RDCK FLOODPLAIN AND STEEP CREEK STUDY

Sitkum Creek

Final
March 31, 2020

BGC Project No.:
0268007

BGC Document No.:
RDCK2-SC-004F

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 6, 2020		Interim draft. Drawing 07 excluded and model results included for discussion purposes.
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 Sitkum Creek. Sitkum creek was chosen as a high priority creek amongst hundreds in the Regional District of Central Kootenays from a risk perspective because of its comparatively high hazards and 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 Sitkum 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, if required.

Sitkum Creek is one of ten steep creeks selected for detailed assessment, which can be grouped by hazard process as those principally dominated by floods and debris floods (Wilson, Cooper, Eagle, Kokanee, Sitkum, Harrop and Duhamel creeks); those by debris flows (Kuskonook Creek); and hybrids (Procter and Redfish creeks). Sitkum Creek is a debris-flood prone creek which implies that most grain sizes are being mobilized during the return periods considered.

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

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

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

Process	Key Observations
Clearwater inundation (HEC-RAS results for all return periods)	• Sitkum Creek likely remains in its current channel for return periods up to 20 years except from activation of near-channel floodplains between the fan-delta apex and Highway 3A. For return periods of 50 years and higher the creek tends to avulse downstream of Highway 3A where flows are prone to escape to the east. • Avulsion flow depths are shallow but can reach up to 2 m near the lake front • At the 500-year return period (modelled as a Type 3 debris flood) the Highway 3A bridge's capacity is likely exceeded and flood water would likely run west on Highway 3A all the way to the western fan-delta edge with water escaping towards Kootenay Lake in various locations. Some water would also flow towards the east along Highway 3A with substantial inundation of the eastern fan-delta sector downstream of Highway 3A which is largely uninhabited.
Sedimentation	• Sedimentation associated with debris floods can occur on the central and western fan-delta sector upstream and downstream of the Highway 3A crossing. Deposition depth could be up to 1 m for the 50-year debris flood and up to 4 m in the channel near the fan-delta apex and at the Highway 3A crossing. • In the lower central fan-delta, debris deposits up to 1 m thickness may develop outside of the active channel for return periods in excess of 50 years.
Bank Erosion	• The maximum total modelled erosion ranges from 8 m in a 20-year event to 42 m in a 500-year event. The likely erosion (i.e., the erosion adjusted based on the elevation of the surrounding terrain) ranges from 1 m to 8 m during the 20-year to 500-year event. • The abutments of the Highway 3A bridge may be impacted by erosion during a very high return period debris-flood event. Property located at the intersection of Kane Road and Highway 3A may also be impacted by progressive erosion and falls within the improbable erosion corridor for the 500-year return period event.
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 Sitkum Creek will build up sediment and avulse east or west of the active channel downstream of Highway 3A. • None of the numerical modeling accounts for breaches of the highway embankment. While modeling currently indicates that the development near MacGregor Road has low hazard potential, overtopping of the highway and erosion of the downstream (southern) highway embankment could lead to substantial impacts to the existing development in the MacGregor Road vicinity.

The multiple process numerical modelling ensemble approach demonstrates the key hazards and associated risks stem from avulsions at the Highway 3A crossing and may be attributable to exceeding channel capacity, channel aggradation, log jams or bridge failure. This could result in widespread flooding particularly on the central and western lower 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 is suited for debris floods and debris flows alike. The individual hazard scenario maps are useful for hazard assessments of individual properties as part of the building permit process as well as to guide emergency response as they provide a high degree of detail.

The composite hazard rating map (CHRM) 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 CHRM can serve to guide subdivision and other development permit approvals. It requires discussions and regulatory decisions on which hazard rating 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 rating zones could be impacted by flows of higher return periods, or if, over time, the channel bed of Sitkum Creek aggrades, or the channel or fan-delta surface is artificially altered. All other hazard categories are classified via the impact force intensity. The CHRM shows that the majority of the Sitkum Creek fan-delta are subject to very low and low hazards. Moderate and high hazards are confined to the main channel of Sitkum Creek upstream of Highway 3A, along Highway 3A west of the main channel, and within the creek and avulsion channel to the east downstream of Highway 3A.

A review of the NHC/Thurber (1990) study which was a detailed hazard and risk assessment of Sitkum 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.

While not comprehensive or quantitative, BGC provides several considerations for creek hazard management. These include (from the top of the fan delta to the bottom): A possible organic debris barrier to avoid bridge blockage and avulsions; an increase in the capacity of the highway bridge to avoid bridge blockage and avulsions; a large culvert west of the Highway 3A bridge crossing and a connector channel back to Sitkum Creek from its outfall to prevent road embankment erosion and flooding of properties in the vicinity of MacGregor Road. Finally, a call for allowing the lower fan delta to persist in a natural state with riparian vegetation allowing avulsions to occur and strongly discouraging future development on the lower fan-delta.

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 Sitkum Creek, bridge re-design or alteration to the existing berms near the fan-delta apex. Breaches of the Highway 3A road embankment due to retrogressive erosion associated with overtopping and undermining of the asphalt could result in inundation and rapid sedimentation not reflected on BGC's individual hazard scenarios or CHRM. 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 degree of 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 can be made.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF DRAWINGS

1. INTRODUCTION

1.1. Summary

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

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

This report details the approach used by BGC to conduct a detailed steep creek geohazards assessment for Sitkum Creek, located approximately 15 km northeast of Nelson, BC, in Electoral Area F. The site lies on the north side of the West Arm of Kootenay Lake and flows through the unincorporated community of Atbara, BC into the lake.

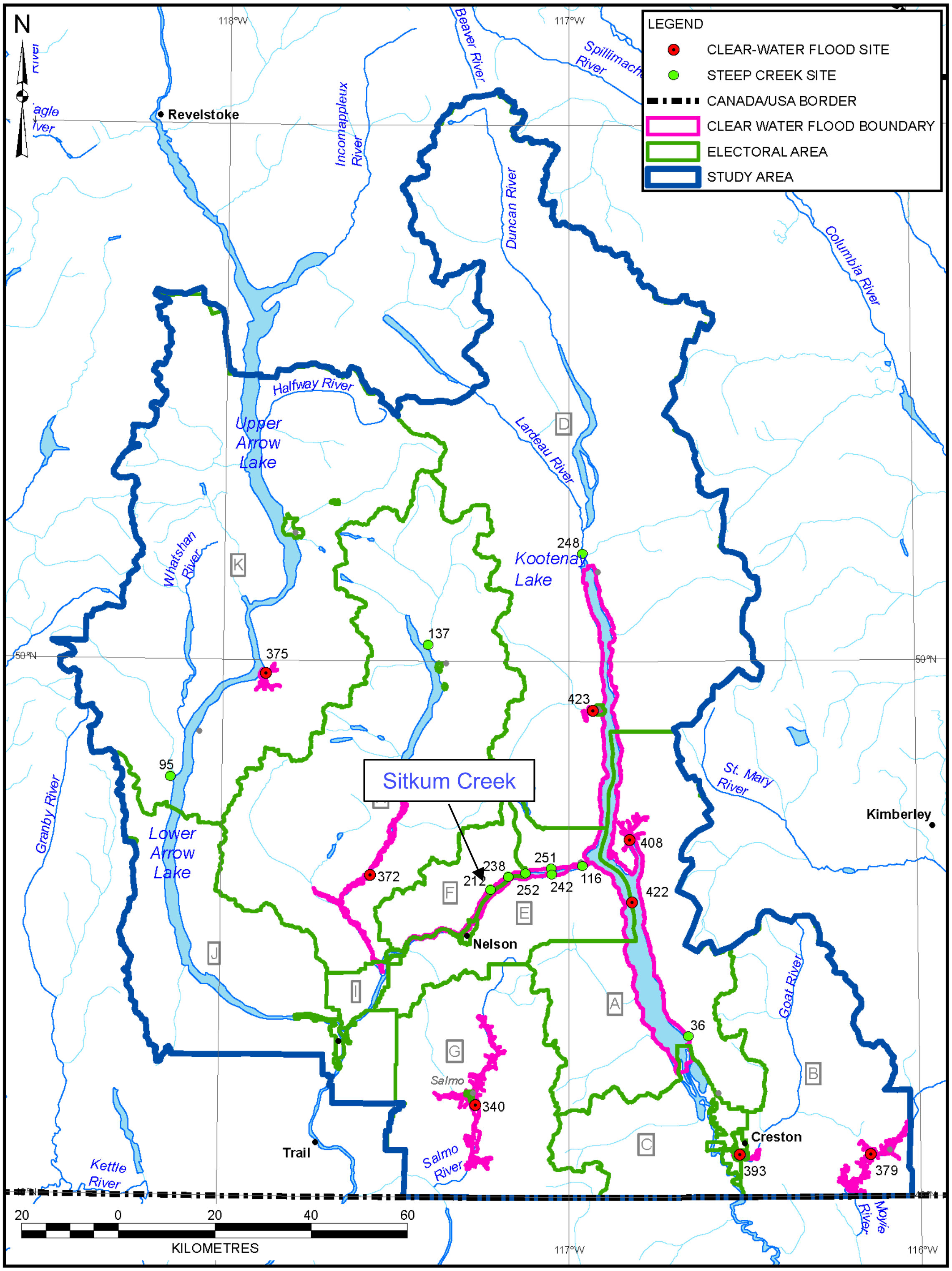


Figure 1-1. Hazard areas prioritized for detailed flood and steep creek mapping. Site labels correspond to hazard identification numbers in Cambio Communities. Sitkum Creek (No. 238) is labelled on the figure.

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 Sitkum 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.

1.2. Scope of Work

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

At Sitkum Creek, the scope of work included:

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

---

[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.

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

1.3. Deliverables

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

This report is best read with access to a BGC web application, Cambio^{TM}. Cambio displays the results of both the Stream 1 and Stream 2 studies. The application can be accessed at *www.cambiocommunities.ca,* using either Chrome or Firefox web browsers. 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 (BGC, March 31, 2020a) 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, Geological Engineer
- Matthias Busslinger, M.A.Sc., P.Eng., Senior Geotechnical Engineer
- Carie-Ann Lau, M.Sc., P.Geo., Intermediate Geoscientist

---

[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.

- 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
- Elisa Scordo, M.Sc., P.Geo., P.Ag., Senior Hydrologist
- Matthew Buchanan, B.Sc., GISP, A.D.P., GIS Analyst
- Sophol Tran, B.A., A.D.P., GIS Analyst
- Lucy Lee, B.A., A.D.P., GISP, GIS Analyst/ Developer
- Matthew Williams, B.Sc., A.D.P., GIS Analyst.
- Alistair Beck, B.S.F., Dip CST, Database/Web Application Developer
- Michael Porter, M.Eng., P.Eng., Director, Principal Geological Engineer.

Table 1-3. Study team.

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

2. STEEP CREEK HAZARDS

2.1. Introduction

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

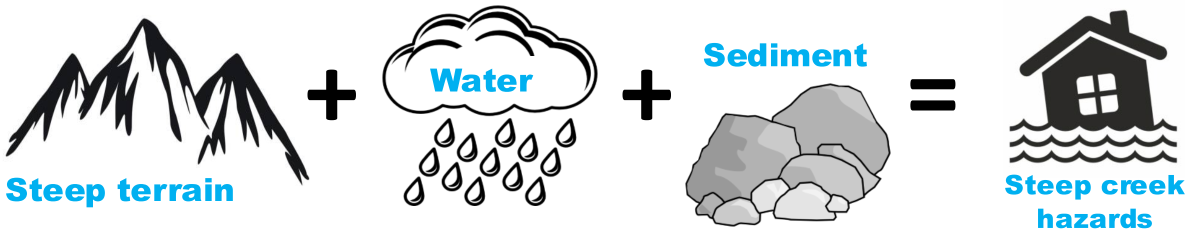


Figure 2-1. Illustration of steep creek hazards.

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

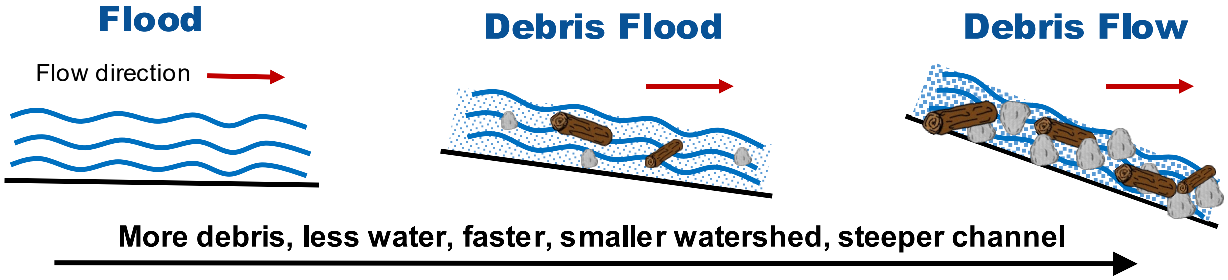


Figure 2-2. Continuum of steep creek hazards.

2.2. Clearwater Floods and Debris Floods

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

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

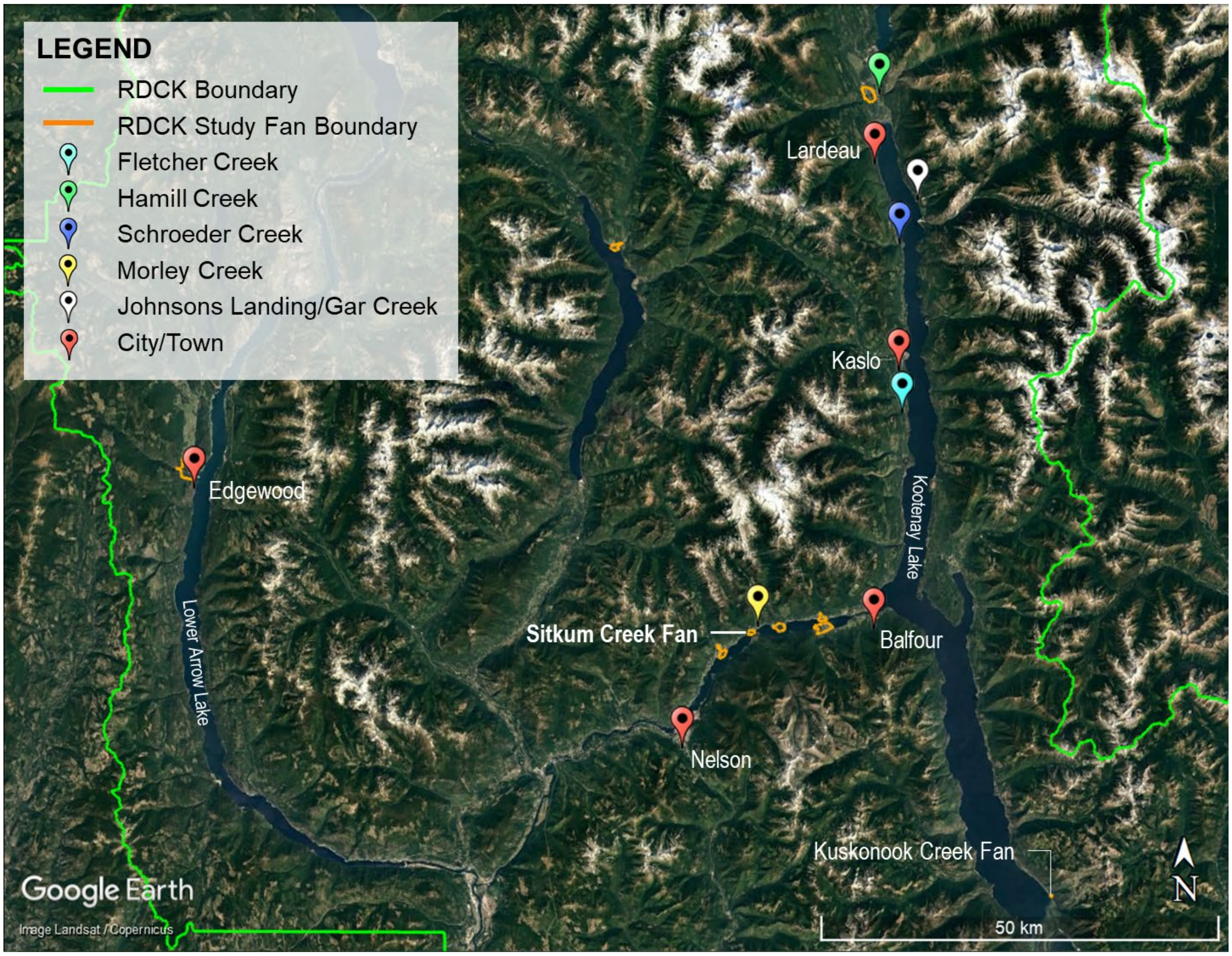


Figure 2-3. Locations of RDCK fan-deltas and recent clear- water floods, debris flows, and debris floods (Google Earth Pro, 2016).

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 modeled Type 2 discharge at the fan-delta apex. If the creek is subject to debris flows, the peak discharge may be 1 to 2 orders of magnitude higher than a 200-year flood (Jakob, 2005). Figure 2-4 demonstrates this concept with an example cross-section of a steep creek, including representative flood depths for the peak discharge of the following processes:

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

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

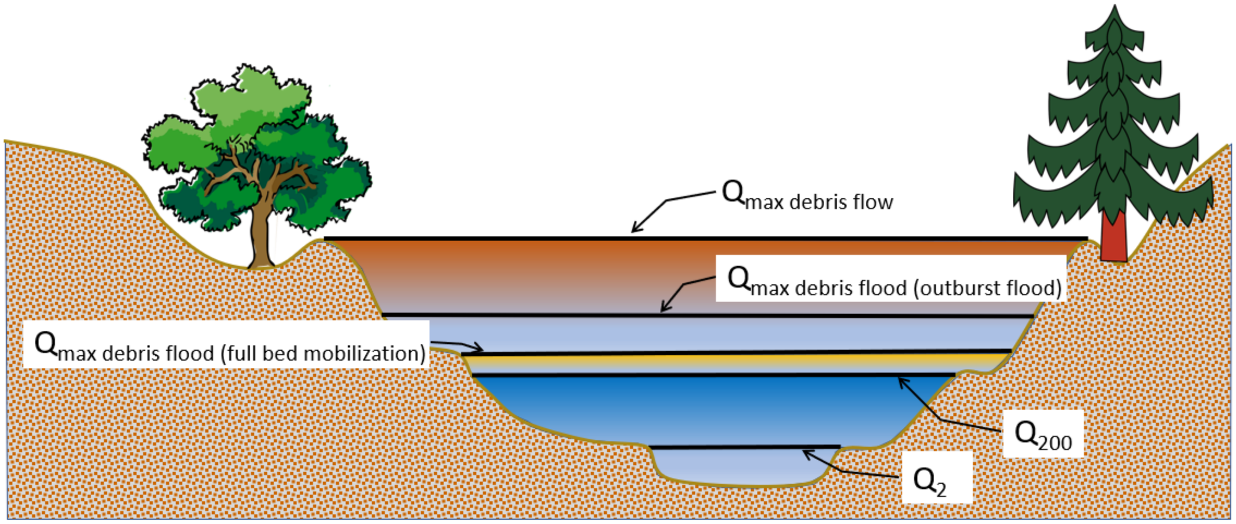


Figure 2-4. **Conceptual steep creek channel cross-section showing peak discharge levels for different events. Note that for some outburst floods or debris flows the discharge may well exceed what is shown here.**

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.

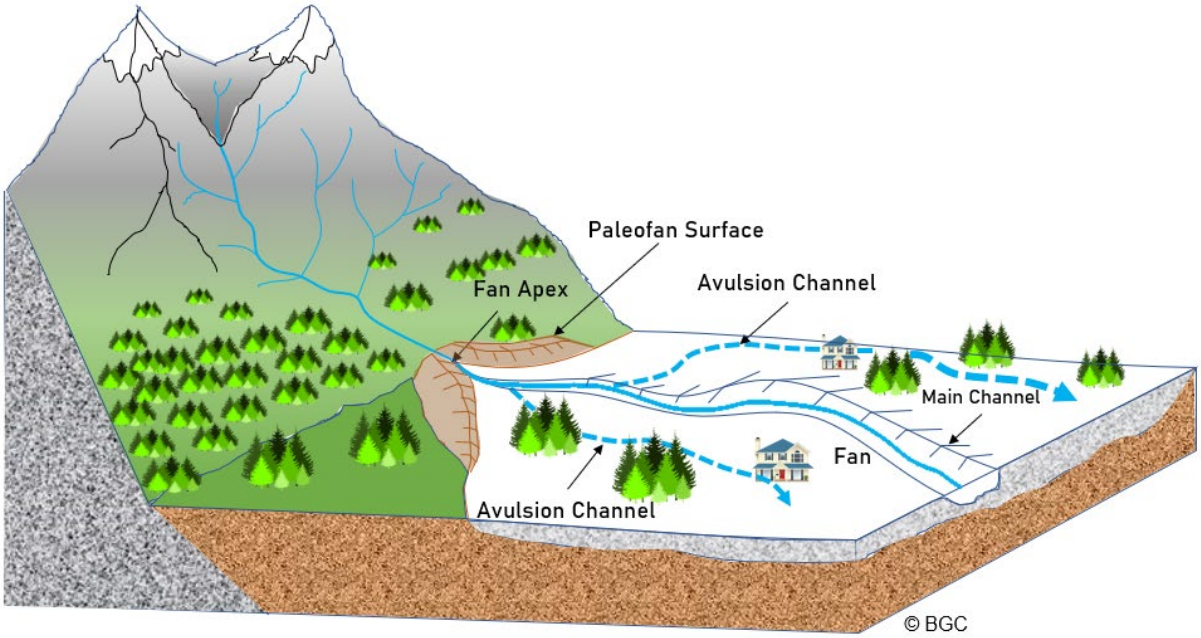


Figure 2-5. Schematic of a steep creek channel with avulsions downstream of the fan apex. Artwork by BGC.

