridge. Photo: BGC, July 29. 2019.

Photo 8.

Upstream of footbridge standing on the left bank of Kokanee Creek looking west. Photo: BGC, July 24. 2019.

Photo 9.

Upstream of the Hwy 3A bridge looking at the right bank (west) across Kokanee Creek. Photo: BGC, July 24, 2019.

Photo 10.

On the Hwy 3A bridge looking downstream (south) at Kokanee Creek and the flood protection on both banks. Photo: July 24, 2019.

Photo 11.

Standing on the left bank of Kokanee Creek looking upstream at the Hwy 3A bridge. Photo: July 24, 2019.

Photo 12.

Standing approximately 50 m downstream of the footbridge looking at a failed dike. Photo: BGC, July 24, 2019.

Photo 13.

Standing on the right bank of Kokanee Creek near the outlet into Kootenay Lake looking upstream (north). Kokanee Creek is backwatered by Kootenay Lake. Photo: BGC, July 24, 2019.

Photo 14.

Standing on the right bank bar looking across (flow is left to right) at the cobble bar and flood protection on the right bank of Kokanee Creek, approximately 800 m upstream of the creek's mouth. Photo: July 24, 2019.

APPENDIX C
SEDIMENT SIZE SAMPLING

C.1. SAMPLING LOCATIONS

At Kokanee Creek, three Wolman Samples were taken, one at the fan apex, one at the Highway 3A bridge, and one near the outlet to Kootenay Lake. The sampling locations (referred to as Kokanee 1, Kokanee 2 and Kokanee 3 are shown in Figure C-1 and Table C-1. Bed material conditions at each site are shown on Figure C-2, Figure C-3, and Figure C-4.

Table C-1. Wolman sampling locations.

Site Name	Kokanee 1	Kokanee 2	Kokanee 3
Location	At the fan apex	At the Highway 3A bridge	Near outlet to Kootenay Lake
Longitude	117° 7'41.25"W	117° 7'34.05"W	117° 7'32.65"W
Latitude	49°36'31.12"N	49°36'17.73"N	49°36'7.86"N
Number of stones measured	101	151	115

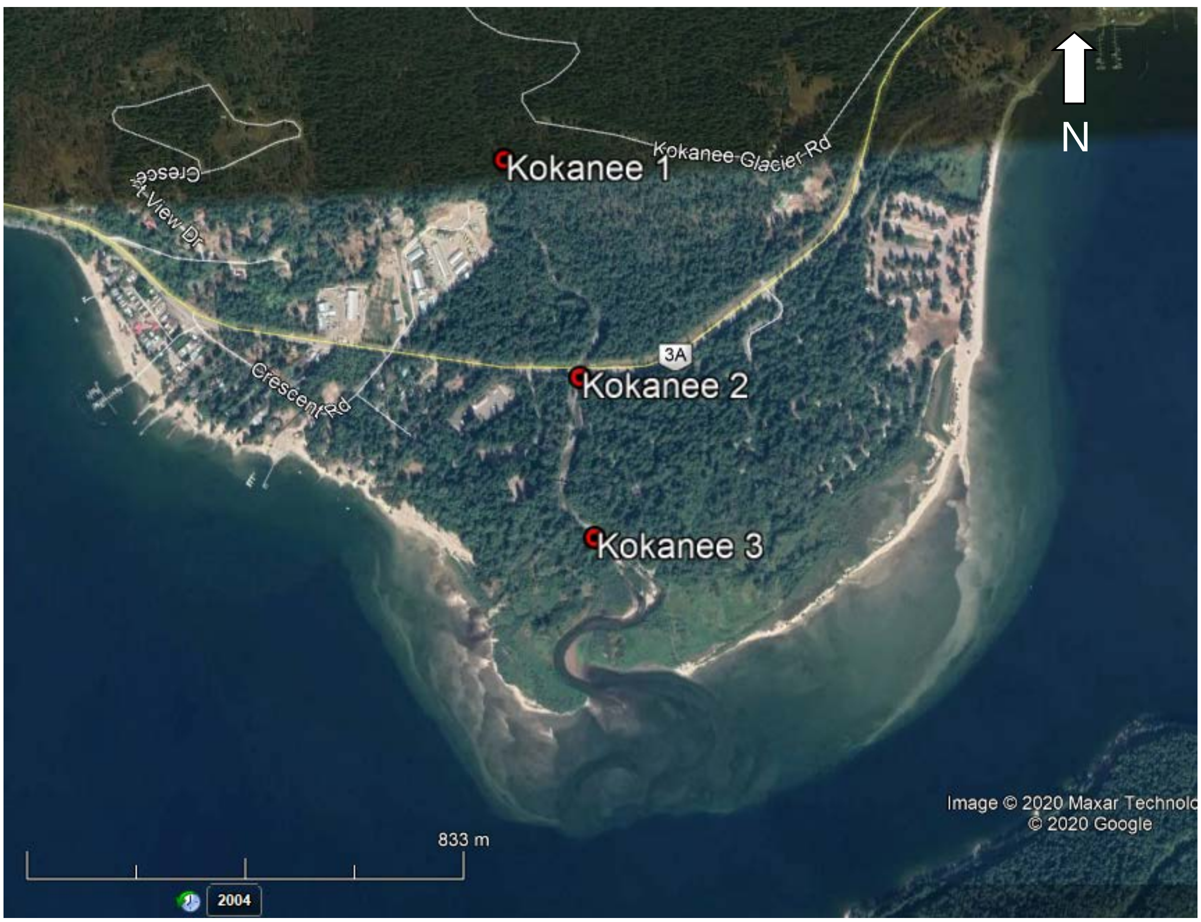


Figure C-1. Wolman sampling locations along Kokanee Creek. Google Earth image of September 11, 2017.

Figure C-2. Photograph taken of Wolman sampling location Kokanee 1. BGC photograph of November 20, 2019.

Figure C-3. Photograph taken of Wolman sampling location Kokanee 2. BGC photograph of July 27, 2019.

Figure C-4. Photograph taken of Wolman sampling location Kokanee 3. BGC photograph of July 27, 2019.

C.2. RESULTS

Results of the Wolman counts are shown in Table C-2 and on Figure C-5, Figure C-6 and Figure C-7.

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

Grain Size	Kokanee 1	Kokanee 2	Kokanee 3
D_{95} (mm)	180	>256	212
D_{84} (mm)	119	188	158
D_{50} (mm)	47	94	71
D_{15} (mm)	18	<2	7
D_{5} (mm)	6	<2	2

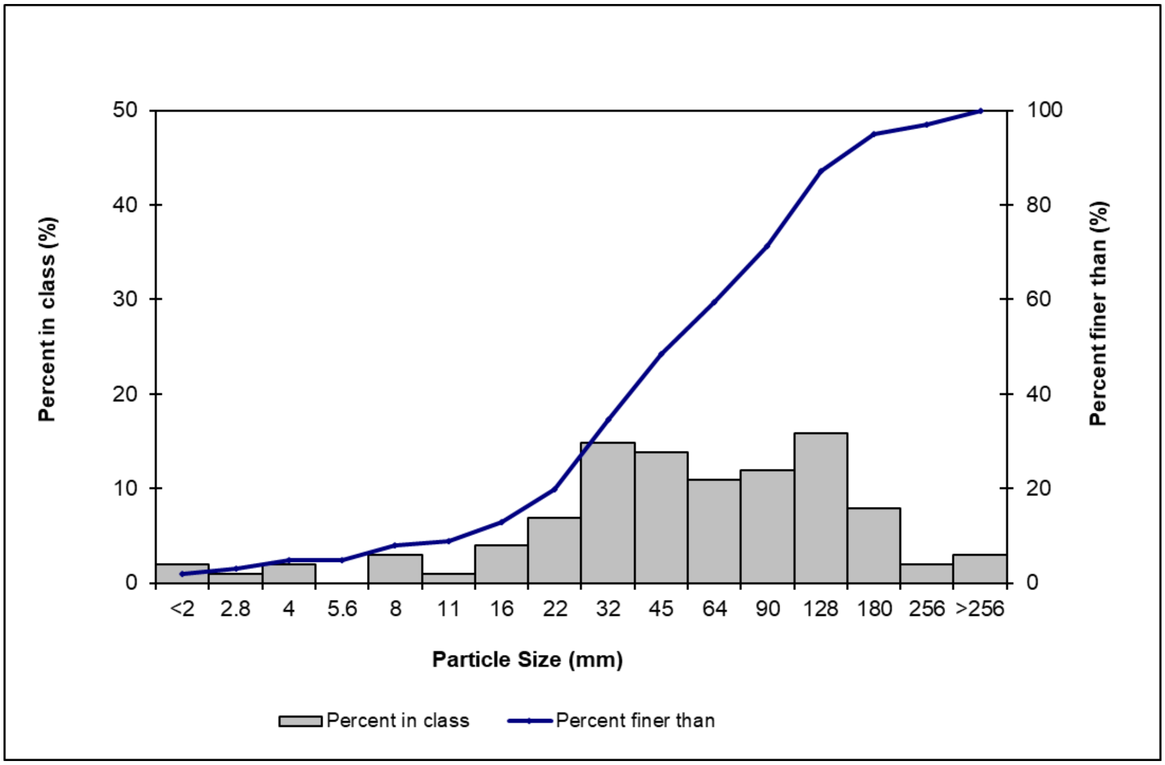


Figure C-5. Kokanee Creek grain size distribution at Kokanee 1 (at fan apex) from Wolman count.

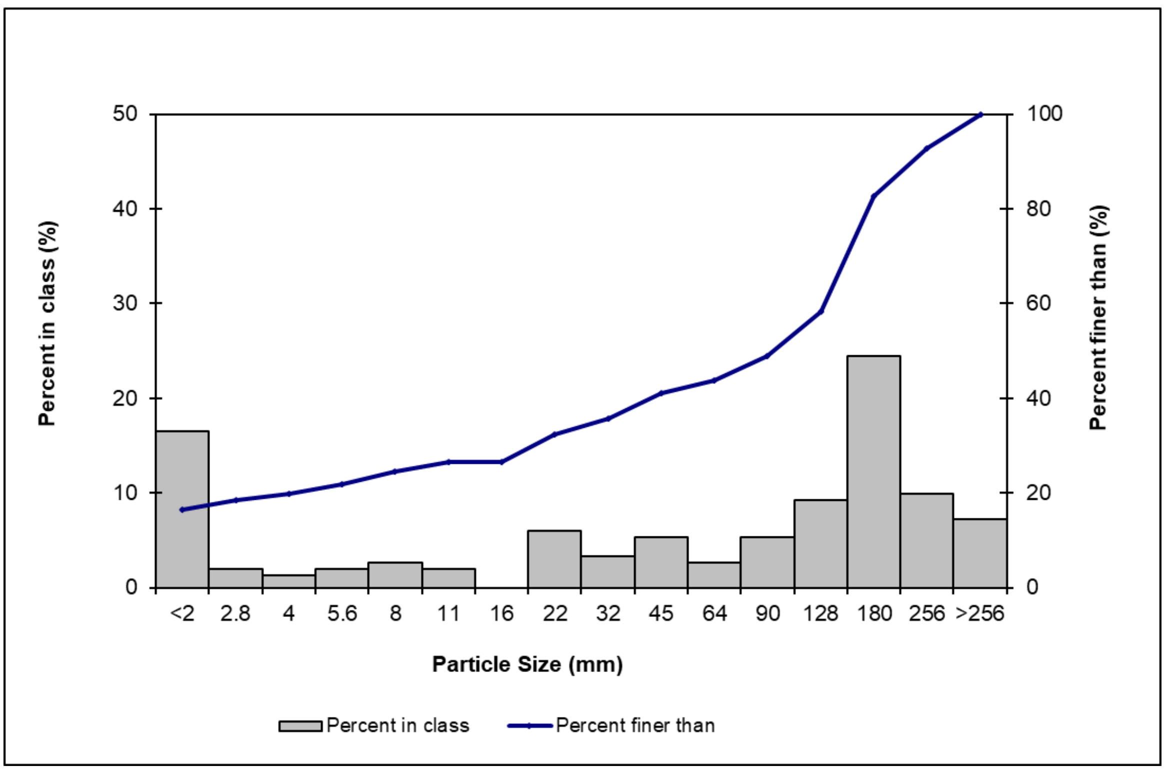


Figure C-6. Kokanee Creek grain size distribution at Kokanee 2 (at Highway 3A bridge) from Wolman count.

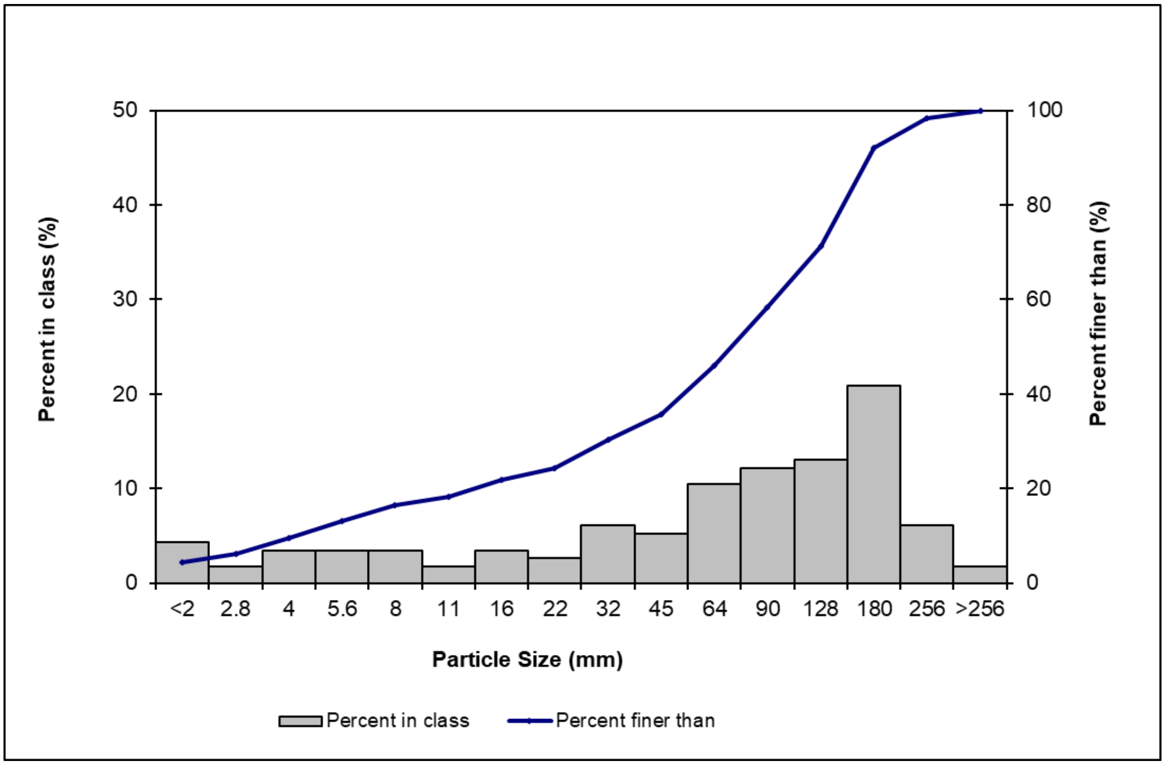


Figure C-7. Kokanee Creek grain size distribution at Kokanee 3 (near outlet to Kootenay Lake) from Wolman count.

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 Kokanee Creek analysis. In addition to the air photos listed, RDCK provided BGC with an air photo from 2017. The original source of the 2017 image is unknown.

Table D-1. Kokanee Creek air photo records.