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 Sitkum Creek watershed (Drawing 01) and existing development on the fan-delta (Drawings 02A, 02B).

3.1. Site Visit

Field work on Sitkum Creek was conducted from July 5 to 9, 2019 and on November 20, 2019 by the following BGC personnel Carie-Ann Lau, Kris Holm, Matthias Busslinger, Beatrice Collier-Pandya, and Hilary Shirra. Field work included channel hikes to look for evidence of high-water marks, measurement of grain size diameters (Wolman sampling) at the fan-delta apex and the channel mouth, measurement of cross-sections at bridge and other infrastructure crossing locations, and collection of tree core samples for dendrogeomorphic analysis (Drawings 02A, 02B). The watershed was also flown by helicopter and numerous photographs were taken for later analysis of major sediment sources to the channel.

3.2. Physiography

Sitkum Creek is located approximately 15 km northeast of Nelson, BC on the north side of the West Arm of Kootenay Lake and flows through an unincorporated community into the lake. For the purposes of this report, the name Atbara is applied acknowledging that the community is referred to by Nine Mile Narrows by some sources. Drawings 01, and 02A show the watershed and fan-delta boundaries of Sitkum 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-delta are provided in Appendix B.

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 very high in the Central Columbia ecosection, 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 elevation) and Engelmann Spruce and Subalpine Fir trees along the mid-mountain slopes. The highest peaks in the Central Columbia ecosection reach up to approximately 3200 m and consist of barren rock.

3.3. Geology

3.3.1. Bedrock Geology

The Sitkum Creek watershed is underlain by granodioritic intrusive rocks of the Nelson Batholith, which formed in the Mid-Jurassic Period. 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). No faults have been mapped within the watershed.

3.3.2. Surficial Geology

The surficial geology of the Sitkum Creek watershed is dominantly colluvium in the valley bottom and along the walls, with talus cones that cover the flanks of the highest ridges (Figure 3-1, Jungen, 1980). Minor till is located in upper and lower reaches. 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.

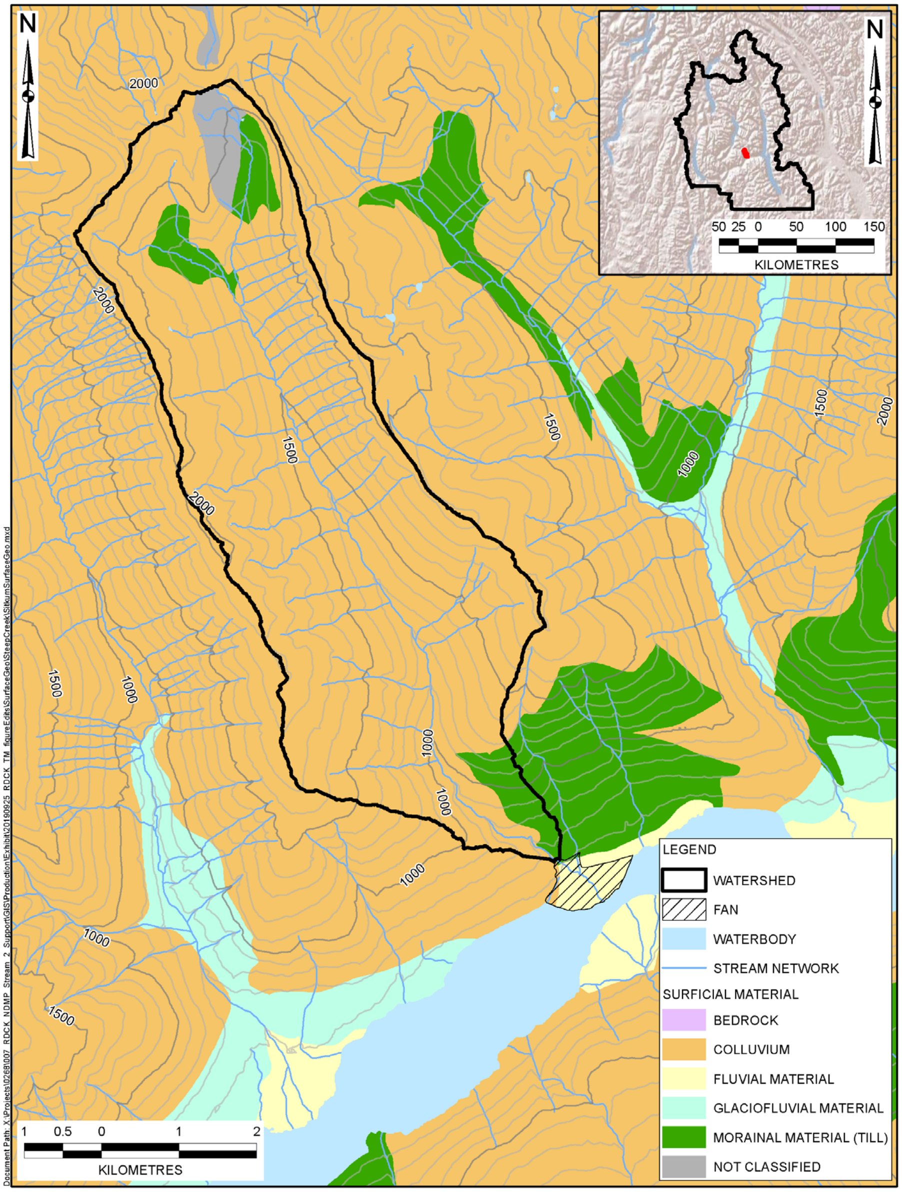


Figure 3-1. Surficial geology of the Sitkum Creek watershed (from Province of BC, 2016).

3.4. Geomorphology

3.4.1. Watershed

Geomorphological analysis of Sitkum Creek included characterization of the watershed and fan-delta 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.

The headwaters of Sitkum Creek are located on the mountainous slopes of Mount Cornfield (approximate elevation of 2360 m) at the northern edge of the watershed. The upper alpine reaches transition into a large U-shaped valley with debris flow tributaries on the east facing slopes in the mid to upper watershed that meet the low gradient, wide alluvial main channel from the steep valley sides. The east facing slopes contain remnant cirque[3] features that feed sediment into the main channel (Drawing 05).

In the middle of the watershed, snow avalanche prone tributaries are visible on both sides of the valley with debris fans mapped at the base. The debris fans are interpreted to be developed from erosion and sediment transport in snow avalanche events. The U-shaped valley transitions into a V-shaped valley approximately 3 km from the fan-delta apex where the main channel becomes more confined and has a steeper gradient (Drawing 03). Here, debris avalanches are mapped on the west-facing slopes.

Most of the watershed is forested with relatively minor logging. Approximately 9% of the total watershed area has been logged since 1900 and 37% of the watershed area has burned since 1919, with the largest forest fire recorded in 2007 (FLNRORD, 2019a; 2019b). There is evidence of logging road failures throughout the logged portion of the watershed.

Table 3-1 summarizes relevant geomorphic characteristics of the Sitkum 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-delta apex provides an indication of whether transportation of sediment is likely, and the fan-delta gradient approximates the angle where sediment deposition of larger flows from the watershed generally ensues.

---

[3] A cirque is an amphitheatre-shaped basin with precipitous walls, at the head of a glacial valley.

Table 3-1. Watershed characteristics of Sitkum Creek.

Characteristic	Value
Watershed area (km^2)	27
Fan-delta area (km^2)	0.51
Active fan-delta area (km^2)[1]	0.50
Maximum watershed elevation (m)	2,360
Minimum watershed elevation (m)	610
Watershed relief (m)	1,750
Melton Ratio (km/km)[2]	0.3
Average channel gradient of mainstem above fan-delta apex (%)	14
Average channel gradient on fan-delta (%)	11
Average fan-delta gradient (%)	14

Note:

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. Sitkum Creek Fan-Delta

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

Sitkum Creek flows southeasterly across the fan-delta that extends into the West Arm of Kootenay Lake. The Sitkum Creek fan-delta creates Nine Mile Narrows with the Lasca Creek fan-delta on the opposite side of Kootenay Lake that also extends into the West Arm. Sitkum Creek has experienced significant avulsion and channel shifting in the past century. The main Sitkum Creek channel shifted 90 m west between the 1929 and 1958 air photo records on the lower fan-delta south of Highway 3A (Section 6.2.1). Currently, the active channel ranges in width from 7 to 25 m on the fan-delta and increases to 35 m at the outlet to Kootenay Lake. The average channel gradient decreases from greater than 20% immediately upstream of the fan-delta apex to less than 5% near the channel outlet (Drawing 03).

Approximately 120 m upstream of the fan-delta apex, there is a 5 m high and 25 m long log and debris jam across the main channel with a total debris wedge volume of approximately 300 m^3 (Photo 8, Appendix B). At the location of the debris jam, the channel is 5 m wide. There is no record as to when the jam occurred. Downstream of the jam, the channel is bedrock controlled leading to the fan-delta apex (Photo 9, Appendix B).

The Sitkum Creek fan-delta has adjusted due to the raise of lake levels when Corra Linn Dam, located southwest of Nelson, was activated in 1938. The dam raised lake levels by approximately

2 m (Touchstone Nelson, 2007) and BGC understands that this level will be held. The distal portions of the fan-delta, visible in historical air photos (Section 6.2.1), were flooded by the lake level raise. Avulsion channels are visible on the lower fan-delta over an area of waterfront approximately 75 m long.

3.4.3. Steep Creek Process

BGC assessed the potential steep creek process types and hazards on Sitkum 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, Sitkum Creek plots in the zone of floods to debris floods (Figure 3-2). The points shown on the plot are subject to some error and watersheds can be subject to multiple processes at different timescales; for this reason, it is important to consider additional evidence to supplement the assessment of process type.

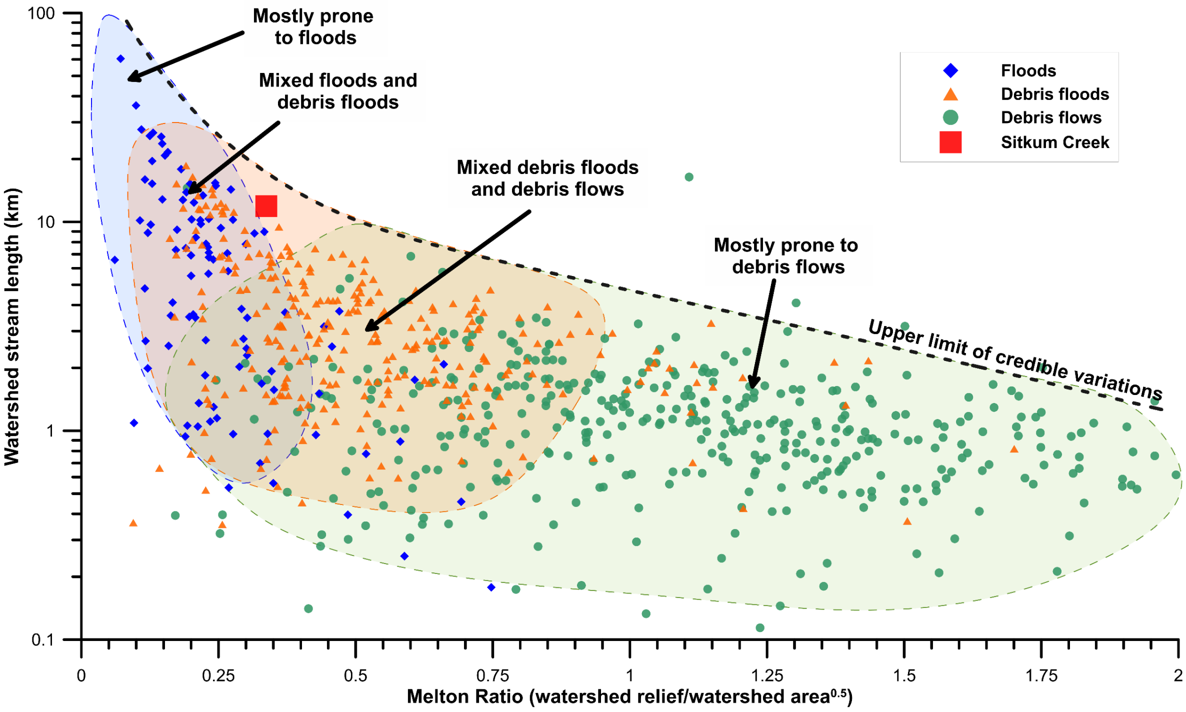


Figure 3-2. Tendency of creeks to produce floods, debris floods and debris flows, as a function of Melton Ratio and stream length (data from Holm et al., 2016 and Lau, 2017). See Section 3.2 for Sitkum Creek watershed data.

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.

BGC interprets Type 1 debris floods to be the dominant hydrogeomorphic process at Sitkum Creek for low return periods (20-year), while Type 2 debris floods dominate in the higher return periods (50-, 200-, and 500-year) that were studied. This rationalization is discussed further in Section 6.1.

3.5. Existing Development

Development on the Sitkum Creek fan-delta comprises the unincorporated community of Atbara. Highway 3, and petroleum and communications infrastructure which transect the mid-fan-delta. There is a furnace store, Enerwest Distribution, on the southwest distal fan-delta.

The 2016 census does not have a population estimate for Atbara and instead groups the community into the RDCK electoral area (Statistics Canada, 2016). As part of the Stream 1 study, BGC (March 31, 2019) estimated a population that directly intersects the fan-delta area. This estimate should be treated as a minimum as it does not account fully for all population sources. The estimated total improvement value of parcels intersecting the Sitkum Creek fan-delta based on the 2018 BC Assessment Data is $12,435,000 (BGC, March 31, 2019).

There are six water intakes along Sitkum Creek upstream of Highway 3A, two at the Highway 3A crossing, and an additional two downstream of the Highway (e.g., Photo 10, Appendix B) (Drawings 02A, 02B).

3.5.1. Bridges

Sitkum Creek passes under two bridges on the fan-delta. (Figure 3-3, Table 3-2). Bridge locations are shown on Drawings 02A, 02B. The Highway 3A bridge (Figure 3-3 A-D) is at mid-fan-delta. The channel has steep (2H:1V to 1.5H:1V) slopes armoured in riprap on either side upstream of the bridge. The Sitkum Creek channel gradient decreases abruptly from approximately 14% upstream of the bridge to approximately 6% on the downstream side. During the site visit in July 2019, BGC noted locations on the east and west sides of Sitkum Creek along Highway 3A where the downstream (south) side of the road drops steeply into properties and identified the potential for overland flooding to affect the properties if a bridge blockage led to Sitkum Creek overtopping or avulsing. This hazard was evaluated as part of a past assessment associated with a building permit application west of MacGregor Road on the south side of Highway 3A (Integrated Hydropedology, 2005). Overland flood and avulsion potential were also investigated with numerical models in the present study (Section 6.5).

Approximately 130 m downstream of the Highway 3A bridge, Sitkum Creek passes under a wooden trestle bridge (Figure 3-3E, Drawings 02A, 02B). The bridge is set onto concrete blocks above the active channel which is approximately 8 m wide at this location.

A) On right bank looking upstream from Highway 3A bridge. Bridge is to the right of this picture.

B) On right bank looking at left bank rip rap armouring approximately 1.5 m wide, 4 m high.

C) Looking downstream at Highway 3A bridge over Sitkum Creek.

D) On right bank looking northeast at gas pipeline on downstream side of bridge.

E) Wooden trestle bridge

Figure 3-3. Highway 3A bridge (A – D) and wooden trestle bridge (E) over Sitkum Creek. BGC photos taken July 4, 2019.

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

Bridge	Span (m)	Height Above Channel Center (m)	Notes
Sitkum Highway Bridge	11	2.1	Highway 3A, 2-lane road
Wood Bridge (Trestle)	11	2	Downstream of Sitkum Highway Bridge, 2.0 m clearance on July 4, 2019

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

3.5.2. Flood Protection Structures

Sitkum Creek is paralleled by a series of berms on the right (west) side of the channel upstream of Highway 3A and that parallel the channel on both banks downstream of Highway 3A. The attributes of the berms based on the iMac Flood Protection Structural Works layer are outlined in Table 3-3. These berms were presumably constructed to protect against channel avulsions. In a 1990 assessment of Sitkum Creek (NHC and Thurber, 1990), multiple avulsion pathways were identified on the fan-delta. This observation is consistent with BGC's observations of multiple low spots in the channel and berms were identified.

In the proximal fan-delta, there is a 4 m high berm located approximately 75 m west of the main channel. While a majority of the berm is well vegetated, it appears to have been constructed with piled river rock (Figure 3-4A). BGC believes this berm is an extension of flood protection structure STK-FP-1 (Figure 3-4A, Table 3-3), as delineated on Drawings 02A, 02B. The exact length of this undocumented structure is not known as it was not measured in the field, therefore it was delineated using the lidar DEM and should be treated as approximate. South of this, there is a natural levee approximately 2-3 m high that runs generally north south (Integrated Hydropedology, 2005). This natural levee appears to tie into STK-FP-2.

Downstream of Highway 3A, there is a berm constructed of rounded cobbles and an old concrete foundation (STK-FP-4, Figure 3-4B). Approximately 40 m downstream from the Highway 3A bridge, there is a low spot in this berm where there is the potential for flow to overtop and follow a low, linear feature interpreted to be an old road that runs southeast from the low point.

In the distal fan-delta, a boulder and cobble bar was observed on the right bank adjacent to flood protection berm STK-FP-5 (Photo 16, Appendix B). The bar measured approximately 1 m high and 6 m wide and was vegetated with cedar trees estimated to be 30 to 50 years old. This bar was likely deposited during a major flood event.

A) Berm approximately 75 m west of main channel in proximal fan-delta (STK-FP-1).

C) Low point in berm (STK-FP-6) on right bank approximately 275 m downstream o Hwy 3A. Right bank berm height was 0.6 m, left bank was 0.7 m compared with 1.2 m high upstream and downstream of this location on both banks.

B) Berm constructed of rounded cobbles and old concrete foundation approximately 2 m high on left bank approximately 20 m downstream of Highway 3A bridge (STK-FP-4).

Figure 3-4. Select flood protection structures along Sitkum Creek. BGC photos taken July 4, 2019. Refer to Table 3-3 for attributes and Drawings 02A, 02B for locations.

Table 3-3. Flood protection structure attributes along Sitkum Creek.

Attribute	Flood Protection Structure								
BGC ID	STK-FP-1	STK-FP-2	STK-FP-3	STK-FP-4	STK-FP-5	STK-FP-6	STK-FP-7	STK-FP-8	STK-FP-9
Source[1,2]	iMapBC / BGC Field Observation	iMapBC	iMapBC	iMapBC	iMapBC	iMapBC	iMapBC	iMapBC	iMapBC
Type	Dike	Protection	Dike	Dike	Dike	Dike	Dike	Dike	Dike
Orphan (Y/N)[4]	Y	Y	Y	Y	Y	Y	Y	Y	Y
Comments	Piled river rock		Berm	Piled rock	Berm	Berm	Piled rock	Piled rock	Piled rock
Survey Year(s)	2004	-	2004	2004	2004	2004	2004	2004	2004
Erosion Protection Side	Right	Left	Right	Left	Left	Right	Left	Left	Left
Length (m)	31	22	43	89	64	275	45	88	53

Notes:

1. iMapBC data downloaded from Flood Protection Structural Works layer on February 23, 2020.
2. BGC Field Observation made on July 5-9, 2019.
3. Only the structures within iMapBC data were classified as orphan structures.

3.5.3. Water Intake and Access Road

In addition to the low points in the berms paralleling the channel, NHC/Thurber (1990) identified the potential for a channel avulsion near the fan-delta apex where the access road to a water intake provides a preferential flow path west of the channel. The road is visible on the lidar on Drawings 02A, 02B. The right (west) bank below the water intake was armoured in 1990 (Integrated Hydropedology, 2005) and the road grade of the access trail built up to reduce the potential for overland flow down the road (WSA, 2007). Additional improvement works were completed following a wildfire in the watershed in 2007 including excavation of a deep cross ditch near the apex of the fan-delta and a boulder deflection berm to direct overbank flood water and debris towards the active channel. Two arcuate trenches measuring 4 to 5 m wide and 1.5 m deep were also constructed on the southwestern side to direct floodwater back towards the active channel (Perdue, 2012). These features were not visited during BGC's site visit in 2019 and therefore BGC can provide no comment on the current condition. The features are not discernible in the lidar.

Previous assessments indicated that flooding in this area would be directed back towards the channel (NHC/Thurber, 1990; Integrated Hydropedology, 2005; WSA, 2007). As part of this scope, BGC completed numerical modelling with lidar to investigate the potential for avulsion and overland flooding during flood and debris flood events. Model results are presented in Section 6.5.

3.6. Hydroclimatic Conditions

3.6.1. Existing Conditions

Climate normal data were obtained from Environment and Climate Change Canada's South Slocan weather station (457 m), located approximately 30 km southwest of the Sitkum Creek outlet (Environment and Climate Change Canada, n.d.). Daily precipitation and temperature data are available from 1940 to 2008. Figure 3-5 shows the average monthly temperature and precipitation for this station from the 1971 to 2000 climate normals. Precipitation (rain and snow) peaks in November. Average rainfall peaks in June with a slightly lower value. Total annual precipitation is 853 mm at the South Slocan weather station, as summarized in Table 3-4.

The measured historical (1971 to 2000) precipitation at the South Slocan weather station is lower than the historical (1961 to 1990) precipitation in the Sitkum Creek watershed, where the mountaintops extend more than 1800 m above Kootenay Lake. This difference in precipitation is due to orographic effects, which occur when an air mass is forced up over rising terrain from lower elevations. As the air mass gains altitude, it quickly cools down, the water vapour condenses forming clouds resulting in precipitation.

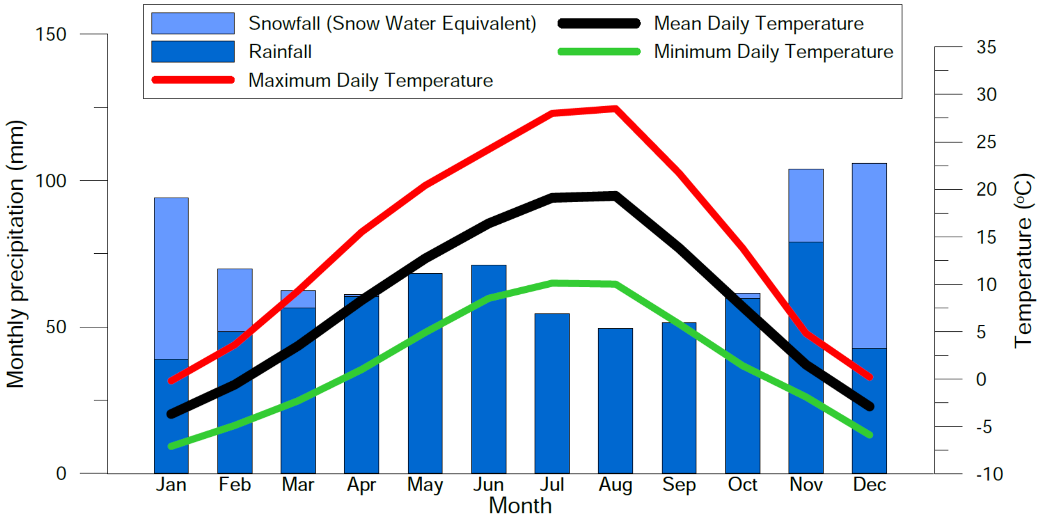


Figure 3-5. Climate normal data for South Slocan station from 1971 to 2000.

Table 3-4. Annual total of climate normal data for South Slocan weather station from 1971 to 2000.

Variable	Annual Total	Percent of total annual precipitation (%)
Rainfall (mm)	680	80
Snowfall (cm)	173	20
Precipitation (mm)	853	100

To understand the regional distribution of precipitation and snowfall patterns and supplement the data from the South Slocan station, BGC obtained climate data based on the CRU-TS 3.22 dataset (Mitchell & Jones, 2005) for the period 1961 to 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 1303 mm, varying as a function of elevation. The same trend is evident in the historical annual average Precipitation as Snow (PAS) over the watershed where the historical average PAS is 694 mm. PAS increases with higher elevation; therefore, the watershed accumulates greater precipitation falling as snow compared to the South Slocan weather station.

3.6.2. Climate Change Impacts

The watershed lies within the Southern 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 mean annual temperature (MAT) in the Sitkum Creek watershed is projected to increase from 3.1ºC (historical period 1961 to 1990) to 6.6ºC by 2050 (average for projected period 2041 to 2070). The MAP is projected to increase from 1303 mm to 1378 mm while PAS is projected to decrease from 694 mm to 430 mm by 2050 in the Sitkum Creek watershed. Projected change in climate variables from historical conditions for the Sitkum Creek watershed are presented in Table 3-5.

Changes in streamflow vary spatially and seasonally based on snow and precipitation changes and topography-based temperature gradients. Researchers anticipate that streamflow will increase in the winter and spring in this region due to earlier snowmelt and more frequent rain-on-snow events, while earlier peak discharge timing is expected in many rivers (Schnorbus et al., 2014; 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 (1961 to 1990) conditions for the Sitkum Creek watershed (Wang et. al, 2016).

Climate Variable	Projected Change
Mean Annual Temperature (MAT)	+3.5 ºC
Mean Annual Precipitation (MAP)	+76 mm
Precipitation as Snow (PAS)	-264 mm

4. SITE HISTORY

4.1. Introduction

Sitkum Creek flows through an unincorporated community on the fan-delta of Sitkum Creek and into Kootenay Lake at Nine Mile Narrows. Residents have lived on the fan-delta since the late 1800s.

Historic mining activity at Alpine Mine dates back to at least 1896. Mining activity continued until 1988. The historic mine is located at in the upper watersheds of Sitkum, Duhamel and Lemon Creeks (Figure 4-1). The Sitkum-Duhamel Forest Service Road provides access to southern portion of the mine (Drawings 02A, 02B). When in production, the mine produced approximately 11,500 oz of gold, 7.,200 oz of silver, 49 tonnes of lead, and 17 tonnes of zinc (Duhamel Watershed Society, 2017). In 2017, the first phase of a new 5-year mineral exploration project began with exploration drilling.

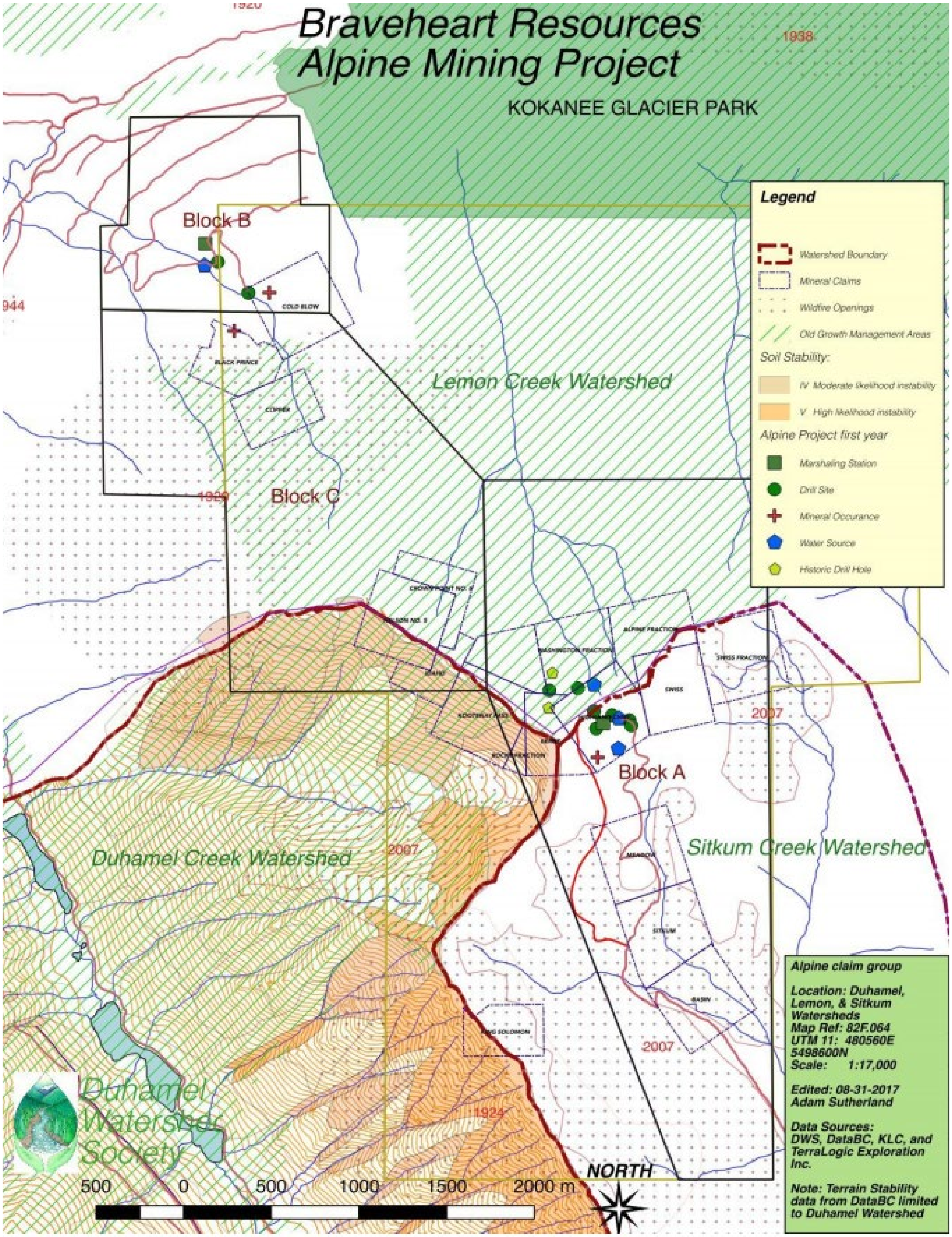


Figure 4-1. Alpine Mine claim group (Duhamel Watershed Society, 2017)

4.2. Document Review

In developing a flood, mitigation, and development history for Sitkum 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) (Table 4-1).
- Historical flood and landslide events from the following sources:
    - Social media and online media reports
    - Septer (2007)
    - DriveBC historical events (2009 to 2017)
    - Canadian Disaster Database (Public Safety Canada, n.d.)
    - MFLNRORD.
- Historical wildfire perimeters (MFLNRORD, n.d.).
- Cut block perimeters (MFLNRORD, n.d.)

BGC's review of the above work is not aimed as a critique but rather a brief summary of the findings of each report. Each scientific or engineering/geoscientific study builds on the preceding one benefitting from the added knowledge. In the case of the NHC/Thurber (1990) study, 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. By summarizing aspects of the studies listed below, BGC is neither endorsing nor rejecting the findings of those studies.

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

Year	Month/Day	Source	Purpose
1972	June	Water Resources Branch (BC Government)	Flood survey report
1990	April	Northwest Hydraulic Consultants Ltd. and Thurber Consultants Ltd.	Hazard Assessment
1998	February 23	Klohn-Crippen	Terrain Stability Inventory
2005	May 4	Integrated Hydropedology Ltd.	Precondition for Building Permit
2006	February 3	Integrated Hydropedology Ltd.	Precondition for Subdivision
2006	November 8	Intermountain Engineering & Surveying Ltd.	Precondition for Building Permit
2007	January 16	WSA Engineering Ltd.	Precondition for Subdivision
2007	September 17	BC Ministry of Forests and Range	Post-Wildfire Risk Analysis
2008	March 21	Klohn Crippen Berger	Post-Wildfire Hazard Assessment
2012	April 30	Perdue Geotechnical Services	Precondition for Building Permit
2015	September 22	MFLNRO	Post-wildfire Risk Analysis
2017	September	Skmana Creek Consulting Ltd.	Precondition for Subdivision
2017	November	Skmana Creek Consulting Ltd.	Precondition for Subdivision

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, Laird, Harrop, Narrows, and Procter creeks. Except for Laird and Narrows creeks, the same creeks were prioritized for detailed study by BGC. The NHC/Thurber (1990) study is highlighted and discussed separately as it is the key detailed study now being superseded by this report. A detailed comparison of the NHC/Thurber study with the present work is included in Section 6.7.2.

4.2.2. Post-Wildfire Hazard Assessments

Post-wildfire hazard assessments were completed by Jordan et al. (2007), and Klohn Crippen Berger (KCB) (2007, 2008). In 2015, Jordan completed a post-wildfire risk analysis (Jordan, 2015). The 2007 wildfire burned 39% of the Sitkum Creek watershed, with areas of high and moderate vegetation burn severity covering 10% and 11% of the watershed, respectively (burn extents shown on Drawing 05). Soil burn severity and water repellency were widespread in some areas but less abundant than in previous fires (Jordan et al, 2007). Jordan et al. (2007) outlined anticipated hazards with elevated risk in the first three to five years following the fire, namely, increased streamflow from burned areas, increased soil erosion from burned areas, and increased likelihood of debris flows in tributary streams with the potential to generate debris floods on Sitkum Creek.

KCB (2007) summarized the anticipated changes in hazards post-wildfire on Sitkum Creek:

- Spring/summer peak discharges increase by 10 to 20% for the next 20 to 30 years.
- Summer/fall flood peak discharges increase by 2 to 3 times (average floods) to 1.5 times (for 50- to 100-year floods) for next 3 to 5 years.
- Flood events increase in frequency.

According to this assessment, the spring/summer peak discharges would be anticipated to be increased relative to pre-wildfire peak discharges for an additional approximately 10 to 20 years. KCB (2008) completed HEC-RAS modelling of post-wildfire flood and debris flood events and recommended that the existing hazard zonation in the RDCK Floodplain Management Bylaw be maintained.

In the 2015 post-wildfire risk analysis, Jordan concluded that to have an effect on Sitkum Creek fan-delta, a debris flow originating on a tributary in the watershed would need to be of a size capable or blocking the channel. Jordan noted that one tributary to Sitkum Creek experience a debris flow that entered Sitkum Creek in a confined reach approximately 2 km upstream of the fan-delta apex, but 10 similar gullies did not.

A discussion of post-wildfire effects relevant to the present study are described in Section 6.4.2.

4.2.3. Assessments to Support Building Permit and Subdivisions

Numerous reports prepared to support applications for building permits and subdivision were provided by RDCK (Table 4-1). A selection of these are summarized in the coming subsections

4.2.3.1. WSA Engineering Limited (2007)

WSA Engineering Limited was retained to assess 3905 Highway 3A west of MacGregor Road on the Sitkum Creek fan-delta (WSA, 2007). WSA describes the Sitkum Creek channel as deeply incised and bedrock controlled at the fan-delta apex, transitioning to an approximately 8 to 10 m wide relatively straight channel with slight, gentle bends upstream of Highway 3A. WSA observed an abandoned avulsion channel on the southwestern side of the active channel approximately 100 m downstream of the fan-delta apex. The channel was noted to be vegetated with mature coniferous timber (over 100 years old) but with minor evidence of tree scarring and woody debris accumulation and surface flow in the upper extents of the channel indicating that the avulsion channel has accommodated flow in the past 100 years. This abandoned channel is in the vicinity of an old road dug into the fan-delta identified by BGC during the 2019 site visit (Photo 9, Appendix B, Drawings 02A, 02B).

This property was identified as hazard code 2 indicating that it would be subject to low severity or moderate severity but low risk flooding (NHC/Thurber, 1990). WSA concluded no significant hazards that could adversely affect the proposed subdivision of the property were identified and estimated ‘less than a 10% probability in 50 years’ of an ‘unforeseen event’ adversely affecting the property.

4.2.3.2. Perdue (2012)

Perdue Geotechnical Services (Perdue) completed an assessment of the Sitkum Creek fan-delta to support a request for additional development on a property along the lakeshore on Sitkum

Creek (Perdue, 2012). Perdue noted improvements to reduce the potential risk of avulsion and overland flooding associated with the water intake and associated access road near the fan-delta apex. Perdue also noted a potential location of low confinement approximately 100 m upstream of Highway 3A.

It is noted that no discernible channel change was identified in the airphoto record since 1978 and no significant effects related to the 2007 wildfire were known to have occurred. BGC's air photo interpretation is described in Section 6.2.1.

Perdue assessed the most likely hazard on the Sitkum Creek fan-delta to be blockage of Highway 3A and resultant overland flooding.

4.2.3.3. Skmana Creek Consulting (September 2017, November 2017)

Skmana Creek Consulting (Skmana) completed hazard assessments to fulfill pre-conditions for subdivision on Sitkum Creek fan-delta (Skmana, September 2017; Skmana, November 2017). Skmana agreed with Jordan et al (2015) that Sitkum Creek does not have the gradient and morphology to produce debris flood events and any debris flood would likely be associated with a debris flow on a tributary blocking the channel leading to a debris flood in a dam outbreak. Skmana further assessed that a blockage of Highway 3A was possible during a 50-year flood event.

4.3. Historic Timeline

Figure 4-2 provides a timeline summary of floods and mitigation history for Sitkum Creek. For location references, refer to Drawings 01, 02A, and 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:

- At least four notable hydrogeomorphic events have occurred in recorded history (pre-1950s, 1968, 1972, and 1974). Flood events typically occur during freshet (snowmelt) conditions. BGC interprets that at least the 1972 event could be classified as a damaging debris flood, given the record of extensive erosion and avulsion.
- The historical channel location prior to 1958 was approximately 80 to 100 m northeast of its present location.
- Previous reports (NHC and Thurber, 1990) noted the presence of large boulders at the fan-delta apex and potential avulsion channels, suggesting a prehistoric hydrogeomorphic flood event took place at an unknown date in the past.
- A forest fire burned a large portion (39%) of the watershed in 2007. Following this wildfire, several hazard and risk assessments were undertaken to assess the expected impacts on the community and water system.
- Underground gold mining took place in the upper watershed between 1896 and 1988.
- Water levels at the toe of the fan-delta are influenced by the reservoir levels on Kootenay Lake.

Geohazard History

Upper Sitkum Creek watershed burn area, 2007 (Copyright Province of British Columbia. All rights reserved. Reproduced with permission from the Province of British Columbia)

Low-level aerial photo of the Sitkum Creek fan, August 2007 (Copyright Province of British Columbia. All rights reserved. Reproduced with permission from the Province of British Columbia)

July 4, 2015 - Wildfire in Duhamel, Sitkum, and Ainsley Creek watersheds burned approximately 7 km^2

July 2007 - Wildfire burned 1,075 ha (approximately 39%) of the Sitkum Creek watershed

April 24, 1999 - Debris avalanche along Sitkum Creek FSR at 3.1 km entered Bourke Creek, causing turbidity in the community watershed
August 7, 1997 - Landslide into creek in watershed, potentially associated with historical mining
April 16, 1991 - Flooding of Bowolin property reported in FLNRO hazard reports database. Property location not reported.

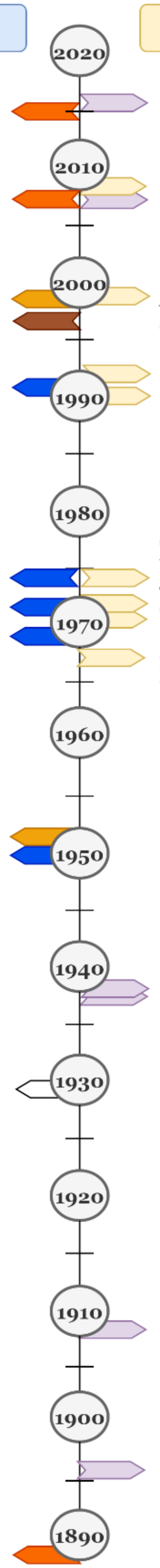
June 1974 - Flooding caused bank erosion, avulsions downstream of highway bridge, debris and log jams upstream of highway bridge
June 1972 - Flooding caused avulsions downstream of highway bridge, channel filled with 1 m large boulders
May 27, 1968 - Avulsion and erosion associated with flooding

1952 to 1958 - Aerial photographs depict possible debris flow or debris flood on Sitkum Creek
1950s - Fresh sediment deposit observable in 1958 air photo

1929 - Aerial photograph shows channel approximately 100 m northeast of present location

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

- 🟧 Wildfire
- 🟦 Flood
- 🟫 Landslide
- 🟨 Debris flow or debris flood
- ◁ Channel location
- ▷ Mitigation
- ▷ Development event



Mitigation

2008 - Straw mulch dropped from a helicopter to help reduce surface erosion and sedimentation in burned area

April 1999 - Installation of temporary water line, site stabilization, and hydro seeding

1990s - Dike constructed 150 m downstream from the main water intake
1990 - Armouring of the west bank just below the main water intake

September to December 1974 - Aggradation removed from channel by equipment
July 1972 - Highways department cleaned aggradation in channel
1970/71 - Log stringer bridge over Sitkum Creek replaced by a 40 ft steel stringer span on concrete abutments
May 22, 1968 - Channelization of side channel

Development

2016 - Three local men built a functional bridge across Sitkum Creek on Sitkum-Alpine forestry service road approximately 8 km north of the fan apex to allow access to the area following closure of logging road

2007 - Deactivation of the Sitkum-Alpine Road from bridge (at 1,310 m elevation) to mine at head of valley

1938 - Corra Linn Dam activated downstream of Sitkum Creek on Kootenay Lake
1937 - Construction of 9 miles of road along Sitkum Creek was completed

September 1, 1908 - Nos. 11 and 12 mines were discontinued and the equipment of the mines withdrawn

Early Development History - Alpine Mine dates back to at least 1896. Between 1915 and 1988, the mine produced 11,457 oz of gold and other minerals

Figure 4-2. Summary of recorded geohazard, mitigation, and development history at Sitkum Creek.