Year	Date	Roll Number	Photo Number	Scale
2006	9/1/2006	BCC06135	203-204	20,000
	7/21/2006	BCC06061	39-42	20,000
2000	9/17/2000	BCB00038	124-129, 159-162	15,000
1997	8/22/1997	BCB97047	166-169, 259-261	15,000
1994	5/31/1994	BCB94016	42-47	15,000
	5/9/1994	BCB94011	187-194, 69-74	5,000
	5/9/1994	BCB94007	131-138, 179-181	5,000
1988	7/22/1988	BC88090	48-53, 109-11	15,000
1986	7/20/1986	BC86059	58-60, 45-48, 80-83	16,000
1981	6/25/1981	BC81028	209-216	5,000
1980	10/30/1980	BC80137	211-213	40,000
1979	8/2/1979	BC79134	4-8, 40-45, 100-102	10,000
	7/31/1979	BC79126	219-222	20,000
1978	7/29/1978	BC78129	156-157	40,000
	6/5/1978	BC78051	243	10,000
1974	6/17/1974	BC7568	112-115, 129-135	8,000
1969	7/28/1969	BC5348	170-172	40,000
1968	8/31/1968	BC7109	17-21	16,000
	9/8/1968	BC7111	21-24	16,000
	8/31/1968	BC7109	18-24	16,000
1958	7/24/1958	BC2478	3, 4, 5	15,840
1952	7/24/1958	BC2477	57-62	15,840
	6/14/1952	BC1455	81-83, 98-99	31,680
1945	6/5/1945	A7735	81-82	25,000
1939	7/30/1939	BC163	48-52	31,680
1929	4/18/1929	A1015	9-11	10,000

APPENDIX E
MODELLING SCENARIOS

E.1. MODELLING SCENARIOS

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

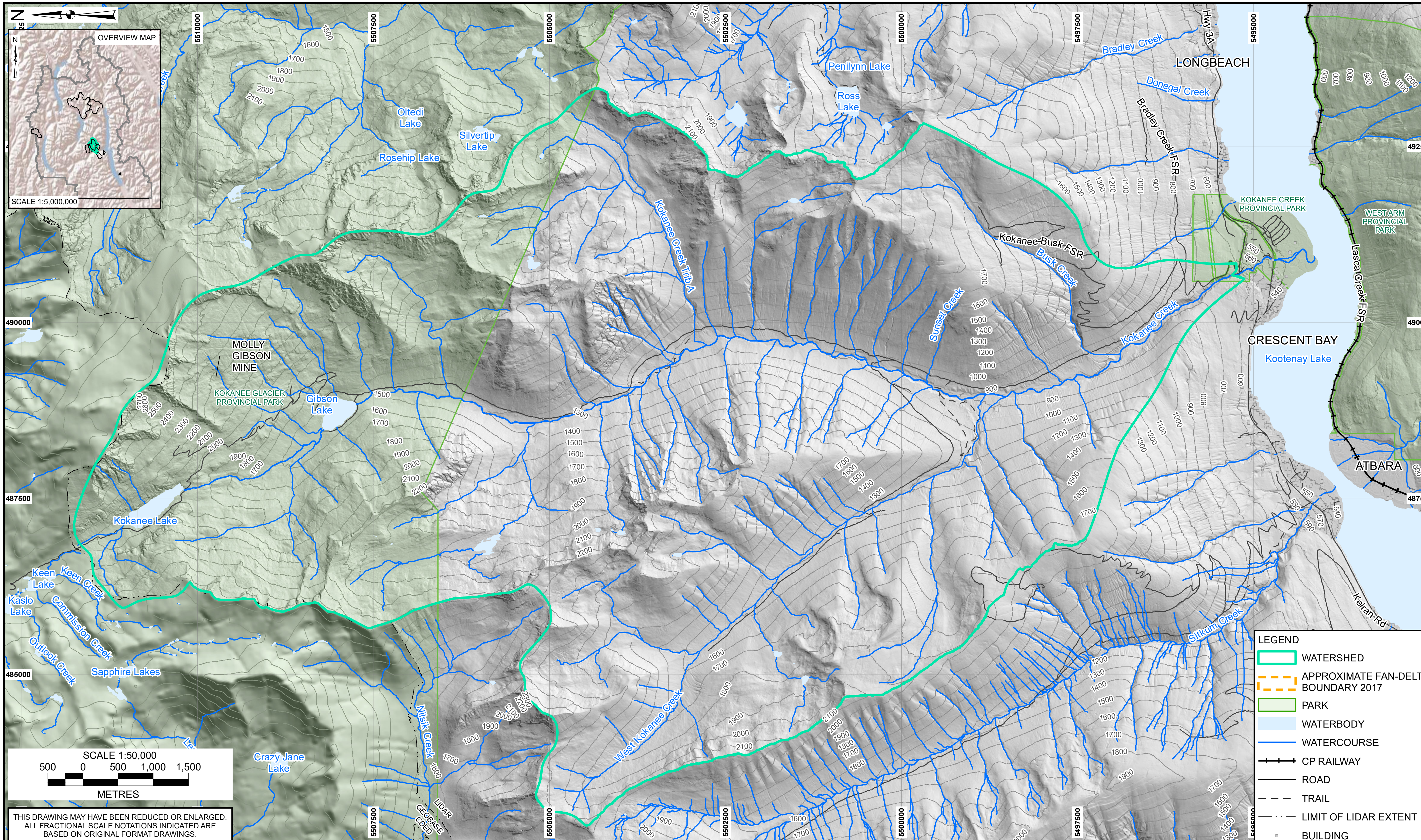
Table E-1. Modeling scenario summary for Kokanee Creek.

Scenario Name	Return Period (years)	Process Type	Bulking Factor	Bulked Peak Discharge (m³/s)	Conveyance Structures			Flood Protection Structures				
					Name	Estimated Capacity[1] (m³/s)	Assumption	Name	Type	Bank Erosion Encroaching	τ/τc ≥ 2	Assumption
KKN-1	20	Debris Flood (Type 1)	1.05	64	Kokanee Highway Bridge	400	Functioning as intended	KKN-FP-01	Bank erosion protection, not orphaned.	N	Y	Functioning as intended
								KKN-FP-02	Berm covered in vegetation, not orphaned.	N	Y	Functioning as intended
					Pedestrian Bridge	130	Functioning as intended	KKN-FP-03	Berm covered in vegetation, orphaned.	N	Y	Functioning as intended
KKN-2	50	Debris Flood (Type 2)	1.05	78	Kokanee Highway Bridge	400	Functioning as intended	KKN-FP-01	Bank erosion protection, not orphaned.	N	Y	Functioning as intended
								KKN-FP-02	Berm covered in vegetation, not orphaned.	N	Y	Functioning as intended
					Pedestrian Bridge	130	Functioning as intended	KKN-FP-03	Berm covered in vegetation, orphaned.	N	Y	Functioning as intended
KKN-3	200	Debris Flood (Type 2)	1.3	123	Kokanee Highway Bridge	400	Functioning as intended	KKN-FP-01	Bank erosion protection, not orphaned.	Y	Y	Removed from topography, assumed to fail
								KKN-FP-02	Berm covered in vegetation, not orphaned.	Y	Y	Removed from topography, assumed to fail
					Pedestrian Bridge	130	Blocked	KKN-FP-03	Berm covered in vegetation, orphaned.	Y	Y	Removed from topography, assumed to fail
KKN-4	500	Debris Flood (Type 2)	1.3	144	Kokanee Highway Bridge	400	Functioning as intended	KKN-FP-01	Bank erosion protection, not orphaned.	Y	Y	Removed from topography, assumed to fail
								KKN-FP-02	Berm covered in vegetation, not orphaned.	Y	Y	Removed from topography, assumed to fail
					Pedestrian Bridge	130	Blocked	KKN-FP-03	Berm covered in vegetation, orphaned.	Y	Y	Removed from topography, assumed to fail

Note:

1. Estimated bridge capacity was derived from field and lidar measurements as a preliminary screening tool for model scenario development. They should not be treated as design capacity values.