5. METHODS

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

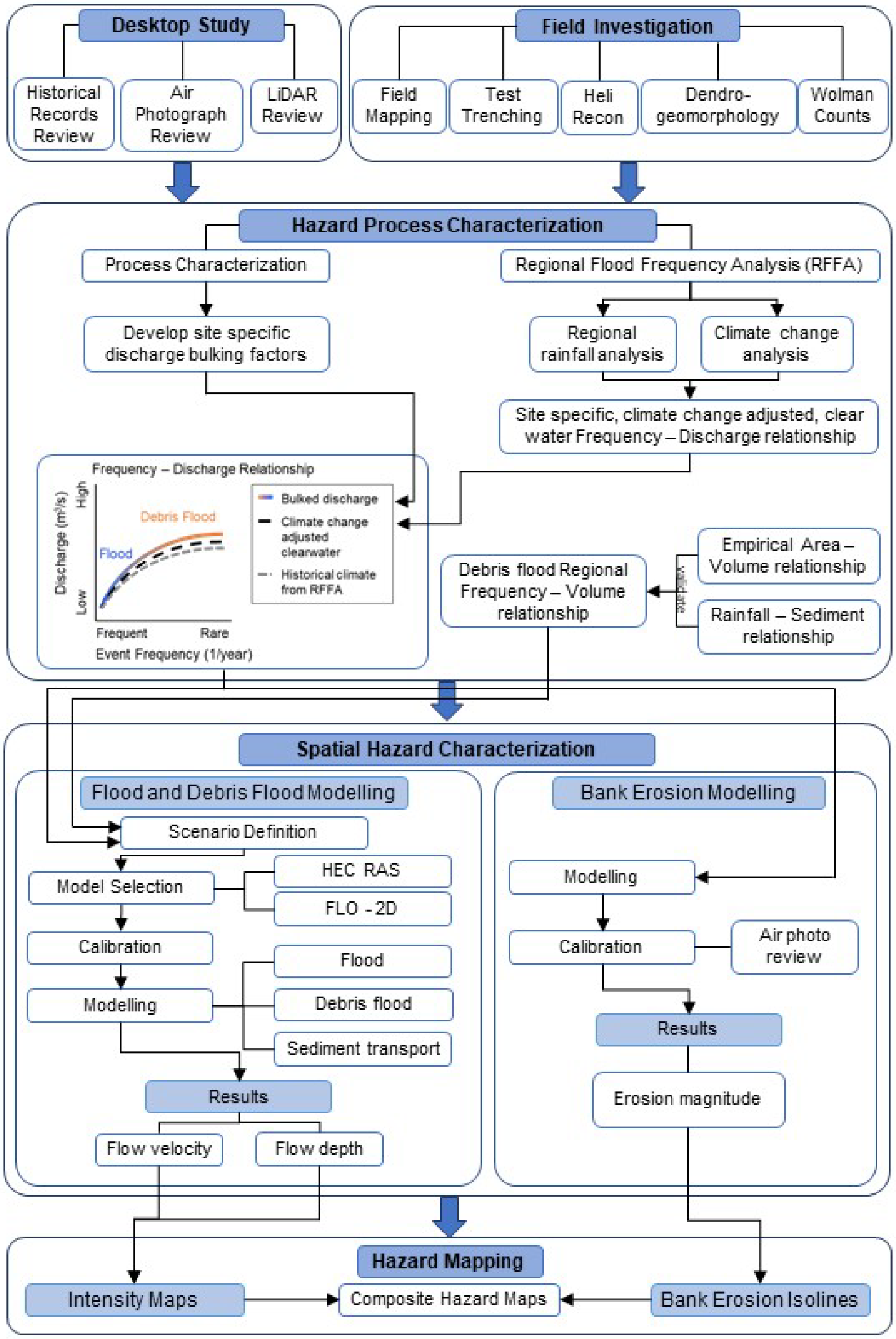


Figure 5-1. Flood and debris flood prone steep creeks workflow used for developing frequency-magnitude relationships, modelling, and preparing hazard maps.

5.1. Debris Flood Frequency Assessment

This section combines the methods established to estimate debris-flood frequencies from remote sensing and field methods on Sitkum Creek. They entail air photo interpretation and dendrogeomorphological assessment.

5.1.1. Air Photo Interpretation

Air photos dated between 1929 and 2017 were examined for evidence of past sediment transport events on Sitkum Creek. A complete list of the air photos reviewed is included in Appendix D. Events were identified from the appearance of bright areas and disturbed vegetation relative to previous air photos. Smaller events that did not deposit sediment outside the channel or significantly change the course of the channel are not captured in this analysis. Similarly, events that occurred during large gaps between air photos or successive events that overlap may not be captured. Air photo interpretation was supplemented by historical records of past events (Figure 4-2).

5.1.2. Dendrogeomorphology

Five tree core samples were collected for dendrogeomorphological analysis from Sitkum Creek (Drawings 02A, 02B). Characteristics of the samples including the tree type, minimum establishment date[4], and features that indicate physical damage to the tree are presented in the results section (Section 6.2.2). The presence of features indicating a tree sustained damage in a given year can supplement the historical records and air photo interpretation, as well as the extents of such events.

5.2. Peak Discharge Estimates

5.2.1. Clearwater Peak Discharge Estimation

There are no hydrometric stations on Sitkum Creek, therefore peak discharges (flood quantiles) were estimated using a regional flood frequency analysis (Regional FFA) and compared with the results from previous studies. 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 each creek is determined from watershed characteristics. The index-flood was estimated using a regional and provincially based ensemble of multiple regression models. The peak discharge estimates were compared with historical estimates published by previous studies (e.g., NHC, 1990; KCB, 2008; Perdue Geotechnical Services, 2012). Based on its watershed characteristics, the Sitkum 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).

---

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

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 Sitkum 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 Sitkum 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

---

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

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. 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

BGC modeled the 20-, 50-, 200- and 500-year return periods debris floods. 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.

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 (BGC, March 31, 2020b). 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).

Table 5-1. Summary of numerical modelling inputs.

Variable	HEC-RAS	FLO-2D
Topographic Input	Lidar (2018)	Lidar (2018)
Grid cells	Variable (1- 10 m)	5 m
Manning' n	0.1 (channel), 0.02 (main roads), 0.1 (fan-delta)	0.06 (channel), 0.02 (main roads), 0.1 (fan-delta)
Upstream boundary condition	Steady Flow (Q_{20} and Q_{500})	Steady Flow (Q_{50} and Q_{200})
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 0.1 m above the approximate peak recorded reservoir level (July 4, 2012) since commissioning of the Libby Dam (BGC, January 15, 2020).

A series of modelling scenarios were developed for Sitkum 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 Sitkum Creek, all flood protection structures were assumed eroded away for all modelled return periods (STK-FP-1 to STK-FP-9).

Modelling results show inundation areas for various return periods and scenarios, while FLO-2D also provides approximate sediment deposition areas and depths that are compared to the regional frequency-volume relationship.

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

5.6. Hazard Mapping

BGC prepared hazard maps based on the combined results from the numerical debris flood modelling and bank erosion assessment. Specifically, BGC prepared two types of steep creek hazard maps for Sitkum Creek: debris flood model result maps (i.e., model scenarios) 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 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:

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

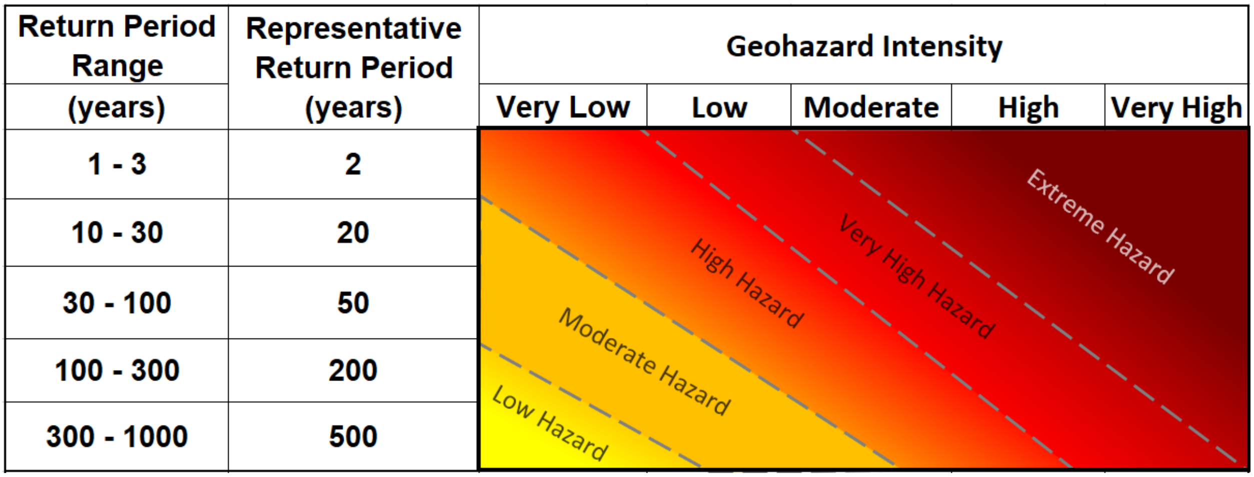
where v is flow velocity (m/s), ρ_f is the fluid density (kg/m^3) and d_f is the fluid’s flow depth (m), to obtain a unit of force per metre flow width for the three left terms in Equation 5-1. $P(H)$ is the annual probability of the geohazard. The unit of IIF is then Newton or kilo Newton per metre per year (kN/m per yr). BGC purposely did not use units of pressure (Pascal) as pressure does not include the important variable of flow depth and is not directional. In contrast impact force is directional. The use of Equation 5-1 and the concordant mapping is new in Canada.

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 hazard on Sitkum 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, the raw (no interpretation nor zone homogenization) impact force modelling results are presented. For the composite hazard rating maps, 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. Note that for debris floods, orange, red and dark red zones will be confined to the channel where the highest flow depths and flow velocities will be encountered. Overbank flows associated with debris floods will have much lower flow depths and velocities.

6. RESULTS

6.1. Hydrogeomorphic Process Characterization

Figure 3-2 indicates that Sitkum Creek is prone to floods and debris floods. This result is consistent with the following evidence:

- The average channel gradient above the fan-delta apex is 14% (Drawing 03), which is insufficient to sustain debris-flow transport.
- The average fan-delta gradient of 14% is within the range of debris flood-prone creeks.
- The east side of the fan-delta is dissected by multiple shallow avulsion channels that Sitkum Creek occupied prior to the 1950s (Drawings 04A and 06). Past events led to significant avulsions as evident in air photos from 1958, 1968, and 1974 (Drawings 04A, 04B).
- The historical channel location prior to 1958 was approximately 80 to 100 m northeast of its present location.
- The surficial expression of previous fan-delta deposits (gravel “carpets” as described in Section 1 of the Methodology Report (BGC, March 31, 2020b)) are typical of Type 1 debris floods.
- Accounts of previous flood events and analyses of historic air photos (see Section 6.2.1) are consistent with debris-flood activity due to associated erosion and observed movement of sediment in air photos.

This evidence indicates that Sitkum Creek is subject to Type 1 debris floods for low return periods (20-year). For higher return periods (50-, and 200-year), Type 2 (debris flow transitional) debris floods are believed to be the dominant process. These hydrogeomorphic events can inject substantial volumes of debris leading to surging flow and higher sediment concentrations compared to Type 1 debris floods. This interpretation is based on the numerous tributaries in mid to lower reaches of the watershed that are prone to debris avalanches and have the potential for debris flows (Drawing 05).

For the 500-year return period, Type 3 debris floods may evolve when a tributary debris flow temporarily impounds Sitkum Creek leading to an outbreak flood when the dam is breached through overtopping and incision. They could also be facilitated by a large stand-replacing moderate to high intensity fire in the watershed, which may lead to an abundance of shallow landslides, with the potential to impound the creek, if followed by high intensity rainstorms or rapid snowmelt.

6.2. Debris Flood Frequency Assessment

Debris flood frequency was assessed using historic air photos, dendrochronology, and historical accounts.

6.2.1. Air Photo Interpretation

At least three notable hydrogeomorphic events have occurred since 1929 as identified from the air photo interpretation. An additional event on 1974 is known from historical records (Figure 4-2) but was not delineated in the air photos. Drawings 04A and 04B show air photos with events delineated. The interpreted deposition area and characteristics of the sediment transport events are described in Table 6-1. BGC interprets that all the noted events are likely Type 1 debris floods due to the observed pattern 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 0.3 to 0.5 m for the two events delineated from air photos.

Table 6-1. Summary of Sitkum Creek sediment transport events in air photo record (1929-2006).

Event Year[1]	Air Photo Year	Deposition Area (m^2)	Estimated Event Volume (m^3)	Event Characteristics
1952 - 1958	1958	42,700	20,000	Avulsion of channel to the southwest. Fresh deposits in channel from the proximal fan-delta to the creek outlet.
1968	1968	20,200	7,000	Avulsion of channel. Fresh deposits in channel from the mid-fan-delta to the creek outlet
1972	1974	41,600	20,000	Fresh deposits in channel from fan-delta apex to creek outlet.

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.

6.2.2. Dendrogeomorphology

Results for the five dendrogeomorphological samples on Sitkum Creek are presented in Table 6-2; tree locations are shown on Drawings 02A, 02B.

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

Sample[1]	Tree type	Minimum establishment date (first ring)	Features[2]
Sitkum-01	Cedar	1950	Pith not reached due to rot in centre of tree, scar in 1957
Sitkum-02	Cedar	1908	Pith not reached due to rot in centre of tree
Sitkum-03	Hemlock	1942	Scar sometime before 1942, scar and pith not intersected at centre, moderate TRDs in 1983 and 1985
Sitkum-04	Hemlock	1910	Scar in 1960, moderate to strong TRDs in 1951, 1952, 1965, 1972, 1976, 1978, 1979, 1986 and 1991
Sitkum-05	Hemlock	1942	Reaction wood from 1967 to 1970, moderate TRDs in 1960 and 1975

Notes:
1. Sample locations are shown on Drawings 02A, 02B.
2. Traumatic resin ducts (TRDs) are small circles that appear within the wood, which indicate that the tree sustained physical damage during that year (similar to a scar tissue).

Based on the dendrogeomorphological analysis, three events have been identified: in the late 1950’s, late 1970’s, and late 1980’s. The 1950’s event is correlated with moderate confidence and aligns with the 1950’s event identified from air photo interpretation (Table 6-1). The 1970’s and 1980’s events are more ambiguous based on the dendrogeomorphological analysis. The 1970’s event may be associated with the 1972 and 1974 events (Table 6-1). The 1980’s event is not well supported by the air photo record.

6.2.3. Summary

Notable Type 1 debris floods have occurred approximately every 18 years on Sitkum Creek (Table 6-3). These events have led to significant past avulsions as evident in air photos from 1958, 1968, and 1974 (Drawings 04A, 04B). However, the channel location has remained relatively consistent since 1974. This relative stability is likely associated with the construction of berms along both sides of the channel (Drawings 02A, 02B, 06). While the construction date of the berms is unknown (excepting the dike constructed in the 1990s approximately 150 m downstream of the main water intake (Figure 4-2)); it is likely that these structures are at least several decades old.

Table 6-3. Summary of past floods and debris floods on Sitkum Creek.

Event Year	Description
1952 - 1958	Fresh sediment deposit visible in 1958 air photo. Corroborated by dendrogeomorphological analysis.
1968	Avulsion and erosion with flooding
1972	Flooding caused bank erosion and avulsions downstream of Highway 3A as well as debris and log jams upstream of Highway 3A.
1974	Flooding caused bank erosion and avulsions downstream of Highway 3A as well as debris and log jams upstream of Highway 3A.
1991	Flooding of Bowolin property (property location not reported)

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 Table 6-4 and Figure 6-1. With respect to these results, the reader should note the following:

- Because there are no hydrometric stations on Sitkum Creek, historical peak discharges (flood quantiles) were estimated using a Regional FFA. The provincial index-flood model was selected because it produced slightly higher peak flows than the regional model.
- The climate change impact assessment results were difficult to synthesise in order to select climate-adjusted peak discharges on a site-specific basis. Consequently, a 20% increase in peak discharge was adopted as per Section 4 of the Methodology Report (BGC, March 31, 2020b).
- The climate-adjusted, bulked peak discharges were used in the numerical modelling.

- The 500-year event was deemed to be a Type 3 debris flood (landslide dam outbreak flood) as the peak discharge estimated for an outbreak flood was greater than the bulked Type 2 debris flood peak discharge. The Type 3 peak discharge is not based off the climate change adjusted, Regional FFA peak discharges. Instead, it was estimated by empirical equations relating landslide geometry to peak flow for a representative debris flow tributary 2 km upstream of the fan-delta apex. This tributary is the closest subject to debris flows to the Sitkum Creek fan-delta apex. Therefore, an outbreak flood from this tributary would result in the least amount of attenuation compared to upstream tributary debris flow outbreak floods. Due to variability in the peak flow results, BGC employed a median of the following methods; O'Connor and Beebee (2009), Costa (1985), Fröhlich (1985), Costa and Schuster (1988), Pierce, Thornton and Abt, (2010), Peng and Zhang (2012), and Evans (1986).

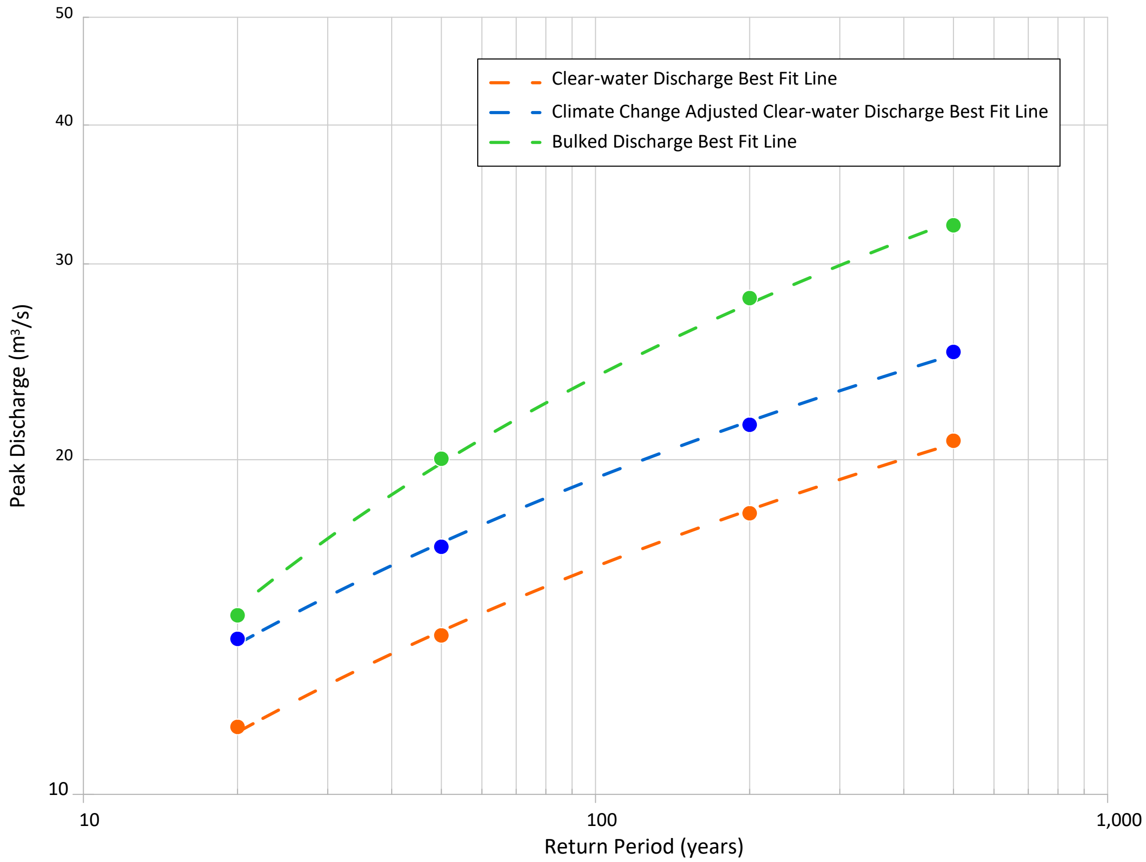


Figure 6-1. Frequency-discharge relationship for Sitkum Creek.

Table 6-4. Peak discharges for selected return period events.

Return Period (years)	AEP	Non-adjusted 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	5	5	1.0	5	N/A	Flood
20	0.05	10	15	1.05	15	1	Few active landslides in lower 20% watershed
50	0.02	15	15	1.2	20	2	Tributaries in the lower 4 km are debris-flow prone
200	0.005	20	20	1.3	30	2	Tributaries in the lower 4 km are debris-flow prone
500	0.002	N/A	N/A	1.1	60	3	Debris flows (possibly associated with substantial wildfires) could impound the creek leading to outbreak floods. Peak discharge calculated from likely outbreak size and compared to bulked Type 2 debris flood. Outbreak flood was larger and taken as 500-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 Sitkum Creek. These included air photo analysis of sediment deposits, dendrochronology, sediment transport equations, and application of regional relationships for fan-delta area – sediment volume and watershed area – sediment volume. The different methods were compared.

Debris volume results from the air photo analysis are shown in Table 6-1 and the results of the regional relationship and sediment transport equations are shown in Table 6-5. The volume estimates from the Rickenmann (2001) analysis are not credible given that events greater than 50,000 m^3 do not appear in the air photo record and are 5 to 6 times higher than those obtained from the regional F-M analysis. The sediment volumes derived from the air photo analysis (Table 6-1), wherein three events were delineated over the 90-year air photo record, more closely align with the regional

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- year return period events are associated with Type 1 debris floods, while the sediment volumes for the 50-, and 200-year return period events are associated with Type 2 debris floods, and the 500-year return period events are associated with Type 3 debris floods.

Table 6-5. 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	17,000	78,900
50	22,000	112,400
200	29,000	168,400
500	34,000	209,000

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 impact of forest fires on hydrogeomorphic response include:

- The elevation of the fires in the watersheds is important as it could either increase peak flows 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 Sitkum Creek watershed, especially for large moderate to high burn severity wildfires.

6.5. Numerical Debris Flood Modelling

A summary of the key observations from the debris flood modelling is included in Table 6-6. 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 6-6. Summary of modelling results.

Process	Key Observations
Clearwater inundation (HEC-RAS results for all return periods)	• Sitkum Creek likely remains in its current channel for return periods up to 20 years except from activation of near-channel floodplains between the fan-delta apex and Highway 3A. For return periods of 50 years and higher the creek tends to avulse downstream of Highway 3A where flows are prone to escape to the east. • Avulsion flow depths are shallow but can reach up to 2 m near the lake front • At the 500-year return period (modelled as a Type 3 debris flood) the Highway 3A bridge's capacity is likely exceeded and flood water would likely run west on Highway 3A all the way to the western fan-delta edge with water escaping towards Kootenay Lake in various locations. Some water would also flow towards the east along Highway 3A with substantial inundation of the eastern fan-delta sector downstream of Highway 3A which is largely uninhabited. • While the overall hazard intensity for the return periods investigated is comparatively low, flooding of basements and first floors with low entry elevations could still result in substantial economic damage.
Sedimentation	• Sedimentation associated with debris floods can occur on the central and western fan-delta sector upstream and downstream of the Highway 3A crossing. Deposition depth could be up to 1 m for the 50-year debris flood and possibly up to 4 metres in the channel near the fan-delta apex and at the Highway 3A crossing. • In the lower central fan-delta debris deposits up to 1 m in thickness may develop outside of the active channel for return periods in excess of 50 years.

As with other debris-flood prone creeks in the study area that end in lakes, during high lake levels there is a good chance that the lower portions of Sitkum Creek will build up sediment and avulse east or west of the active channel downstream of Highway 3A.

None of the numerical modeling accounts for breaches of the highway embankment. While modeling currently indicates that the development near MacGregor Road has low hazard potential, overtopping of the highway and erosion of the downstream (southern) highway embankment could lead to substantial impacts to the existing development in the MacGregor Road vicinity.

The multiple process numerical modelling ensemble approach demonstrates that the key hazards and associated risks at Sitkum Creek stem from the multiple avulsion paths as the main channel's capacity is exceeded at higher return periods.

6.6. Bank Erosion Assessment

The air photo assessment compared available air photos from 1929 to 2006 to determine the historical changes in channel width at the six cross-sections considered in the bank erosion assessment (see Drawings 02A, 02B for cross-section locations). Table 6-7 summarizes the maximum channel width change measured between successive pairs of air photos, as well as the cross-section at which the erosion was observed. The maximum observed change in channel width between two successive air photos on Sitkum Creek was 10 m, between 1979 and 1981 at cross-section 6. To provide context for these values, the average current bankfull width is 10 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.

Construction of berms along both banks of the creek have likely had a moderating influence on the observed erosion, although as noted the date of their construction is unknown.

Table 6-7. 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)
1929-1945	0	-
1945-1952	2	3
1952-1958	5	4
1958-1968	0	-
1968-1974	4	5
1974-1979	2	3, 5
1979-1981	10	6
1981-1988	1	1
1988-1994	2	3
1994-1997	4	2
1997-2000	5	5
2000-2006	3	2

A summary of the bank erosion model results by return period is outlined in Table 6-8. 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 6-8. Summary of bank erosion model results by return period.

Return Period (years)	Minimum Erosion (m)	Average Erosion (m)	Maximum Erosion (m)
20	0	2	8
50	1	6	11
200	8	16	22
500	12	23	42

The potential/improbable erosion corridor shows the full modelled erosion if it were applied to both banks. This corridor accounts for the inherent uncertainty in assigning erosion to a particular bank and does not consider the influence of terrain elevation on the predicted erosion distance. The likely erosion corridor shows the modelled bank erosion divided between the left and right bank based on channel geometry (Section 2 of Methodology Report (BGC, March 31, 2020b)). At Sitkum Creek the modelled erosion at each cross-section was divided between the left and right banks based on the bank height criteria outlined in Figure 2-14 of the Methodology Report.

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 cross-section 4 for all return periods (see Drawings 02A, 02B). Abutments of the Highway 3A bridge may be impacted by erosion during a rare (high return period) event, or by progressive erosion over time. Property located at the intersection of Kane Road and Highway 3A may be impacted by progressive erosion and falls within the improbable erosion corridor for the 500-year return period.

Berms are currently present on Sitkum Creek on the right (west) side of the channel upstream of Highway 3A, and along both banks downstream of Highway 3A. As the date of construction of the berms is unknown, it is not clear whether the erosion used to calibrate the model (i.e., the change in width from 1979-1981) occurred prior to, or following, berm construction. Furthermore, any armouring on the berms is not accounted for in the grain size measurements (D_{84}) for each modeled cross-section. As a result, the modeled erosion estimates are likely conservative.

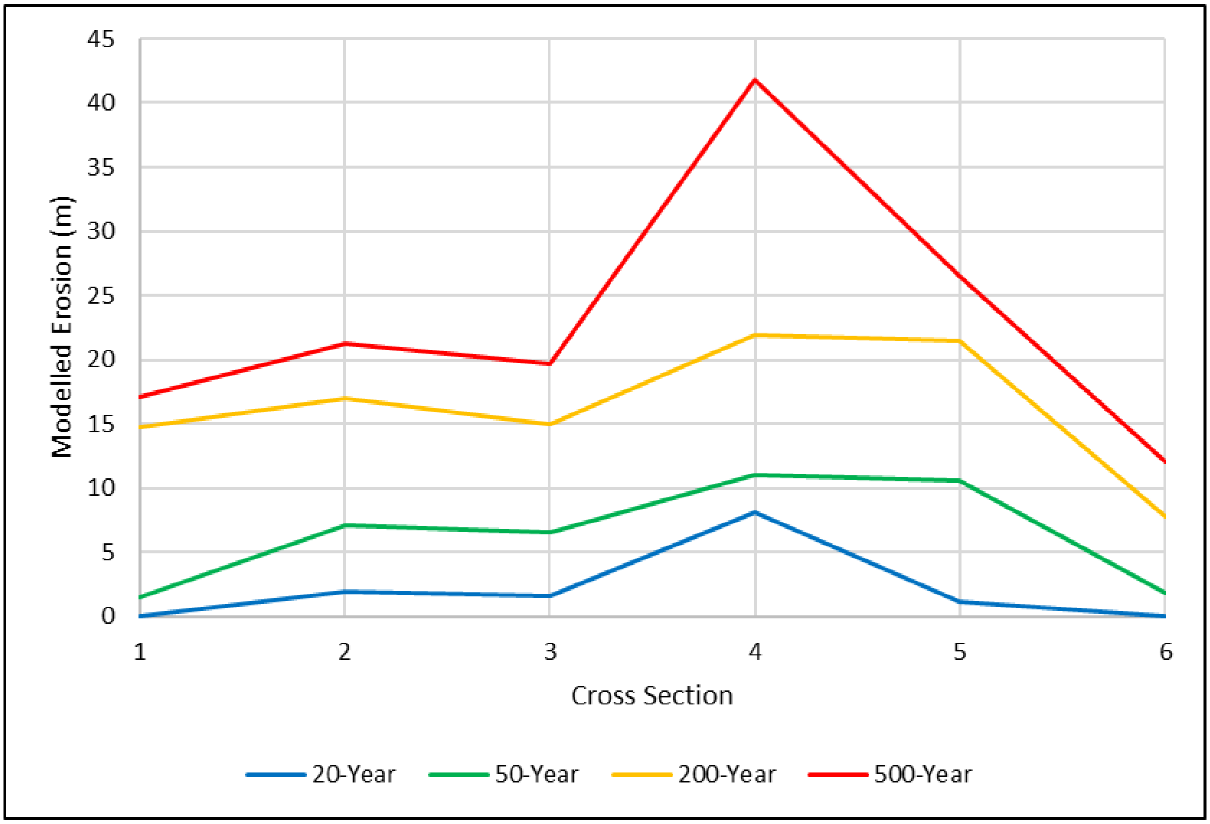


Figure 6-2. Sitkum Creek 50th percentile bank erosion model results at each cross-section.

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, hazard 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 Sitkum Creek is located within the yellow (low) hazard area. It is mostly confined to the eastern fan sector where flow spreads adjacent to the main channel as well as an avulsion to the west that follows the highway before overtopping and spreading downstream of the highway embankment. The orange (moderate) and red (high) hazard areas are confined to the channel and avulsions zones at or downstream of the highway. The dotted zones indicated areas that will likely be inundated with sediment up to 1 m deep outside the active channel and up to 3 m in the active channel.

6.7.2. Comparison with NHC/Thurber (1990)

As outlined in Section 4.2.1, a detailed study of creeks on the West Arm of Kootenay Lake 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-delta investigated, hazard areas were codified between 0 (lowest hazard) and 5 (highest hazard). However, since NHC/Thurber (1990) also included loss of life consequences as a second dimension in their hazard mapping, it renders their hazard maps into risk maps. Specific risk zones are defined as those where individual life loss risk exceeds or falls below specified values. Areas with a hazard (risk) code of 3 or higher are interpreted to have a significant threat to loss of life defined as a life loss risk of > 1:20,000. Figure 6-3 shows the NHC/Thurber risk map for Sitkum Creek.

---

[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.

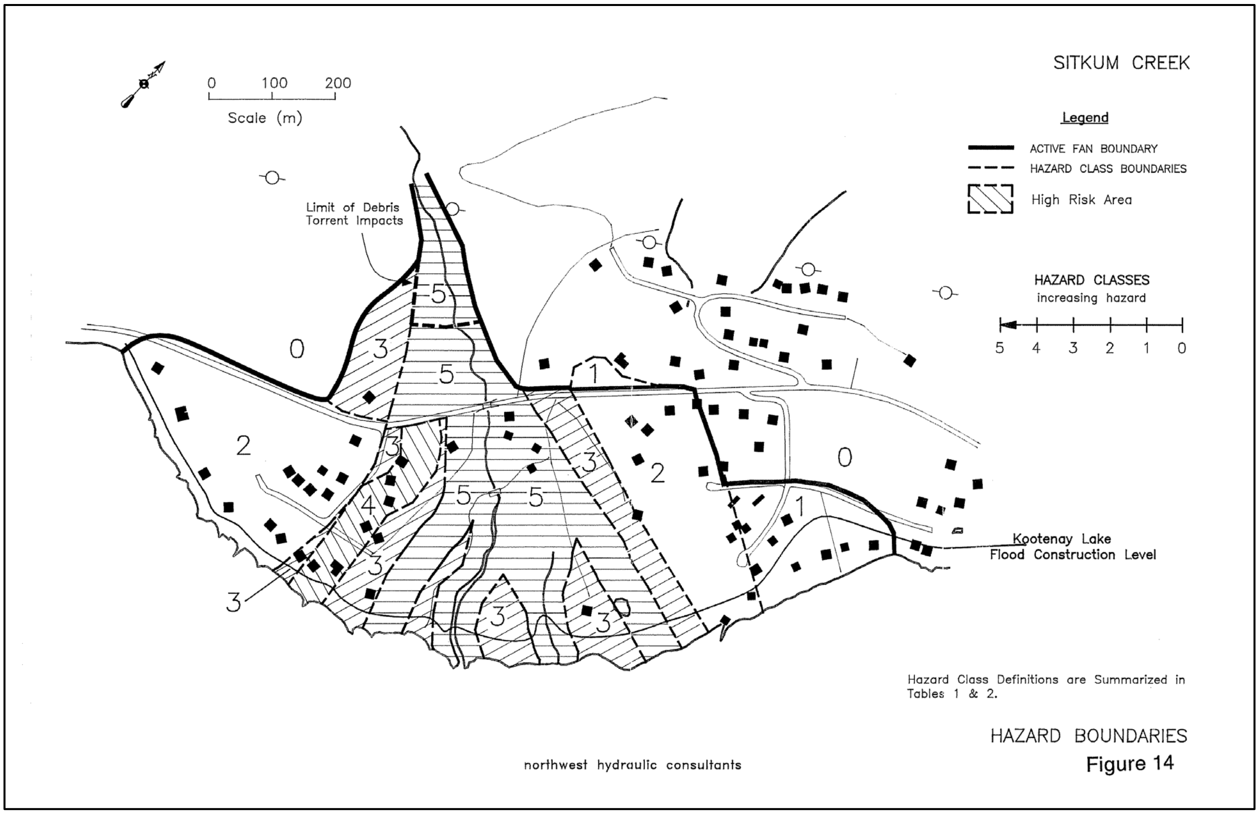


Figure 6-3. NHC/Thurber's (1990) Sitkum Creek individual life risk map. Class 4 and 5 imply individual life loss risk values exceeding 1:10,000. Class 3 1:10,000 to 1:20,000. Class 0, 1 and 2 < 1:20,000. This section compares BGC's and NHC/Thurber's approaches because the hazard maps of the two reports differ significantly with NHC/Thurber's hazards being generally much higher than those of BGC. The principal differences are highlighted in Table 6-9. For convenience NHC/Thurber (1990) is abbreviated in Table 6-9 to N/T.

Table 6-9. 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 Sitkum Creek fan-delta 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
Topography	2 m contours	Lidar DEM	Substantially higher resolution in BGC (2020)
Fan-delta 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 dendrochronology and, 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 modeling of clearwater flows in main channels	Two types of sediment transport calculations, regional F-M sediment volume relationships, empirical relationships between peak discharges and sediment volumes	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 modeling-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 modeled.	Based on flow velocity, depth and fluid density	The key is the association of 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 modeling 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 6-10.

Table 6-10. 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. Sitkum Creek Specifics

At Sitkum Creek, NHC/Thurber (1990) described the channel as having an alternating sequence of boulder steps and pools. Debris levees observed near the fan-delta apex were interpreted to provide channel confinement under normal flood conditions but could be breached where low spots in the levees exist. As identified in the air photo interpretation (Drawings 04A, 04B), NHC/Thurber (1990) noted the history of avulsions at Sitkum Creek and interpreted that these avulsion channels have a high probability of being occupied in the event of a future avulsion. Two notable avulsion locations were identified along the access road to the water intake near the fan-delta apex and at the Highway 3A bridge. For these reasons, NHC/Thurber (1990) recommended re-grading of the water intake access road and channel clearing and ditching near Highway 3A. In total, 58% of the fan-delta was classified as hazard code 3, 4, or 5.

6.7.2.3. Summary

After comparing the NHC/Thurber (1990) work with this study, BGC concludes that the hazards and likely risks to loss of life are substantially higher for the former than estimated herein. The main reason for this discrepancy is that NHC/Thurber did not benefit from lidar topography, detailed numerical modeling, 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 appears justified to be conservative. The loss of life estimates as determined by NHC/Thurber (1990) are therefore also likely conservative; however, BGC has not confirmed this via a quantitative risk assessment.

BGC believes that the current work is a credible representation of hazards on the detailed study creeks including Sitkum Creek up to the 500-year return period scenarios considered in this study.

7. SUMMARY AND RECOMMENDATIONS

7.1. Introduction

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

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

7.2. Summary

7.2.1. Hydrogeomorphic Process

Based on field observations and remote sensing data, Sitkum Creek is subject to Type 1 debris floods for the 20-year return period. For higher return periods (50-, 200- and 500-year), Type 2 debris floods are believed to be the dominant process. For the 500-year return period, Type 3 debris floods may also evolve where tributary debris flows temporarily impound Sitkum Creek leading to outbreak floods when the dam is eventually breached through overtopping and incision.

7.2.2. Air Photo Interpretation, Dendrogeomorphology

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

- Significant debris flood events occurred in 1968, 1972, 1974 and between 1952 and 1958 based on air photo records and historical accounts.
- The largest debris flood is interpreted to be the event in the 1950's as the 1958 air photo shows an area of freshly deposited debris of approximately 42,700 m^2. Dendrogeomorphological analysis of tree core samples supports this event occurrence.
- Prior to 1958, the Sitkum Creek channel was approximately 80 to 100 m north of the present channel.
- Past events led to significant avulsions as evident in air photos from 1958, 1968, and 1974 (Drawings 04A, 04B). However, the channel location has remained relatively consistent since 1974. This period of quiescence is likely associated with installation of berms along both sides of the channel (Drawings 02A, 02B, 06).

7.2.3. Peak Discharge Estimates

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

- The climate change impact assessment results were difficult to synthesise in order to select climate-adjusted peak discharges on a site-specific basis. Consequently, a 20% increase in peak discharges was adopted as per Section 4 of the Methodology Report (BGC, March 31, 2020b).
- The climate-change adjusted peak discharges for Sitkum Creek range from 15 m^3/s (20-year flood) to 25 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 debris flood) were adopted as input to numerical modelling.
- Consideration of climate change and sediment bulking increase the clearwater discharge estimate from 10 to 15 m^3/s for the 20-year debris flood, and from 20 to 35 m^3/s for the 500-year event.

7.2.4. Frequency-Magnitude Relationships

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

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

Return Period (years)	Adjusted Peak Discharge (m^3/s)
20	15
50	20
200	30
500	35

7.2.5. Numerical Flood and Debris Flood Modelling

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

The multiple process numerical modelling ensemble approach demonstrates that the key hazards and associated risks at Sitkum Creek stem from the multiple avulsion paths as the main channel’s capacity is exceeded at higher return periods.

7.2.6. Bank Erosion Assessment

Debris floods can be highly erosive and may undercut unstable banks. Modeling was completed to evaluate the potential 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-delta. The key findings from the bank erosion assessment are:

- The maximum modelled erosion ranges from 8 m in a 20-year event to 42 m in a 500-year event. The likely erosion ranges from 1 m to 8 m during the 20-year to 500-year events.
- Bank erosion is unlikely to affect existing infrastructure along Sitkum Creek, with the exception of the Highway 3A bridge and berms on either side of the channel (see Drawings 02A, 02B). Property located at the intersection of Kane Road and Highway 3A also lies within the potential/improbable erosion corridor for the 500-year return period event, but not within the likely erosion corridor.

7.2.7. Hazard Mapping

Model results are cartographically expressed in two ways:

- The individual hazard scenarios are captured through an index of impact force that combines flow velocity, bulk density and flow depth. 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 scenario maps and the composite impact intensity frequency map serve as decision-making tools to guide subdivision and other development permit approvals.

7.3. Limitations and Uncertainties

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

- Future fan-delta development and substantial flood or debris flood events
- Development of large landslides in the watershed with the potential to impound Sitkum Creek or significant wildfires
- Bridge re-design and/or alteration to the existing berms that parallel the creek
- Substantial changes to Kootenay Lake levels.

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 such processes evolves.

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

7.4. Considerations for Hazard Management

Recommendations are provided in the Summary Report (BGC, March 31, 2020a) as they pertain to all studied RDCK creeks. This section notes Sitkum 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 Sitkum 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 very expensive and requires regular maintenance. In some cases, it may also lead to stream downcutting downstream which may or may not be a desirable consequence.
2. Most creeks on fans tend to be wide and laterally unstable. Forcing the creek in between berms flanking the creek is undesirable. Instead, setback berms that provide maximum room for the creek to shift and build up sediment is preferred. 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.
3. Riprapping confined channels is of limited use as aggradation over time will render the riprap ineffective.

The above options may not achieve a desirable cost-benefit ratio when compared to the asset values currently located on the fan-delta. Sitkum Creek fan-delta hosts a lower value of assets in comparison with the average for the steep creek fan-deltas studied in detail (Table 1-1).

In the interim, the following site-specific mitigation measures could be considered. 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.

In addition to the mitigation considerations listed in Table 7-2, the RDCK could consider enforcement of channel erosion-related construction setbacks from top of bank to avoid undercutting of building foundations during debris floods.

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

Option	Description	Effect on Steep Creek Hazard Reduction
a	Upgrade Highway 3A bridge by raising it, to widen the span and achieve greater clearance above the channel.	Reduction in avulsion potential by increasing the bridge capacity and reducing the risk of flood-related aggradation, log jams or rip-rap failure.
b	Culvert underneath Highway 3A and connecting channel to Sitkum Creek. The reach between the Highway 3A bridge and the culvert should be heavily armoured to avoid erosion.	In case of bridge blockage, water may inundate the western section of Highway 3A, erode the asphalt and possibly lead to flooding of development south of the highway in the vicinity of MacGregor Road. This measure would prevent this.
c	Installation of woody debris barrier upstream of fan apex. Design options to consider include flexible net, engineered steel or concrete structure.	Reduction in organic debris transport downstream and therefore reduction in potential for Highway 3A blockage by log jam. Relevant as a major log jam was identified upstream of the fan-delta apex (Photo 7, Appendix B)
d	Maintain dense riparian forest and limit development.	In absence of major upstream mitigation works, allows natural avulsion processes in areas where it results in little harm.

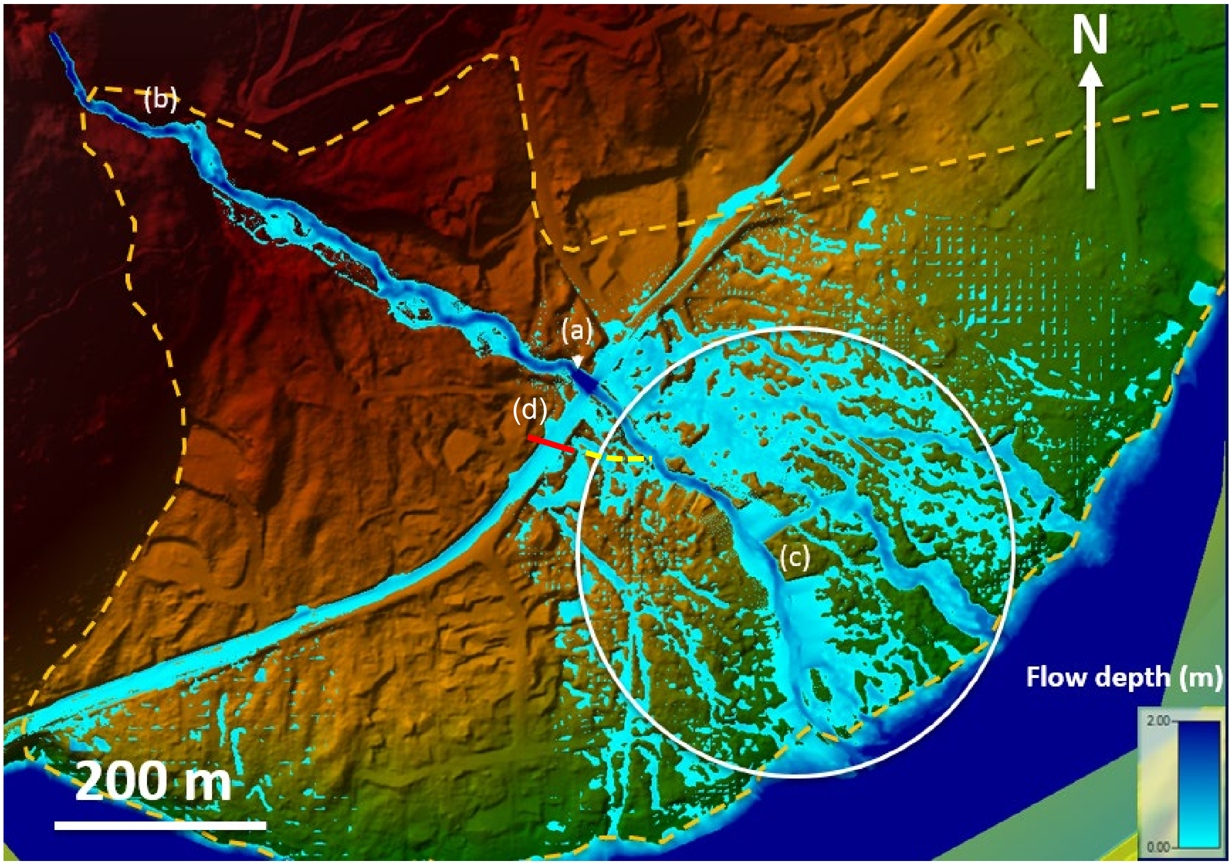


Figure 7-1. **Flood inundation map showing flow depths for a 500-year return period clear-water flood on Sitkum Creek and conceptual-level mitigation options for Sitkum Creek fan-delta. Note that these options have not been scaled or tested by numerical modelling and only serve as an impetus for further discussion. Other options will likely be developed at the conceptual design level.**

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

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

Reviewed by:

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

KH/HW/mp/mm

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

REFERENCES

Aqua Environmental Associates. (2006, June 30). *Harrop Creek watershed assessment: Harrop Face hydrological assessment* [Report]. Prepared for Harrop-Procter Community Co-operative.