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 - KOKANEE CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017, 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 2017. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL FLOODING.
5. BUILDING FOOTPRINTS DIGITIZED BY BGC BASED ON LIDAR AND REPRESENT ONLY A SUBSET OF TOTAL BUILDINGS ON THE FAN-DELTA. PARKS DATA FROM GOVERNMENT OF BC. ROADS DATA FROM BC DIGITAL ROAD ATLAS. RAILWAY DATA FROM GEOBASE NATIONAL RAILWAY NETWORK.
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:	1:50,000
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:
KOKANEE CREEK
SITE LOCATION MAP

PROJECT No.:	DWG No:
0268007	01

X:\Projects\0268007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191018_RDCK_Floodplain_and_Steep_Creek_Study\01_Site_Location_DDP_KOKANEE.mxd

X:\Projects\0268007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191018_RDCK_Floodplain_and_Steep_Creek_Study\02A_Fan_Delta_Site_Map_DDP_KOKANEE.mxd

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY - KOKANEE CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK, DATED 2017. CONTOUR INTERVAL IS 20 m AND 10 m ON FAN.
4. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM BASED ON LIDAR DATED 2017. 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. BUILDING FOOTPRINTS DIGITIZED BY BGC BASED ON LIDAR AND REPRESENT ONLY A SUBSET OF TOTAL BUILDINGS ON THE FAN-DELTA. 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. CAMPGROUND AND STORAGE AREA BOUNDARIES ARE APPROXIMATE AND BASED ON 2017 LIDAR AND BC PARKS MAPS. 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:	1:6,000
DATE:	MAR 2020
DRAWN:	LL
CHECKED:	JJHP
APPROVED:	MJ

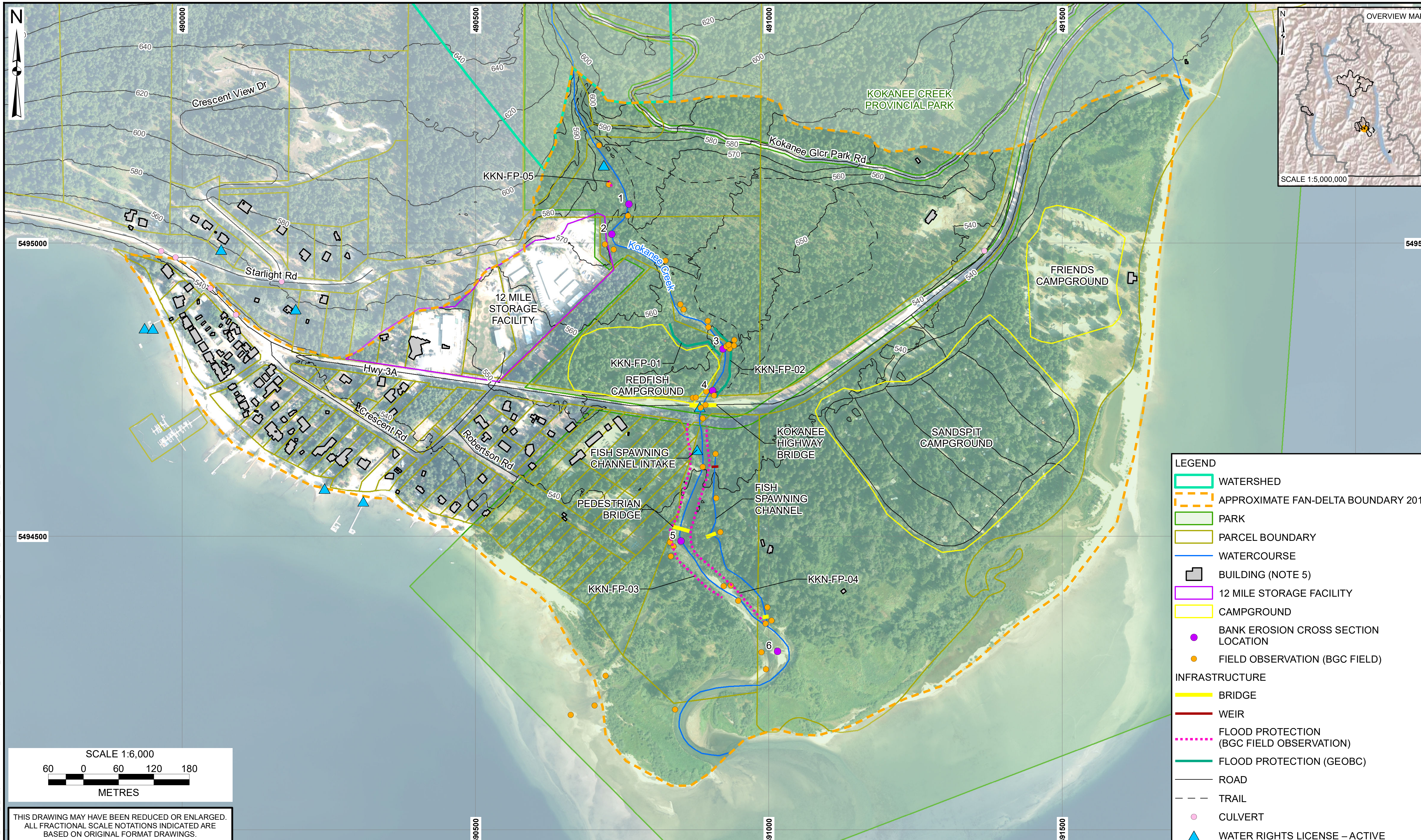
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE: KOKANEE CREEK FAN-DELTA SITE MAP

PROJECT No.:	DWG No:
0268007	02A



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 - KOKANEE CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA AND ORTHOPHOTO BASED ON LIDAR PROVIDED BY RDCK, DATED 2017. CONTOUR INTERVAL IS 20 m AND 10 m ON FAN.
4. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM BASED ON LIDAR DATED 2017. 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. BUILDING FOOTPRINTS DIGITIZED BY BGC BASED ON LIDAR AND REPRESENT ONLY A SUBSET OF TOTAL BUILDINGS ON THE FAN-DELTA. 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. CAMPGROUND AND STORAGE AREA BOUNDARIES ARE APPROXIMATE AND BASED ON 2017 LIDAR AND BC PARKS MAPS. 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:	1:6,000
DATE:	MAR 2020
DRAWN:	LL
CHECKED:	JJHP
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

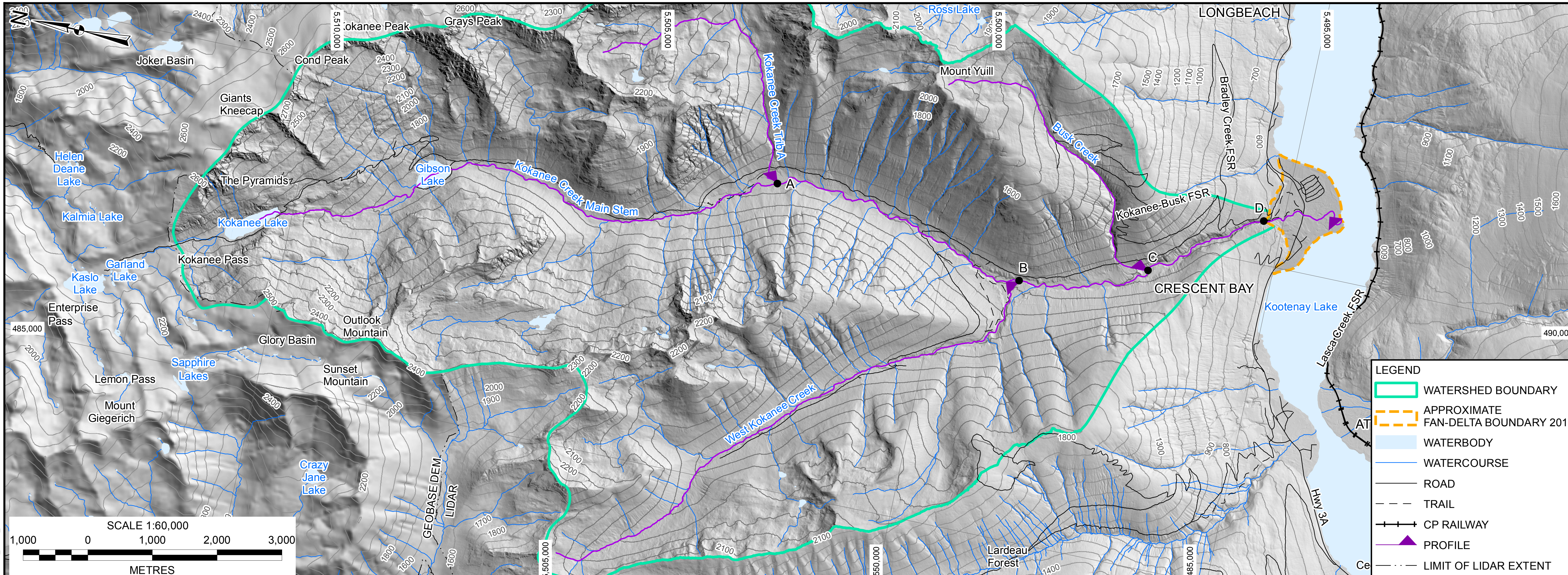
PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY

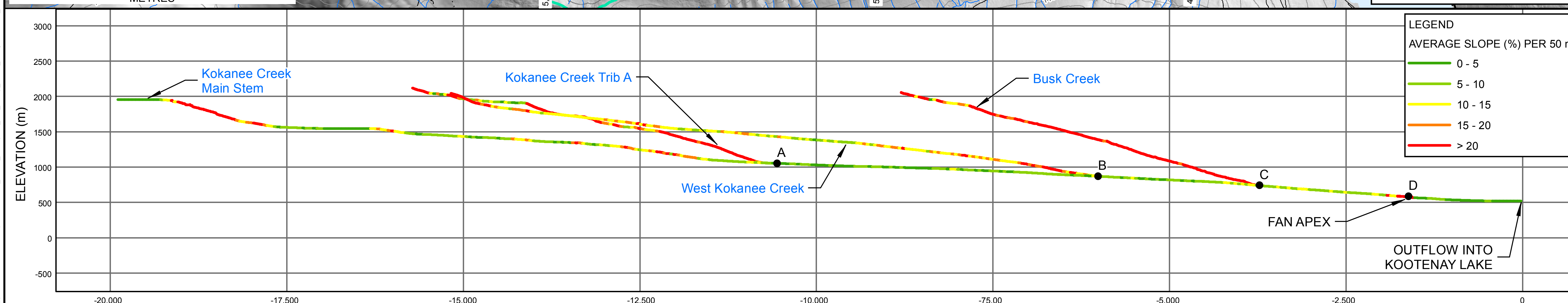
TITLE: KOKANEE CREEK FAN-DELTA SITE MAP

PROJECT No.: 0268007

DWG No: 02B

X:\Projects\0268007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191018_RDCK_Floodplain_and_Steep_Creek_Study\02B_Fan_Delta_Site_Map_DDP_KOKANEE.mxd





NO VERTICAL EXAGGERATION

DISTANCE (m)

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 – KOKANEE CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK AND GEOBASE CDED, DATED 2017 AND 2013, RESPECTIVELY.
4. THE WATERSHED AND FAN BOUNDARIES AS DRAWN ARE APPROXIMATE AND DELINEATE THE LANDFORMS. 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. RAILWAY DATA FROM GEOBASE NATIONAL RAILWAY NETWORK.
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 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:	STT
CHECKED:	JJHP, LCH
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: REGIONAL DISTRICT OF CENTRAL KOOTENAY

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY

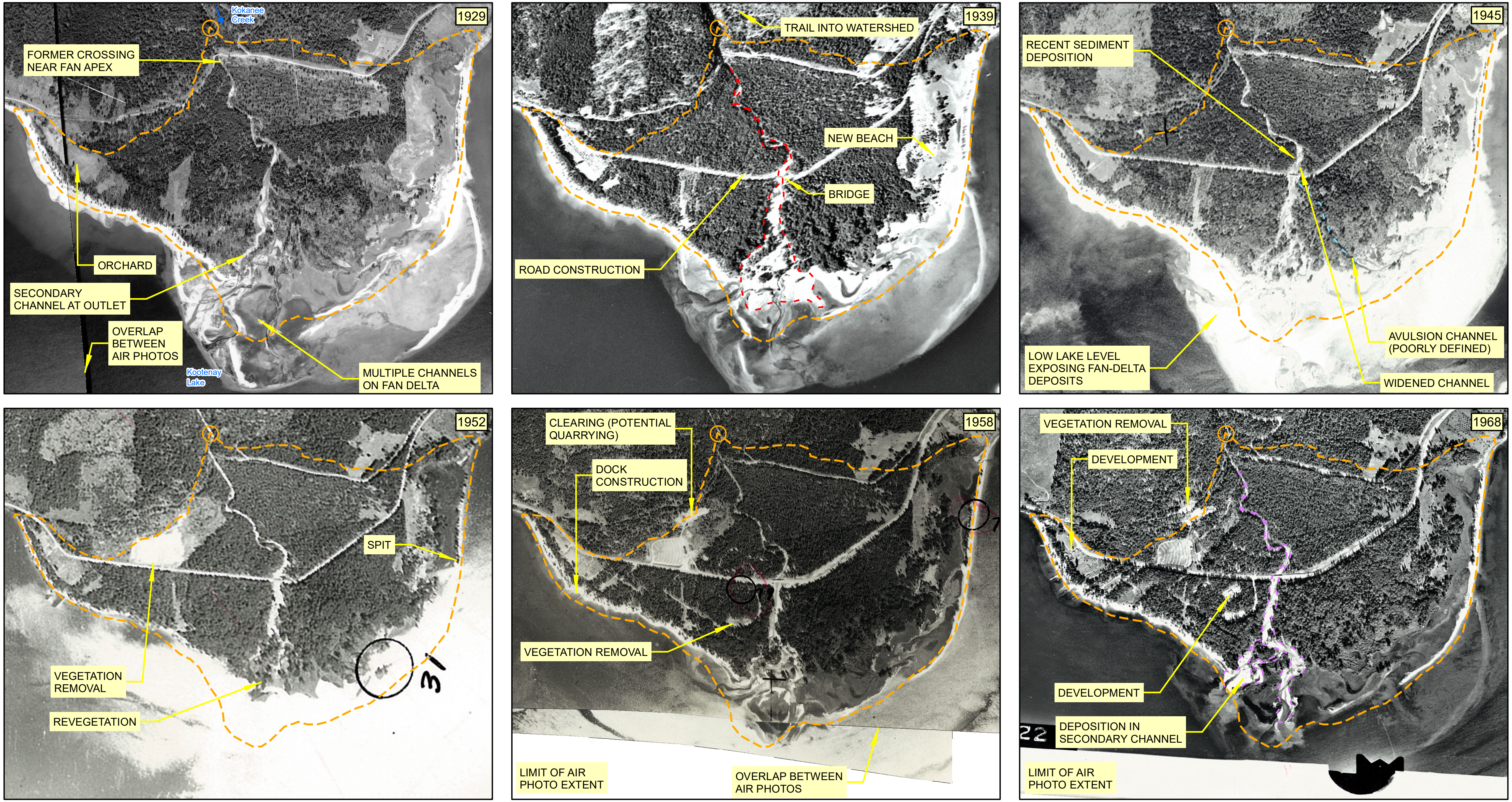
TITLE: KOKANEE CREEK PROFILE

PROJECT No.: 0268007

DWG No: 03

X:\Projects\0268007_RDCK_NDMP_Stream_2_Support\GIS\ProductionReport\20191018_RDCK_Floodplain_and_Steep_Creek_Study\Profile\03_Kokanee_Creek_Profile.mxd

N



SCALE 1:15,000

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 2017
- FAN APEX
- APPROXIMATE EXTENT OF 1930's EVENT
- APPROXIMATE EXTENT OF 1945 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 - KOKANEE CREEK", AND DATED MARCH 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 2017. 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 1952 WAS MARKED ON PHYSICAL COPIES PRIOR TO BGC'S AIR PHOTO INTERPRETATION.
6. LAKE LEVEL RAISED BY CORRA LINN DAM ACTIVATED IN 1938.
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:	1:15,000
DATE:	MAR 2020
DRAWN:	MIB, LL
CHECKED:	JJHP, LCH
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