BC Geographical Names Office. (n.d.). *BC Inventory of Geographical Names* website: http://apps.gov.bc.ca/pub/bcgnws/names/20354.html (last accessed in November, 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.

British Columbia Ministry of Environment. (1989, January). *Harrop Creek Summary Report* [Report]. Unknown publication information.

British Columbia Ministry of Forests, Lands, and Natural Resource Operations (2017, October 2). *Post-wildfire natural hazards risk analysis, Fire N71382, Harrop Creek* [Report].

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

British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD). (2019b, December 17). *Harvested areas of BC (Consolidated Cutblocks)* [GIS Data]. Retrieved from https://catalogue.data.gov.bc.ca/dataset/harvested-areas-of-bc-consolidated-cutblocks-

British Columbia Ministry of Forests, Lands and Natural Resource Operations. (2017). *Post-wildfire natural hazards risk analysis, fire N71382, Harrop Creek*. Victoria, BC: Author.

British Columbia Minister of Highways. (1957). *Report for the fiscal year 1956-57*. Victoria, BC: Author.

British Columbia Minister of Highways. (1975). *Report for the fiscal year 1974/75*. Victoria, BC: Author.

British Columbia Minister of Public Works. (1930). *Report for the fiscal year 1928-29*. Victoria, BC: Author.

British Columbia. (2019). *Flood Protection Structures in B.C.* Retrieved from 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

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

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

Costa, J.E. (1985). *Floods from dam failures* (Open File Report 85-560). Denver, CO: United States of Geological Survey.

Costa, J.E., & Schuster, R.L. (1988). *The formation and failure of natural dams* (Bulletin 100, pp. 1054-1068). Geological Society of America.

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. (2003, August 19). *Corralling Kutetl: Fire officials are teaming up with Harrop-Procter residents on plans to halt the West Arm wildfire if it advances towards the two tiny communities*. Nelson Daily News, p. 1.

Davidson, D. (2004, August 20). *Kutetl: One year later: Looking back on the forest fire season of 2003, which ignited in full force year ago last week*. 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. (2011, May 10). *Natural Hazard Assessment, 6417, Erindale Road, Harrop, BC* [Report for Precondition for Site-specific Exemption]. Prepared for Tony Topolinsky.

Duhamel Watershed Society. (2017). *Alpine Gold Mine being reactivated in the West Kootenay.* Retrieved from http://nelsoncreston.ca/wp-content/uploads/2017/09/2017_09_05_Alpine_Group_Mining_Fact-Sheet.pdf.

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

Evans, S.G. (1986). The maximum discharge of outburst floods caused by the breaching of man-made and natural dams. *Canadian Geotechnical Journal, 23*(3), 385-387.

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

Finished for the season. (1894, December 1). *The Tribune*, p. 4.

Fröhlich, D.C. (1995). Peak outflow from breached embankment dam. *Journal of Water Resources Planning and Management, 121*, 90-97.

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

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

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

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. (2005, May 4). [Report for Precondition for Building Permit]. Prepared for Mark Trione and Leeza Trione.

Integrated Hydropedology Ltd. (2006, February 4). [Report for Precondition for Subdivision]. Prepared for Alex Wallach, and Rosemary Wallach.

Intermountain Engineering and Surveying Ltd. (1995, August 15). *Engineering Report for Johnson's property legally described as Lot 4, Block 19, D.L. 222, K.D. Plan 718A, except part included in Plan 7157* [Report for Precondition for XX]. Prepared for P.B. Jones.

Intermountain Engineering and Surveying Ltd. (2002, March 7). *Report Pursuant to Floodplain management By-Law No. 1000, 1993* [Report for Precondition for Building Permit]. Prepared for David Johnson and Patricia Johnson.

Intermountain Engineering and Surveying Ltd. (2003, March 23). *Report Pursuant to Floodplain management By-Law No. 1000, 1993* [Report for Precondition for Building Permit]. Prepared for Fred Mansveld.

Intermountain Engineering and Surveying Ltd. (2004, December 16). *Report Pursuant to Floodplain management By-Law No. 1650, 2004* [Report for Precondition for Building Permit]. Prepared for Regional District of Central Kootenay.

Intermountain Engineering and Surveying Ltd. (2006, April 4). *Report Pursuant to Floodplain management By-Law No. 1650, 2004* [Report for 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.

Jordan, P. (2015, September 22). *Post-Wildfire Risk Analysis, Fire N70261, 2015, Sitkum – Duhamel.* Prepared for MFLNRO, Nelson.

Jordan, P., Gluns, G., Covert, A., & Curran, M. (2007, September 17). *Sitkum Creek Fire, 2007, N70347 Post-Wildfire Risk Analysis*. Prepared for BC Ministry of Forests and Range.

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 Berger Ltd. (2008, March 21). *Post Wildfire Hazard Assessments Springer and Sitkum Creek* [Hazard Assessment]. Prepared for Jim Whyte.

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

Lau, C.A. (2017). *Channel scour on temperate alluvial fans in British Columbia (Master’s thesis).* Simon Fraser University, Burnaby, BC. Retrieved from http://summit.sfu.ca/system/files/iritems1/17564/etd10198_CLau.pdf

Lasca Group Technical Services Ltd. (2014, November 16). *6032 McConnel Road – Harrop Geotechnical Letter Report* [Report for Precondition for Building Permit]. Prepared for Regional District of Central Kootenay Building Inspection Department.

Lasca Group Technical Services Ltd. (2015, December 27). *Harrop-Procter Road – Lot 4 Harrop (no fire number) Geotechnical Letter Report* [Report for Precondition for Building Permit]. Prepared for Regional District of Central Kootenay Building Inspection Department.

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

Metcalfe, B. (2017, December 28). *2017's top stories no. 1: The Harrop Creek wildfire*. Nelson Star. Retrieved from https://www.nelsonstar.com/

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

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

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

Nelson District Office. (1972, June). *Flood Survey 1972 West Kootenay* [Report]. Prepared for Water Resources Branch (BC Government).

Nesteroff, G. (2015, January 25). *Harrop had myriad other names*. Nelson Star. Retrieved from https://www.nelsonstar.com/

Newton, P. B. (2015). *Land Title Act* (CA4687497). Kamloops, BC: Kamloops Land Title Office.

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.

O'Connor, J.E., & Beebee, R.A. (2009). Floods from natural rock-material dams. In D.M. Burr, P.A. Carling, & V.R. Baker (Eds.), *Megaflooding on Earth and Mars* (pp. 128-171). Cambridge University Pres.

Pearkes, E. D. (2019, September 11). *Making the effort*. Nelson Star. Retrieved from https://www.nelsonstar.com/

Peng, M. & Zhang, L.M. (2012). Breaching parameters of landslide dams. *Landslides, 9*(1), 13-31.

Pierce, M.W., Thornton, C.I., & Abt, S.R. (2010). Predicting peak outflow from breached embankment dams. *Journal of Hydrologic Engineering, 16*(1), 81-88.

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

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.

Perdue Geotechnical Services Ltd. (2012, April 30). *Natural Hazard Assessment Lot 8, Plan 9686, District Lot 7453, Kootenay District* [Report for Precondition for Building Permit]. Prepared for John Quince.

Perdue Geotechnical Services Ltd. (2015, September 4). *Natural Hazard Assessment Lot 2, Plan NEP10024, District Lot 222, Kootenay District* [Report for Precondition for Building Permit]. Prepared for Phil Newton.

Rickenmann, D. (2001). Comparison of bed load transport in torrents and gravel bed streams. *Water Resources Research, 37*(12), 3295-3305.

Scheidl, C., & Rickenmann, D. (2010). Empirical prediction of debris-flow mobility and deposition fans. *Earth Surface Processes and Landforms, 35*(2), 157-173.

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

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

Skmana Creek Consulting Ltd. (2017, September). *Natural Hazard Assessment 3864 Highway 3A Nelson, BC.* Prepared for Susan Wallach.

Skmana Creek Consulting Ltd. (2017, November). *Natural Hazard Assessment 4020 Highway 3A Nelson, BC.* Prepared for Tyler Rice.

Statistics Canada. (2016). Census Profile, 2016 Census [Webpage]. Retrieved from https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/details/page.cfm?Lang=E&Geo1=DPL&Code1=590129&Geo2=PR&Code2=59&Data=Count&SearchText=Harrop/Procter&SearchType=Begins&SearchPR=01&B1=All&GeoLevel=PR&GeoCode=590129&TABID=1

Swollen rivers damage Proctor. (1913, June 4). *The New Westminster News*, p. 3.

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

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

WSA Engineering Limited (2007, January 16). *Natural Hazard Assessment Lot 1, District Lot 7453, Plan 7150 (Except Plan NEP19431) Kootenay Land District* [Report]. Prepared for Stuart Hawes.

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 flight looking northeast at upper Sitkum Creek watershed, approximately 10 km from fan apex. Photo: BGC, July 6, 2019.

Photo 2.

Overview photo taken during helicopter flight looking north at the Sitkum Creek watershed. Photo: BGC, July 6, 2019.

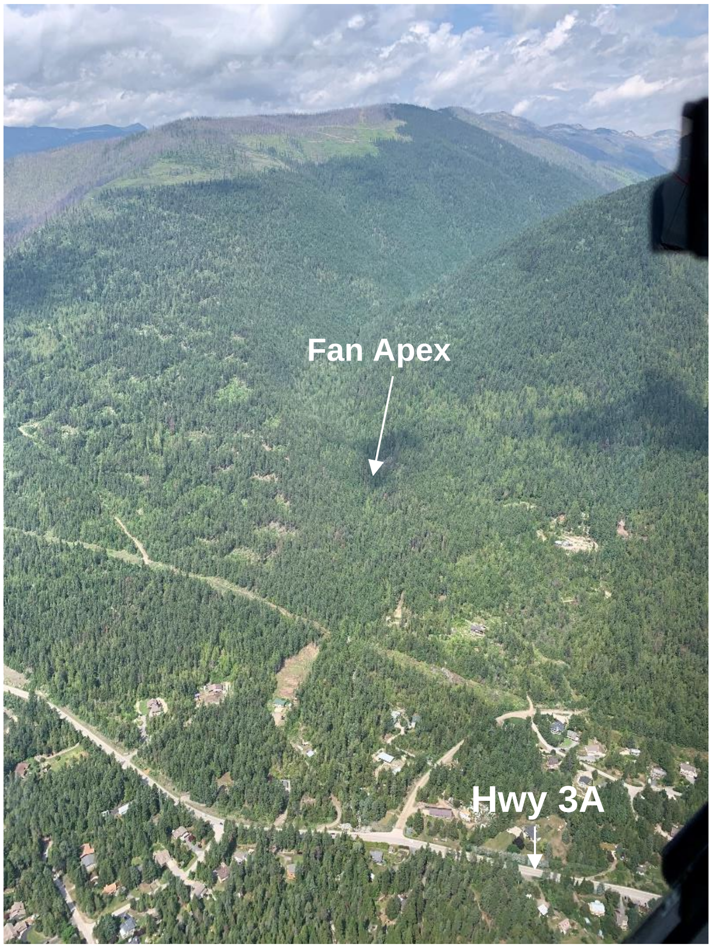


Photo 3.

Overview photo taken during helicopter flight looking northwest at the Sitkum Creek watershed and fan. Highway 3A is visible running left to right. Location of fan apex is shown. Photo: BGC, July 6, 2019.

Photo 4.

Overview photo taken during helicopter flight looking east at Highway 3A passing through the Sitkum Creek fan, and the west arm of Kootenay Lake. Photo: BGC, July 6, 2019.

Photo 5.

Overview photo taken during helicopter flight, looking northeast at Sitkum Creek fan with watershed. The outlet to the west arm of Kootenay Lake, and the fan apex are labelled. Photo: BGC, July 6, 2019.

Photo 6.

Overview photo taken during helicopter flight, looking northeast at Sitkum Creek fan with watershed. The outlet to the west arm of Kootenay Lake, and the fan apex are labelled. Photo: BGC, July 6, 2019.

Photo 7.

Looking downstream at log jam on Sitkum channel just above the fan apex. Photo: BGC, July 4, 2019.

Photo 8.

Standing on left bank looking downstream of Sitkum channel just above the fan apex. Photo: BGC, July 4, 2019.

Photo 9.

Old road dug into fan surface. Photo: BGC, July 4, 2019.

Photo 10.

On right bank looking downstream at water intake, approximately 170 m upstream of the Hwy 3A bridge. Photo: BGC, July 4, 2019.

Photo 11.

On right bank looking at left bank low wall constructed of rounded cobbles, approximately 30 m downstream of the Hwy 3A bridge. Photo: BGC, July 4, 2019.

Photo 12.

Standing on the right bank of Sitkum Creek looking downstream at the Hwy 3A bridge. Photo: BGC, July 4, 2019.

Photo 13.

Underneath the highway bridge showing clearance as well as grain size (with notebook for scale). Photo: BGC, July 4, 2019.

Photo 14.

Standing on the right bank of Sitkum Creek downstream of the Highway bridge looking across at the left bank. Photo: BGC, July 4, 2019.

Photo 15.

Standing on the wooden trestle bridge approximately halfway between the highway and the river mouth. Photo: BGC, July 4, 2019.

Photo 16.

On right bank looking across channel and upstream at boulder and cobble bar adjacent to flood protection berm. Photo: BGC, July 4, 2019.

Photo 17.

Looking at right bank at low point in channel berm. Photo: BGC, July 4, 2019.

Photo 18.

Looking at right bank at Sitkum Creek outlet. Photo: BGC, July 4, 2019.

APPENDIX C
SEDIMENT SIZE SAMPLING

C.1. SAMPLING LOCATIONS

At Sitkum Creek, three Wolman Samples were taken, one upstream of the fan apex, one downstream of the Highway 3A bridge, and one at the outlet to Kootenay Lake. The sampling locations (referred to as Sitkum 1, Sitkum 2 and Sitkum 3) are shown in Figure C-1 and in 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	Sitkum 1	Sitkum 2	Sitkum 3
Location	Upstream of fan apex	Downstream of Highway 3A Bridge	Near outlet to Kootenay Lake
Longitude	117°10'48.08"W	117°10'25.93"W	117°10'15.29"W
Latitude	49°36'7.12"N	49°35'58.68"N	49°35'48.56"N
Number of stones measured	100	101	100

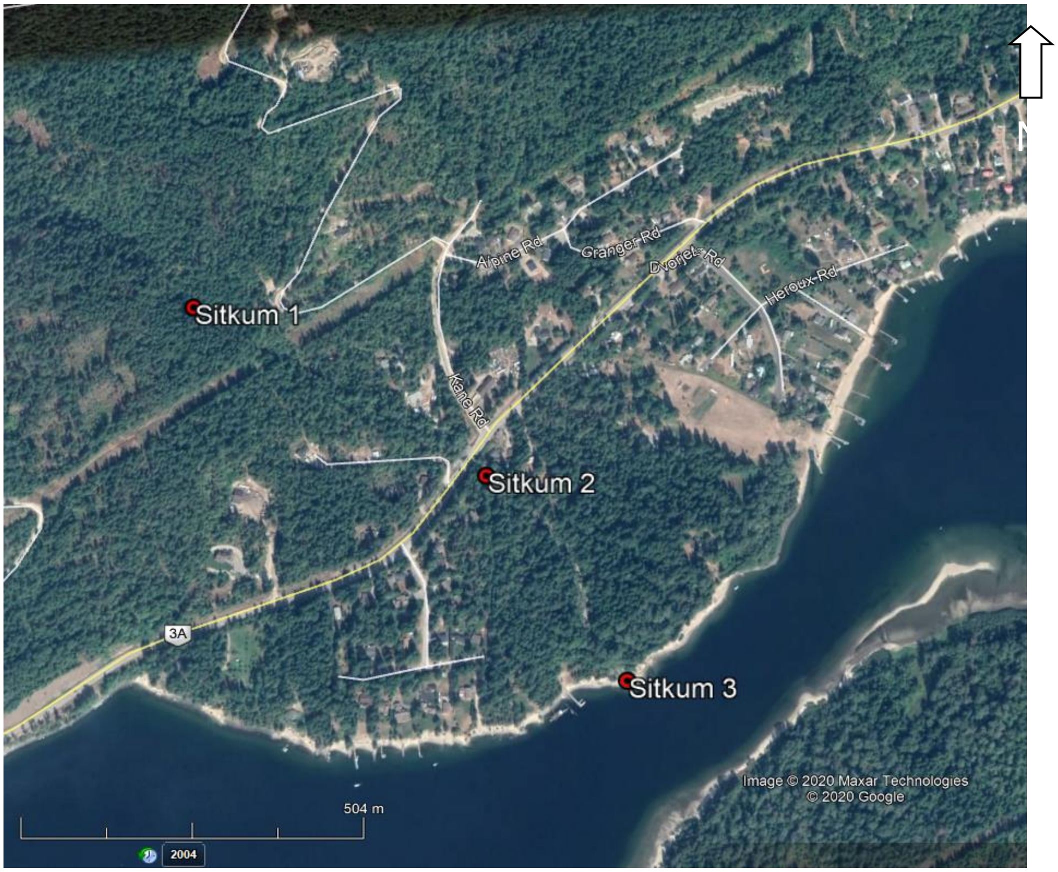


Figure C-1. Wolman sampling locations along Sitkum Creek. Google Earth image of September 11, 2017.

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

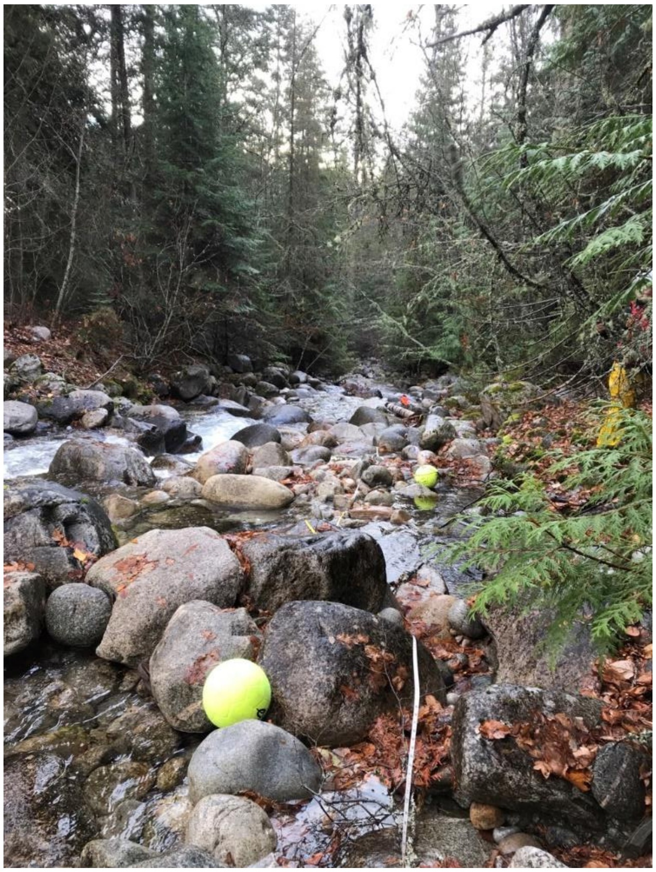


Figure C-3. Photograph taken of Wolman sampling location Sitkum 2. BGC photograph of November 20, 2019.

Figure C-4. Photograph taken of Wolman sampling location Sitkum 3. BGC photograph of July 5, 2019.

At the Sitkum 1 sampling location, the measuring tape was 20 m long and samples were randomly selected at intervals of 20 cm. At the Sitkum 2 sampling location, the measuring tape was 24 m long, and samples were taken every 20 cm.

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. Sitkum Creek sediment distribution from Wolman Count Data.