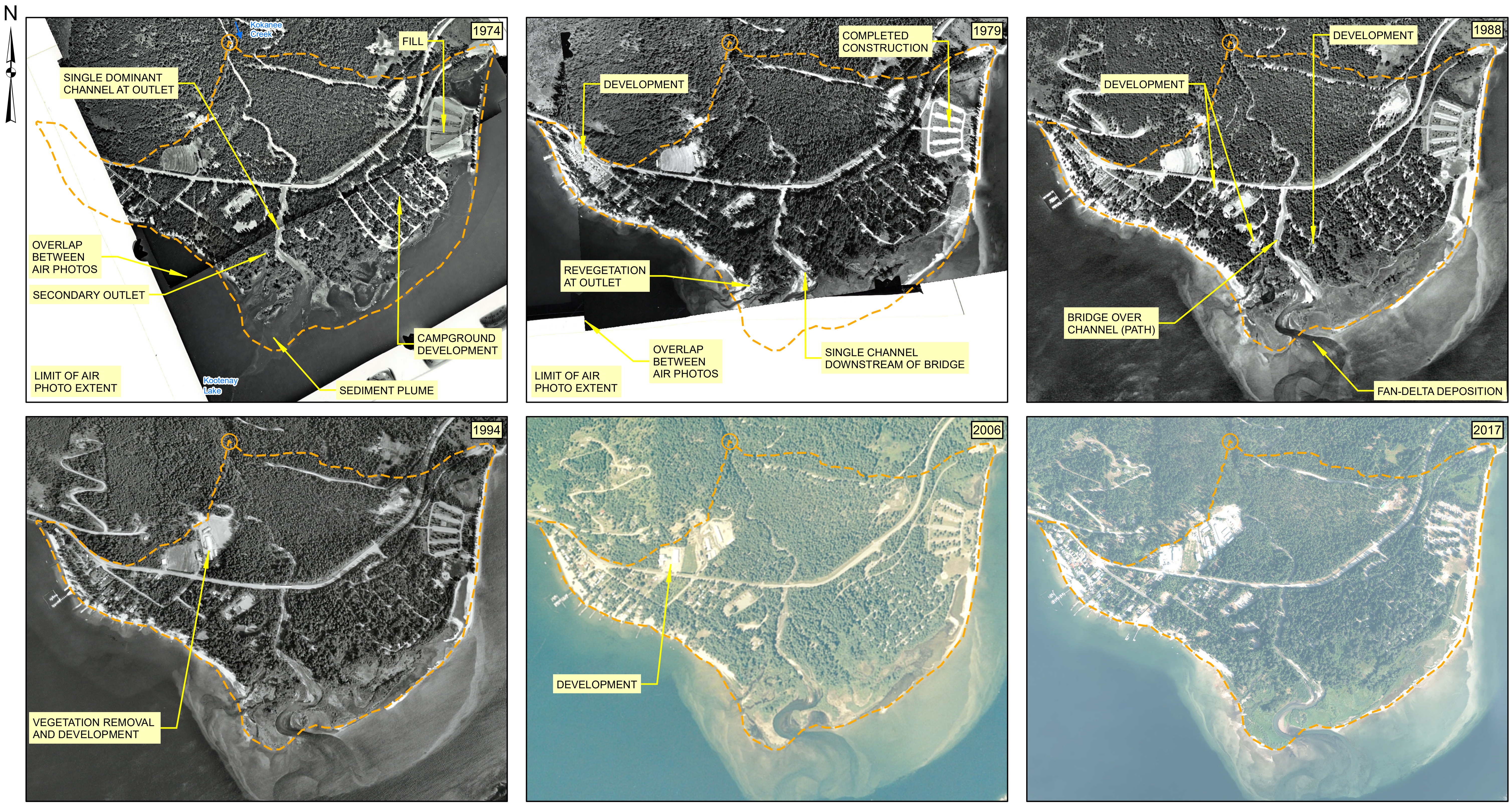
PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE:
KOKANEE CREEK
AIR PHOTO COMPARISON

PROJECT No.: 0268007

DWG No: 04A

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



SCALE 1:15,000

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 2017

FAN APEX

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 - KOKANEE CREEK", AND DATED MARCH 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 2017. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL FLOODING.
5. AIR PHOTOS WITH NO LABELS INDICATE NO MAJOR DEVELOPMENT OR CHANGE IN CHANNEL FEATURES COMPARED TO PREVIOUS AIR PHOTO.
6. LAKE LEVEL RAISED BY CORRA LINN DAM ACTIVATED IN 1938.
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:	1:15,000
DATE:	MAR 2020
DRAWN:	MIB, LL
CHECKED:	JJHP, LCH
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: REGIONAL DISTRICT CENTRAL KOOTENAY

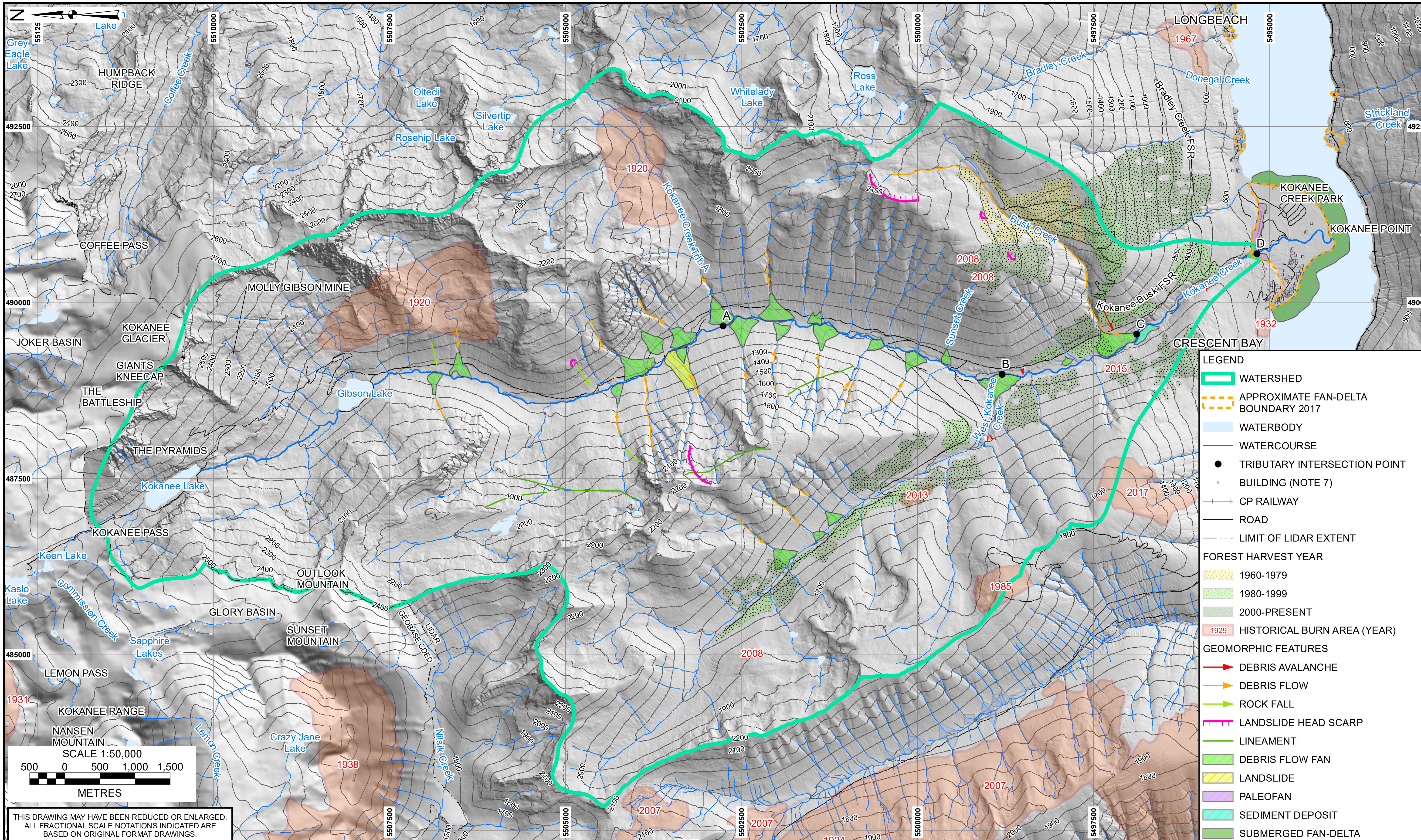
PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE: KOKANEE CREEK AIR PHOTO COMPARISON