Grain Size	Sitkum 1	Sitkum 2	Sitkum 3
D_{95} (mm)	211	>256	249
D_{84} (mm)	156	198	197
D_{50} (mm)	74	66	81
D_{15} (mm)	30	20	22
D_5 (mm)	10	12	6

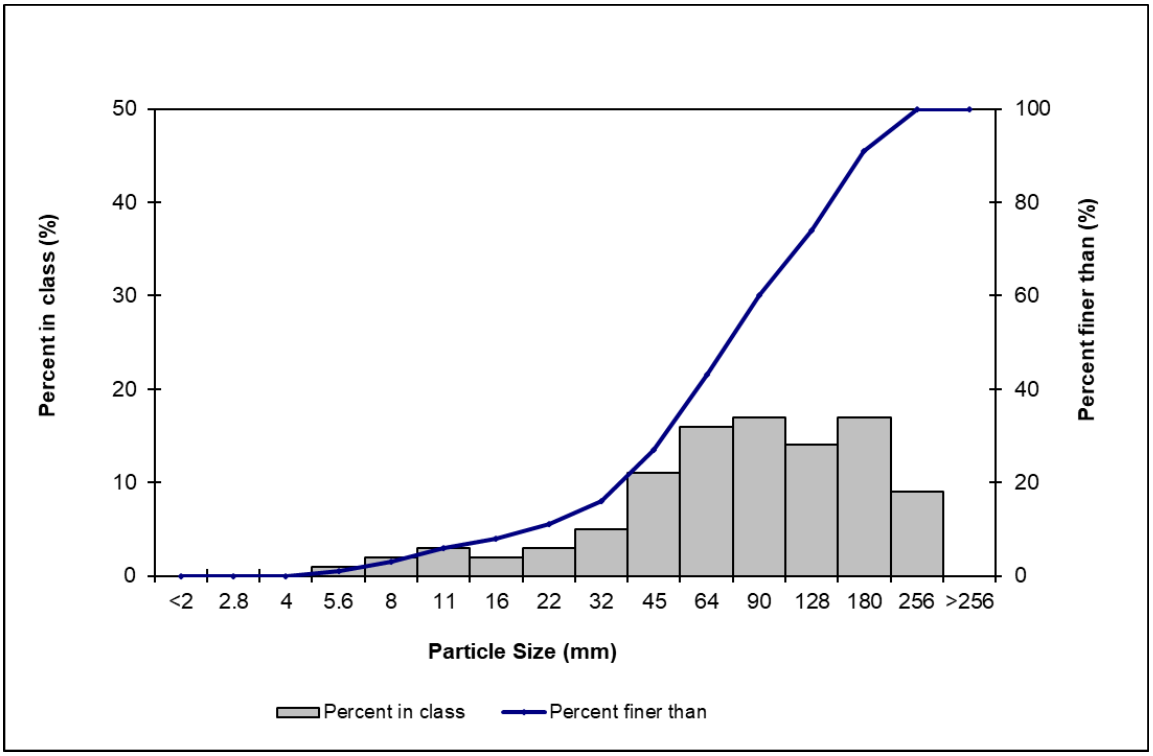


Figure C-5. **Sitkum Creek grain size distribution at Sitkum 1 (at fan apex) from Wolman count.**

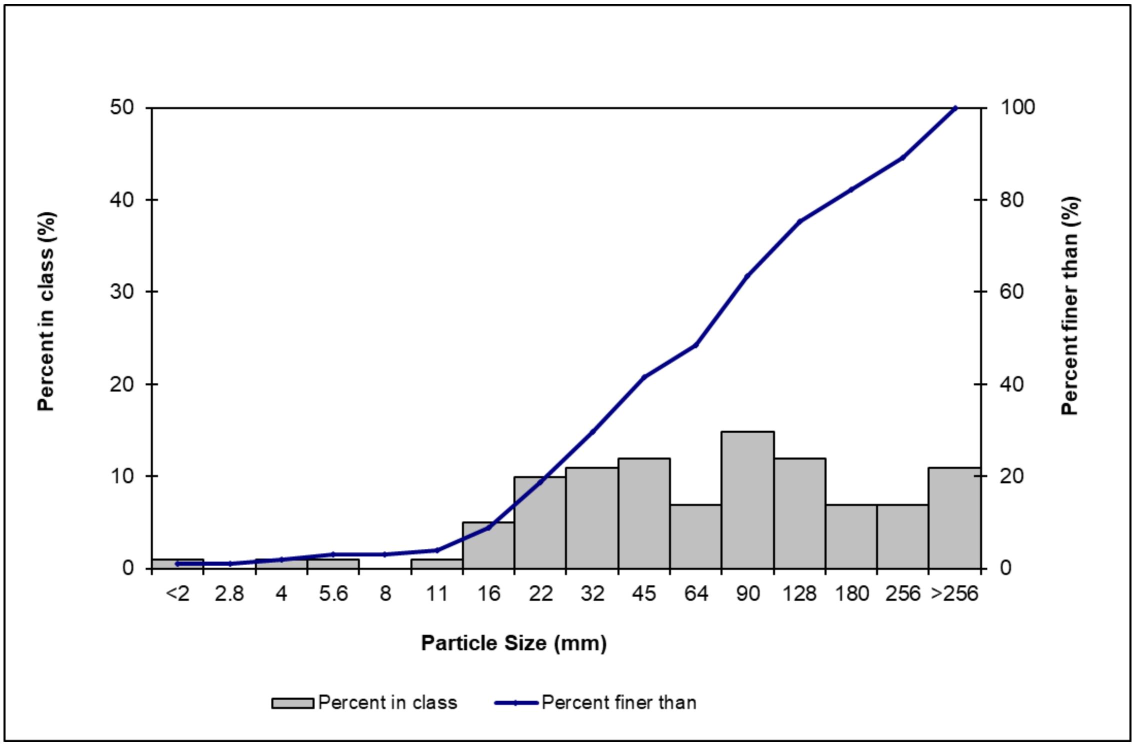


Figure C-6. **Sitkum Creek grain size distribution at Sitkum 2 (downstream of Highway 3A bridge) from Wolman count.**

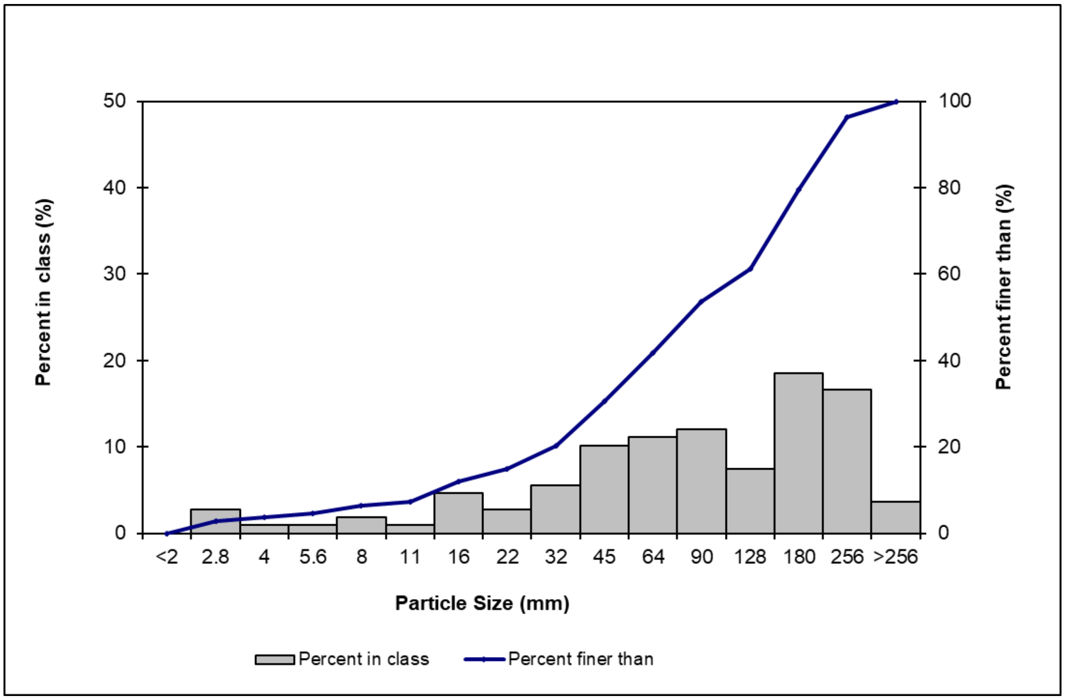


Figure C-7. Sitkum Creek grain size distribution at Sitkum 3 (near outlet to Kootenay Lake) from Wolman count.

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

Table D-1. Sitkum 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	125-129, 160-161	15,000
1994	5/31/1994	BCB94016	42-47	15,000
1988	7/22/1988	BC88090	48-53, 109-11	15,000
1979	8/2/1979	BC79134	4-8, 40-44, 100-102	10,000
1974	6/17/1974	BC7568	112-115, 129-134	8,000
1968	9/8/1968	BC7111	21-23	16,000
	8/31/1968	BC7109	18-24	16,000
1958	7/24/1958	BC2478	3,4,5	15,840
	7/24/1958	BC2477	57-62	15,840
1952	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	4/17/1929	A1014	90-91	10,000

APPENDIX E
MODELLING SCENARIOS

E.1. MODELLING SCENARIOS

The scenarios analyzed for Sitkum 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 Sitkum Creek.

Scenario Name	Return Period (yrs)	Process Type	Bulking Factor	Bulked Peak Discharge (m^3/s)	Conveyance Structures			Flood Protection Structures				
					Name	Estimated Capacity[1] (m^3/s)	Assumption	Name	Type	Bank Erosion Encroaching	$\tau/\tau_c \geq 2$	Assumption
STK-1	20	Debris Flood (Type 1)	1.05	14	Sitkum Highway Bridge	50	Functioning as intended	STK-FP-1	Piled river rock dike, not orphaned.	N	Y	Functioning as intended
								STK-FP-2	Bank protection on left bank, not orphaned.	N	Y	Functioning as intended
								STK-FP-3	Berm, not orphaned.	N	Y	Functioning as intended
								STK-FP-4	Piled river rock dike, not orphaned.	N	Y	Functioning as intended
					Wood Bridge (downstream of Sitkum Highway Bridge)	60	Functioning as intended	STK-FP-5	Berm, not orphaned.	N	Y	Functioning as intended
								STK-FP-6	Berm, orphaned.	N	Y	Functioning as intended
								STK-FP-7	Piled river rock dike, not orphaned.	N	Y	Functioning as intended
								STK-FP-8	Piled river rock dike, not orphaned.	N	Y	Functioning as intended
								STK-FP-9	Piled river rock dike, not orphaned.	N	Y	Functioning as intended

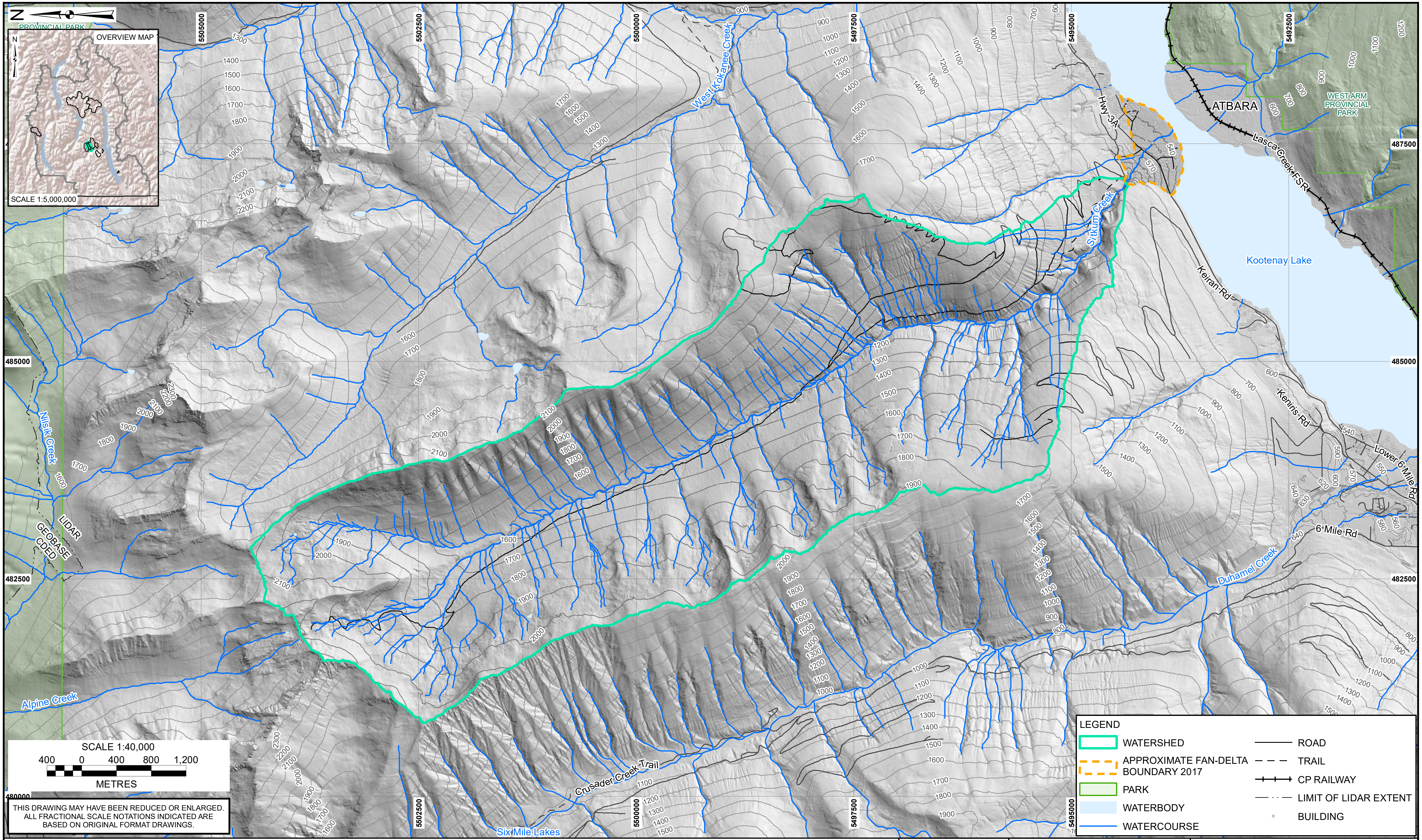
Scenario Name	Return Period (yrs)	Process Type	Bulking Factor	Bulked Peak Discharge (m^3/s)	Conveyance Structures			Flood Protection Structures				
					Name	Estimated Capacity[1] (m^3/s)	Assumption	Name	Type	Bank Erosion Encroaching	τ/τc ≥ 2	Assumption
STK-2	50	Debris Flood (Type 2)	1.2	20	Sitkum Highway Bridge	50	Functioning as intended	STK-FP-1	Piled river rock dike, not orphaned.	Y	Y	Removed from topography, assumed failure
								STK-FP-2	Bank protection on left bank, not orphaned.	Y	Y	Removed from topography, assumed failure
								STK-FP-3	Berm, not orphaned.	Y	Y	Removed from topography, assumed failure
								STK-FP-4	Piled river rock dike, not orphaned.	Y	Y	Removed from topography, assumed failure
								STK-FP-5	Berm, not orphaned.	Y	Y	Removed from topography, assumed failure
					Wood Bridge (downstream of Sitkum Highway Bridge)	60	Functioning as intended	STK-FP-6	Berm, orphaned.	Y	Y	Removed from topography, assumed failure
								STK-FP-7	Piled river rock dike, not orphaned.	Y	Y	Removed from topography, assumed failure
								STK-FP-8	Piled river rock dike, not orphaned.	Y	Y	Removed from topography, assumed failure
								STK-FP-9	Piled river rock dike, not orphaned.	Y	Y	Removed from topography, assumed failure
STK-3	200	Debris Flood (Type 2)	1.3	28	Sitkum Highway Bridge	50	Functioning as intended	STK-FP-1	Piled river rock dike, not orphaned.	Y	Y	Removed from topography, assumed failure
								STK-FP-2	Bank protection on left bank, not orphaned.	Y	Y	Removed from topography, assumed failure
								STK-FP-3	Berm, not orphaned.	Y	Y	Removed from topography, assumed failure
								STK-FP-4	Piled river rock dike, not orphaned.	Y	Y	Removed from topography, assumed failure
					Wood Bridge (downstream of Sitkum Highway Bridge)	60	Functioning as intended	STK-FP-5	Berm, not orphaned.	Y	Y	Removed from topography, assumed failure
								STK-FP-6	Berm, orphaned.	Y	Y	Removed from topography, assumed failure
								STK-FP-7	Piled river rock dike, not orphaned.	Y	Y	Removed from topography, assumed failure

Scenario Name	Return Period (yrs)	Process Type	Bulking Factor	Bulked Peak Discharge (m^3/s)	Conveyance Structures			Flood Protection Structures				
					Name	Estimated Capacity[1] (m^3/s)	Assumption	Name	Type	Bank Erosion Encroaching	$\tau/\tau c \geq 2$	Assumption
								STK-FP-8	Piled river rock dike, not orphaned.	Y	Y	Removed from topography, assumed failure
								STK-FP-9	Piled river rock dike, not orphaned.	Y	Y	Removed from topography, assumed failure
STK-4	500	Debris Flood (Type 3)	1.1	55	Sitkum Highway Bridge	50	Blocked	STK-FP-1	Piled river rock dike, not orphaned.	Y	Y	Removed from topography, assumed failure
								STK-FP-2	Bank protection on left bank, not orphaned.	Y	Y	Removed from topography, assumed failure
								STK-FP-3	Berm, not orphaned.	Y	Y	Removed from topography, assumed failure
								STK-FP-4	Piled river rock dike, not orphaned.	Y	Y	Removed from topography, assumed failure
					Wood Bridge (downstream of Sitkum Highway Bridge)	60	Blocked	STK-FP-5	Berm, not orphaned.	Y	Y	Removed from topography, assumed failure
								STK-FP-6	Berm, orphaned.	Y	Y	Removed from topography, assumed failure
								STK-FP-7	Piled river rock dike, not orphaned.	Y	Y	Removed from topography, assumed failure
								STK-FP-8	Piled river rock dike, not orphaned.	Y	Y	Removed from topography, assumed failure
								STK-FP-9	Piled river rock dike, not orphaned.	Y	Y	Removed from topography, assumed failure

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



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 - SITKUM 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.

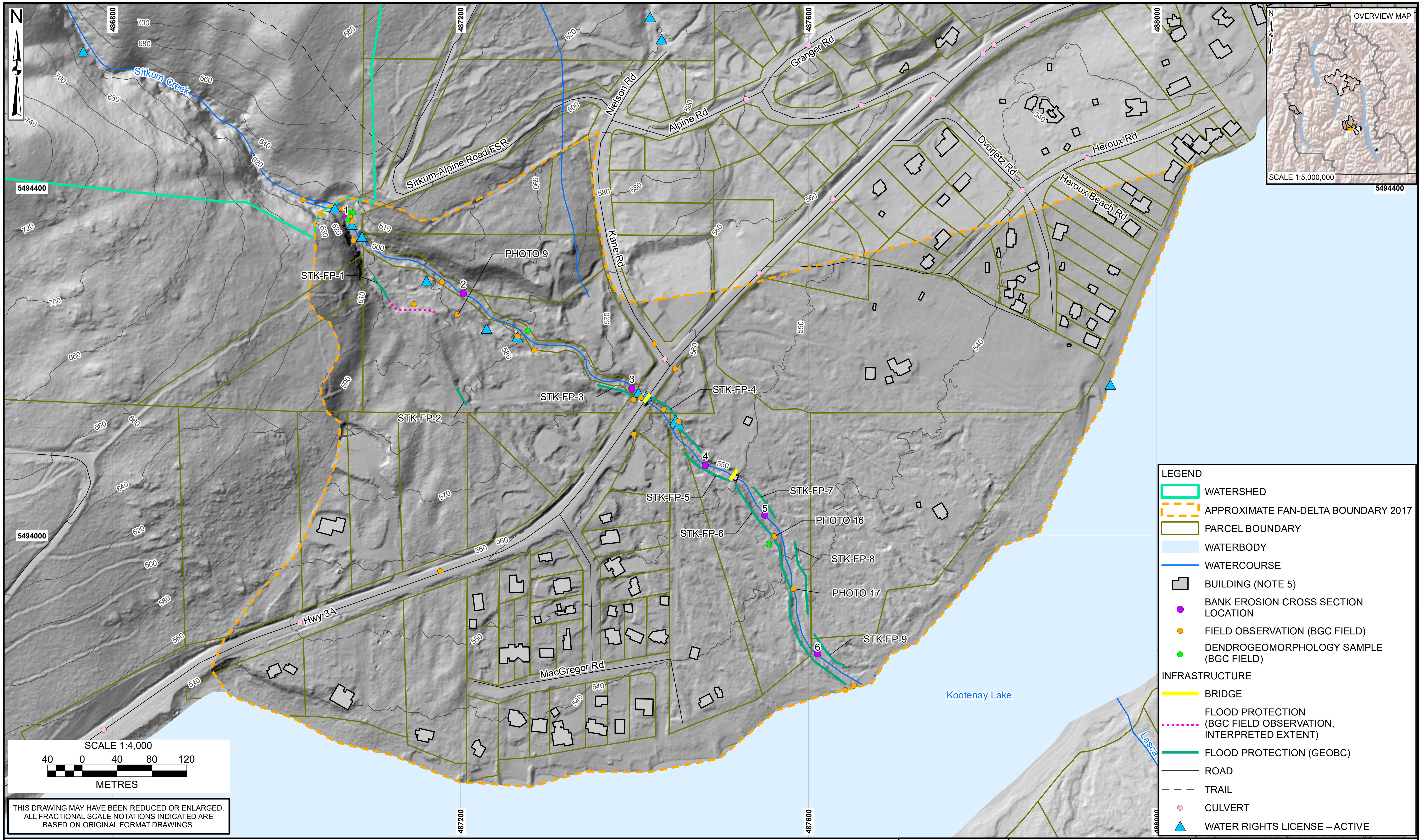
SCALE: 1:40,000
DATE: MAR 2020
DRAWN: LL
CHECKED: JJHP
APPROVED: MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: REGIONAL DISTRICT CENTRAL KOOTENAY