PROJECT No.: 0268007

DWG No: 04B

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



NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY - KOKANEE CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017, 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 2017. 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 ONLY REPRESENTATIVE OF AREAS THAT INTERSECT WATERSHED BOUNDARY.
6. SUBMERGED FAN-DELTA DELINEATED BASED ON LAKE LEVEL FROM LIDAR DATED 2017.
7. BUILDING FOOTPRINTS DIGITIZED BY BGC BASED ON LIDAR AND REPRESENT ONLY A SUBSET OF TOTAL BUILDINGS ON THE FAN-DELTA. ROADS DATA FROM BC DIGITAL ROADS ATLAS. RAILWAY DATA FROM GEOBASE NATIONAL RAILWAY NETWORK.
8. PROJECTION IS NAD 1983 UTM ZONE 11N.
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:	1:50,000
DATE:	MAR 2020
DRAWN:	MW
CHECKED:	JJHP
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

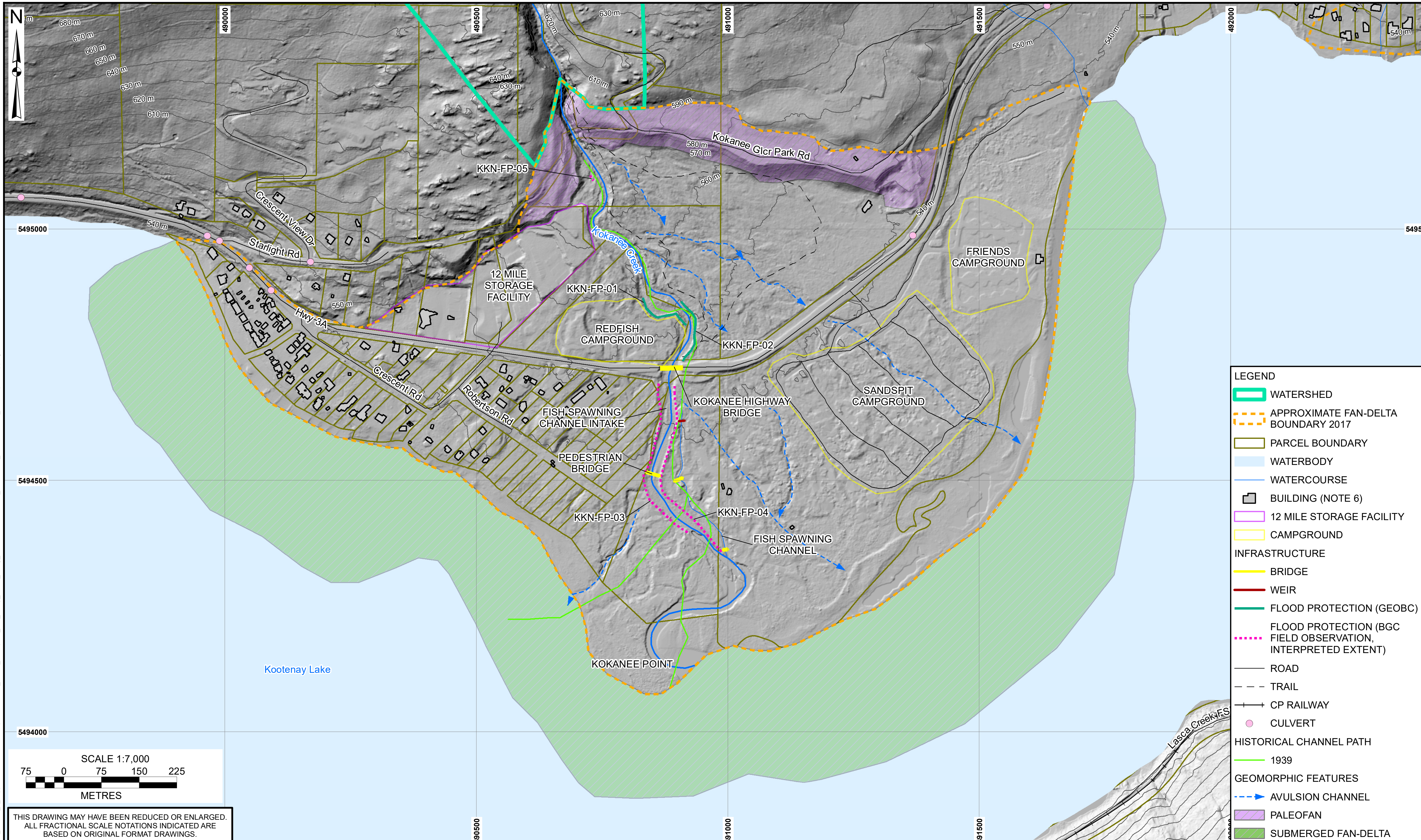
CLIENT:

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE: KOKANEE CREEK 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_KokaneeCreek_GeomorphicMappingWatershed.mxd Date: April 13, 2020 Time: 12:52 PM



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 - KOKANEE CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2017, AND GEOBASE CDED. CONTOUR INTERVAL IS 10m.
4. THE WATERSHED AND FAN-DELTA BOUNDARY AS DRAWN ARE APPROXIMATE AND DELINEATE THE LANDFORMS BASED ON LIDAR DATED 2017. THE BOUNDARIES SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DO THEY SHOW THE SPATIAL EXTENT OF POTENTIAL FLOODING.
5. SUBMERGED FAN-DELTA DELINEATED BASED ON LAKE LEVEL FROM LIDAR DATED 2017.
6. CULVERT LOCATIONS FROM BC MINISTRY OF TRANSPORTATION. ROADS DATA FROM BC DIGITAL ROAD ATLAS. RAILWAY DATA FROM GEOBASE NATIONAL RAILWAY NETWORK. PARCELS FROM PARCELMAP BC. BUILDING FOOTPRINTS DIGITIZED BY BGC BASED ON LIDAR AND REPRESENT ONLY A SUBSET OF TOTAL BUILDINGS ON THE FAN-DELTA. HISTORICAL CUT BLOCK DATA ONLY REPRESENTATIVE OF AREAS THAT INTERSECT WATERSHED BOUNDARY. CAMPGROUND AND STORAGE AREA BOUNDARIES ARE APPROXIMATE AND BASED ON 2018 LIDAR AND BC PARKS MAPS.
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:	1:7,000
DATE:	MAR 2020
DRAWN:	MW
CHECKED:	JJHP
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

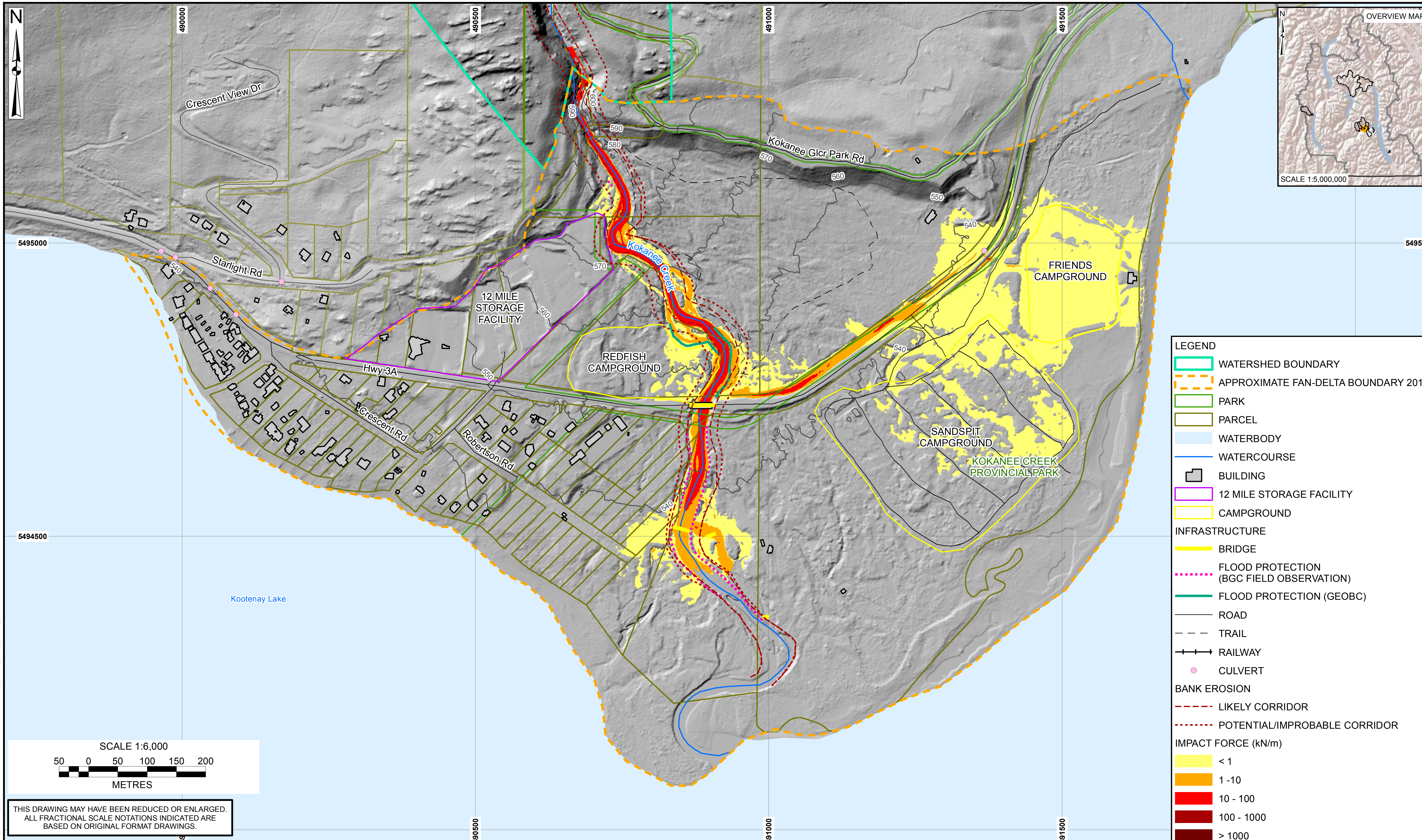
CLIENT:

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE:
KOKANEE CREEK
FAN-DELTA GEOMORPHOLOGY

PROJECT No.:	DWG No:
0268007	06

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191112_RDCK_Floodplain_and_Steep_Creek_Study_STEEPCREEK\FINAL_COPIES\06_KokaneeCreek_GeomorphicMappingofFan.mxd Date: April 13, 2020 Time: 4:33 PM



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 - KOKANEE CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK, DATED 2017. CONTOUR INTERVAL IS 20 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. BUILDING FOOTPRINTS DIGITIZED BY BGC. ROADS DATA FROM BC DIGITAL ROAD ATLAS. FLOOD 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:	1:6,000
DATE:	MAR 2020
DRAWN:	LL, MIB, STT
CHECKED:	LCH
APPROVED:	

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

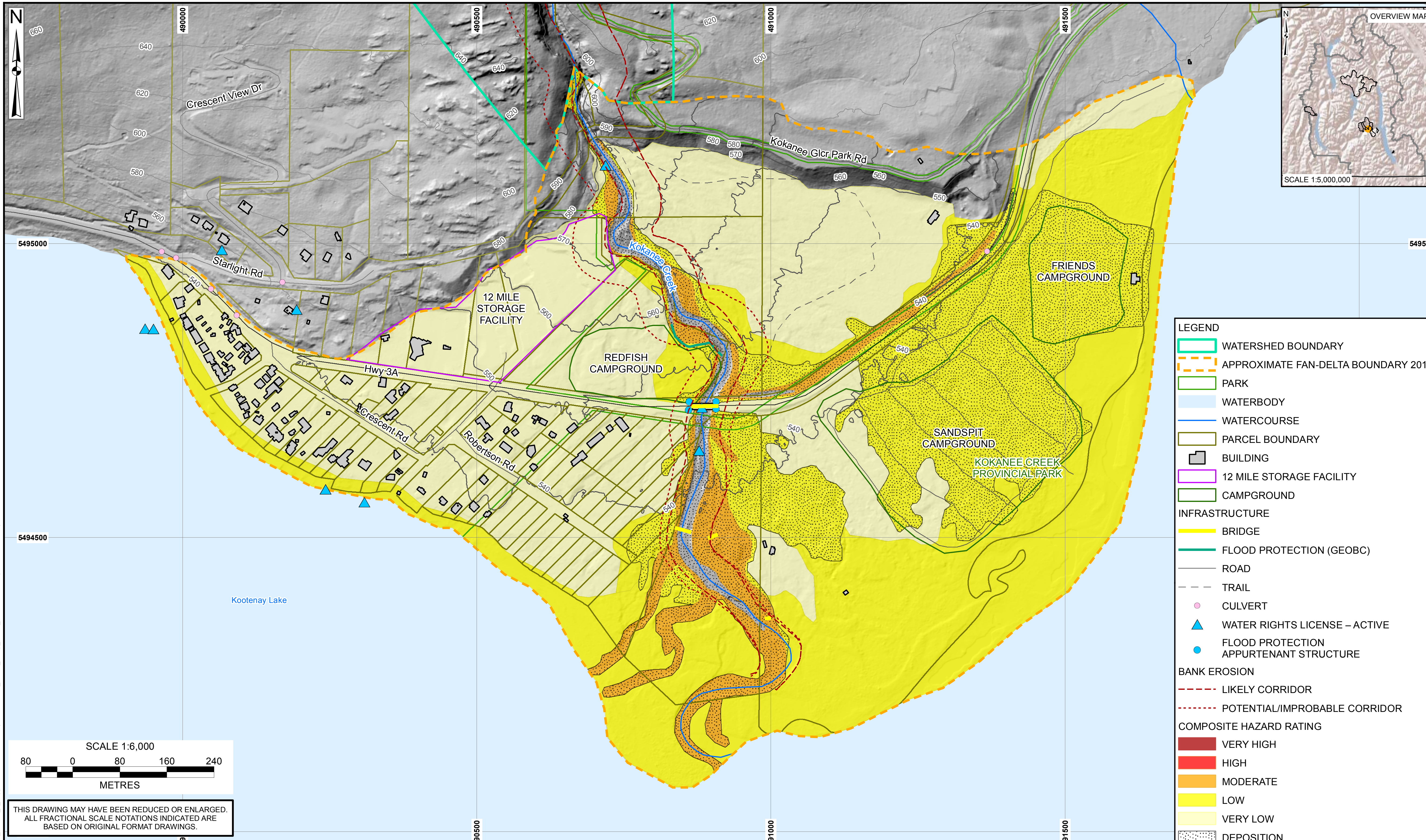
CLIENT: REGIONAL DISTRICT CENTRAL KOOTENAY

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE: KOKANEE CREEK 200 YEAR MODEL SCENARIO KKN-3

PROJECT No.:	DWG No:
0268007	07

X:\Projects\0268007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20200207_RDCK_Steep_Creek_Hazards\07 Kokanee Creek 200 Year Model Scenario.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 REPORTS TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY - KOKANEE CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK, DATED 2017. CONTOUR INTERVAL IS 20 m AND 10 m ON FAN. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM BASED ON LIDAR DATED 2017.
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. THIS MAP REPRESENTS A SNAPSHOT IN TIME. FUTURE CHANGES (DEVELOPMENT, DEBRIS FLOOD MITIGATION, GEOHAZARD EVENTS) MAY WARRANT RE-DRAWING OF CERTAIN AREAS.
6. 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. CAMPGROUND AND STORAGE AREA BOUNDARIES ARE APPROXIMATE AND BASE ON 2017 LIDAR AND BC PARKS MAPS.
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 OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE:	1:6,000
DATE:	MAR 2020
DRAWN:	STT, LL, MIB
CHECKED:	LCH
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE: KOKANEE CREEK COMPOSITE HAZARD RATING MAP

PROJECT No.: 0268007

DWG No: 08

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