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY
TITLE: SITKUM CREEK
SITE LOCATION MAP
PROJECT No.: 0268007
DWG No: 01

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191018_RDCK_Floodplain_and_Steep_Creek_Study\01_Site_Location_DDP_SITKUM.mxd



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

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY - SITKUM 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.
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: 1:4,000
DATE: MAR 2020
DRAWN: LL
CHECKED: JJHP
APPROVED: MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
REGIONAL DISTRICT CENTRAL KOOTENAY

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE:
SITKUM CREEK
FAN-DELTA SITE MAP

PROJECT No.: 0268007
DWG No: 02A

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

LEGEND

- WATERSHED
- APPROXIMATE FAN-DELTA BOUNDARY 2017
- PARCEL BOUNDARY
- WATERCOURSE
- BUILDING (NOTE 5)
- ● BANK EROSION CROSS SECTION LOCATION
- ● FIELD OBSERVATION (BGC FIELD)
- ● DENDROGEOMORPHOLOGY SAMPLE (BGC FIELD)

INFRASTRUCTURE

- BRIDGE
- FLOOD PROTECTION (BGC FIELD OBSERVATION, INTERPRETED EXTENT)
- FLOOD PROTECTION (GEOBC)
- ROAD
- TRAIL
- ● CULVERT
- ▲ WATER RIGHTS LICENSE – ACTIVE

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 - SITKUM 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.
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:	1:4,000
DATE:	MAR 2020
DRAWN:	LL
CHECKED:	JJHP
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: REGIONAL DISTRICT CENTRAL KOOTENAY

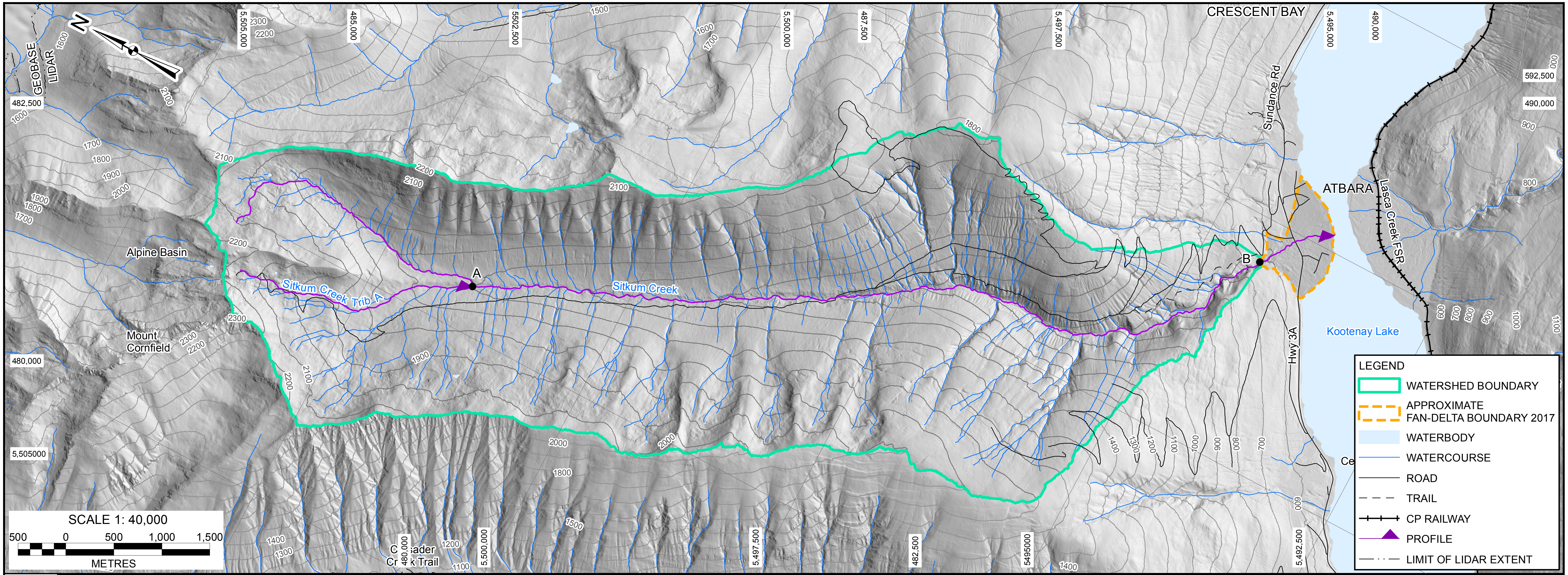
PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY

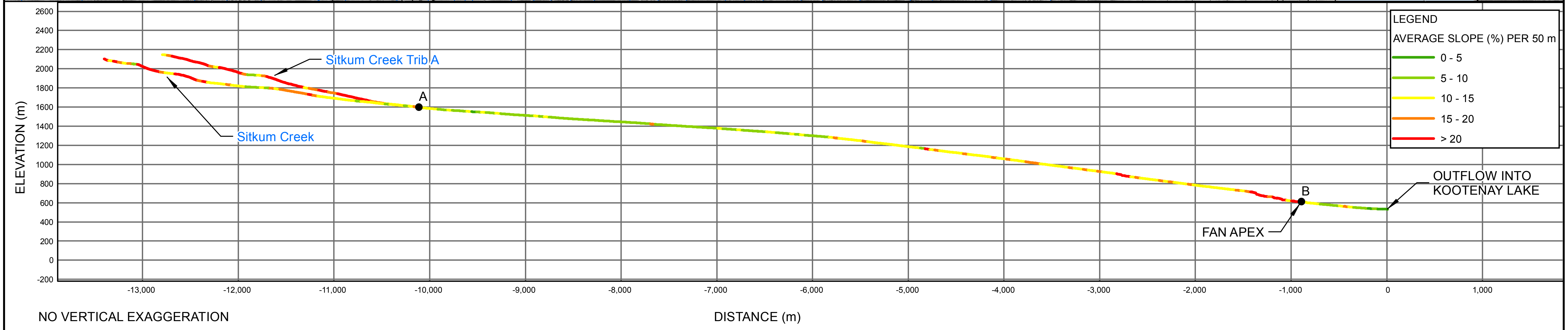
TITLE:
SITKUM CREEK
FAN-DELTA SITE MAP

PROJECT No.: 0268007

DWG No: 02B

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191018_RDCK_Floodplain_and_Steep_Creek_Study\02B_Fan_Delta_Site_Map_DDP_SITKUM.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 – SITKUM CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK AND GEOBASE CDED, DATED 2018, 2019 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 OF OR RELIANCE UPON THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE: 1:40,000
DATE: MAR 2020
DRAWN: STT
CHECKED: JJHP, LCH
APPROVED: MJ

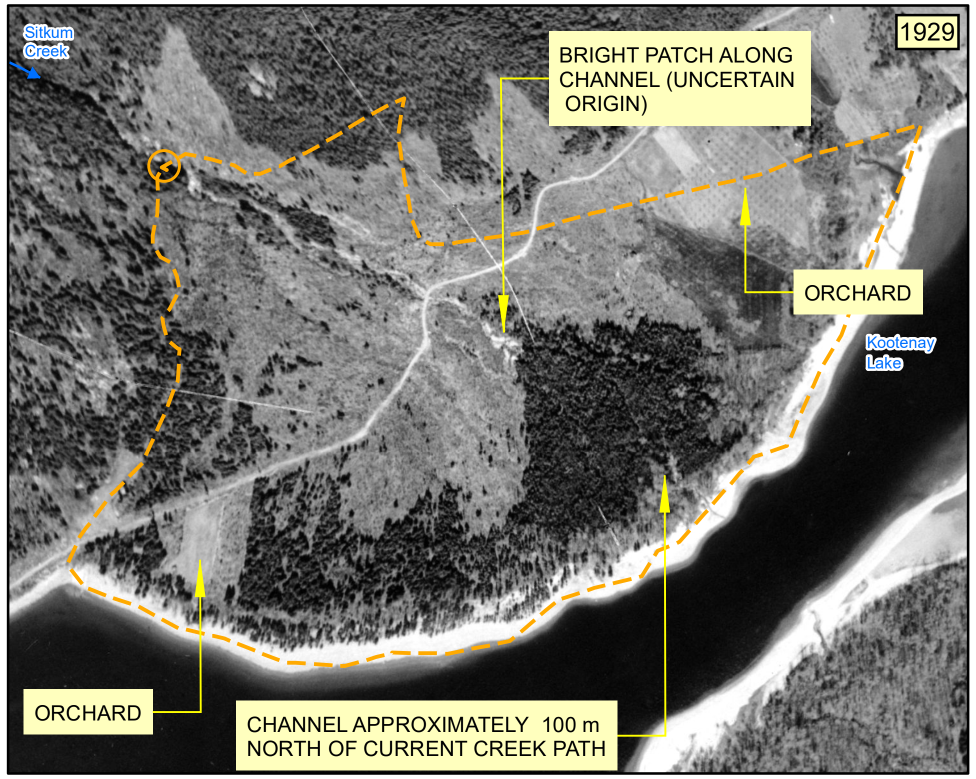
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

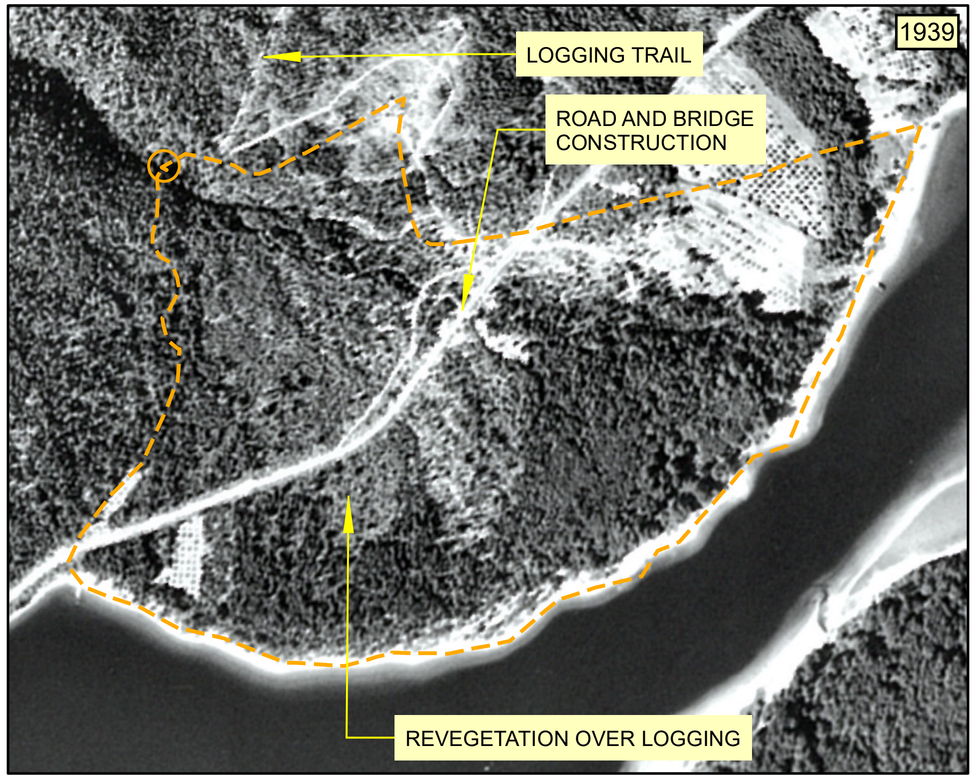
CLIENT: REGIONAL DISTRICT CENTRAL KOOTENAY

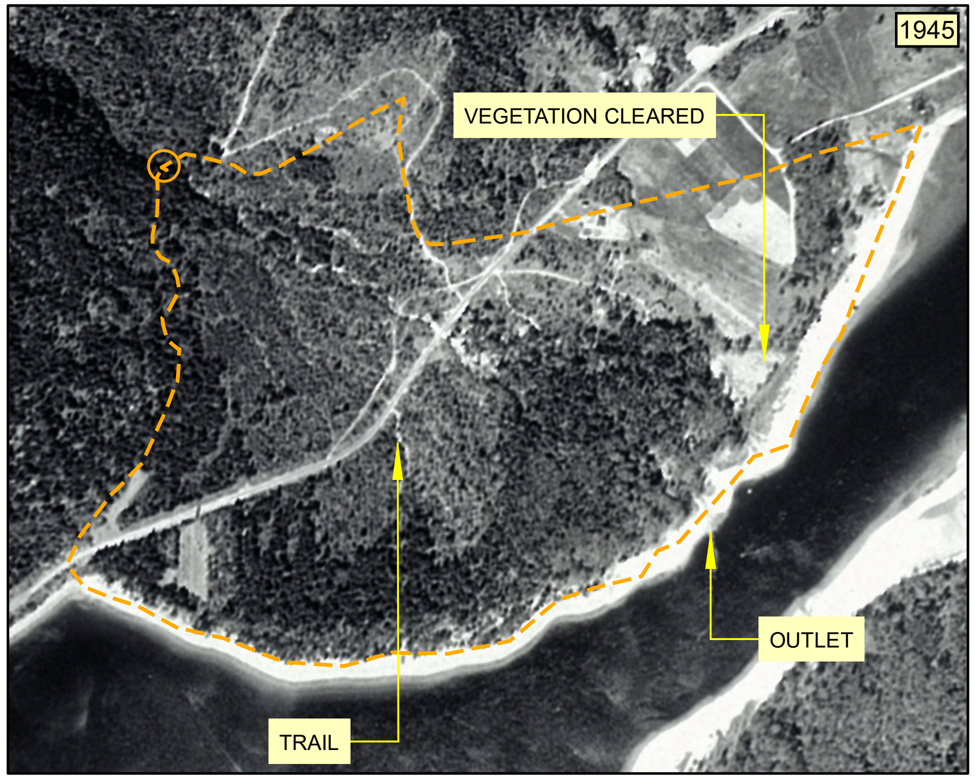
PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY
TITLE: SITKUM CREEK PROFILE
PROJECT No.: 0268007
DWG No: 03

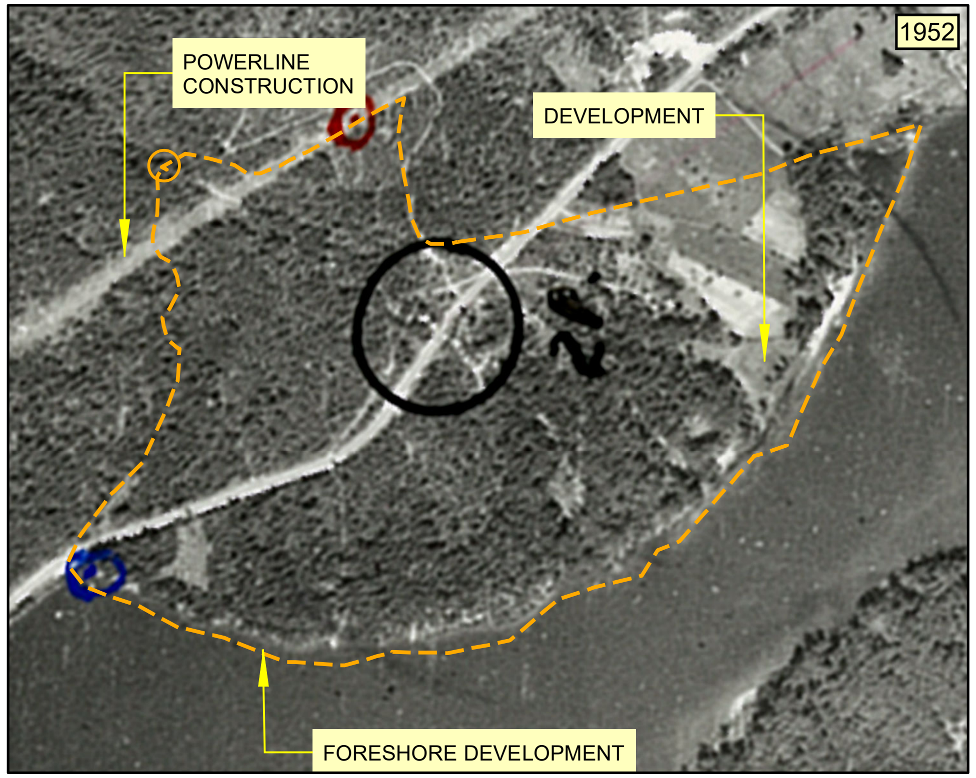
X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\ProductionReport\20191018_RDCK_Floodplain_and_Steep_Creek_Study\Profile\03_Sitkum_Creek_Profile.mxd

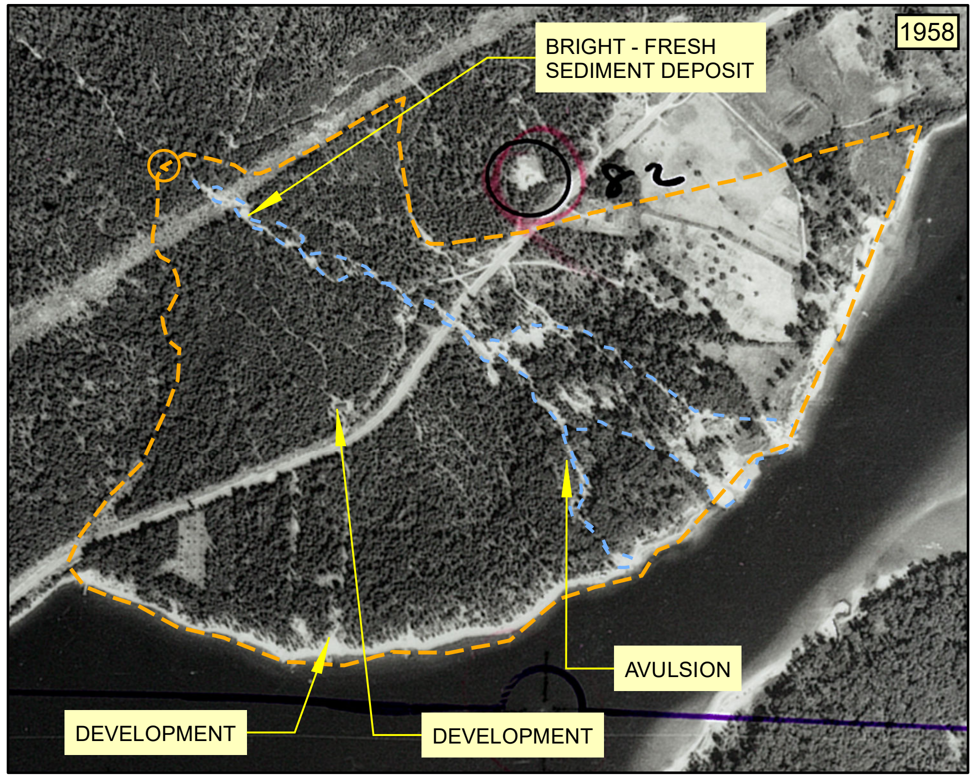
N

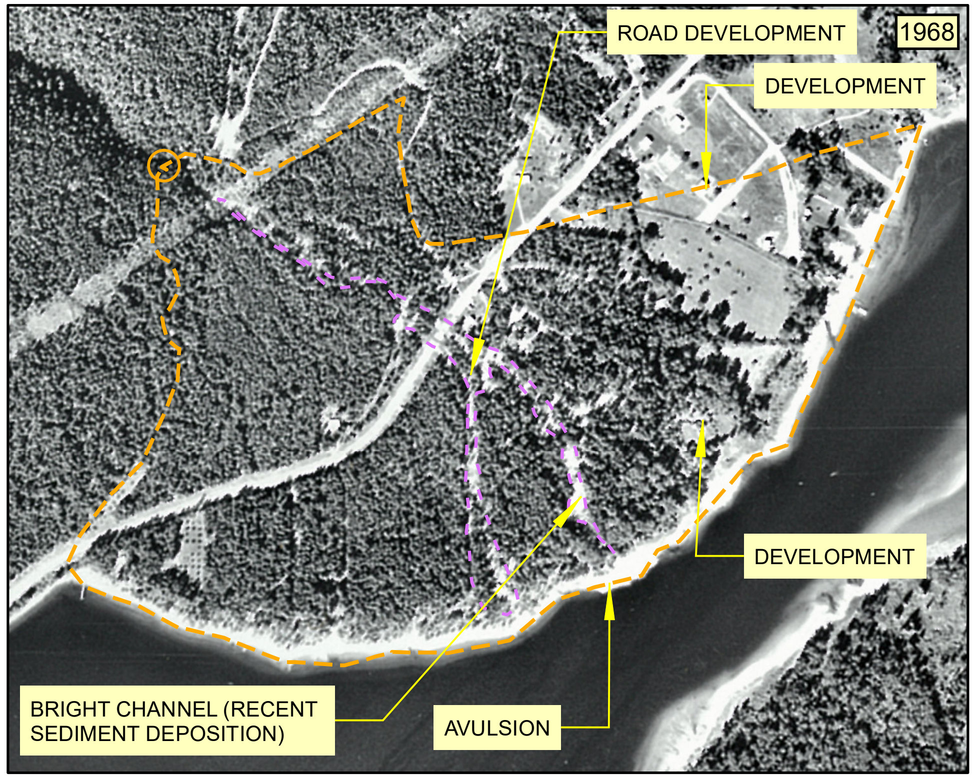












SCALE 1:10,000

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.

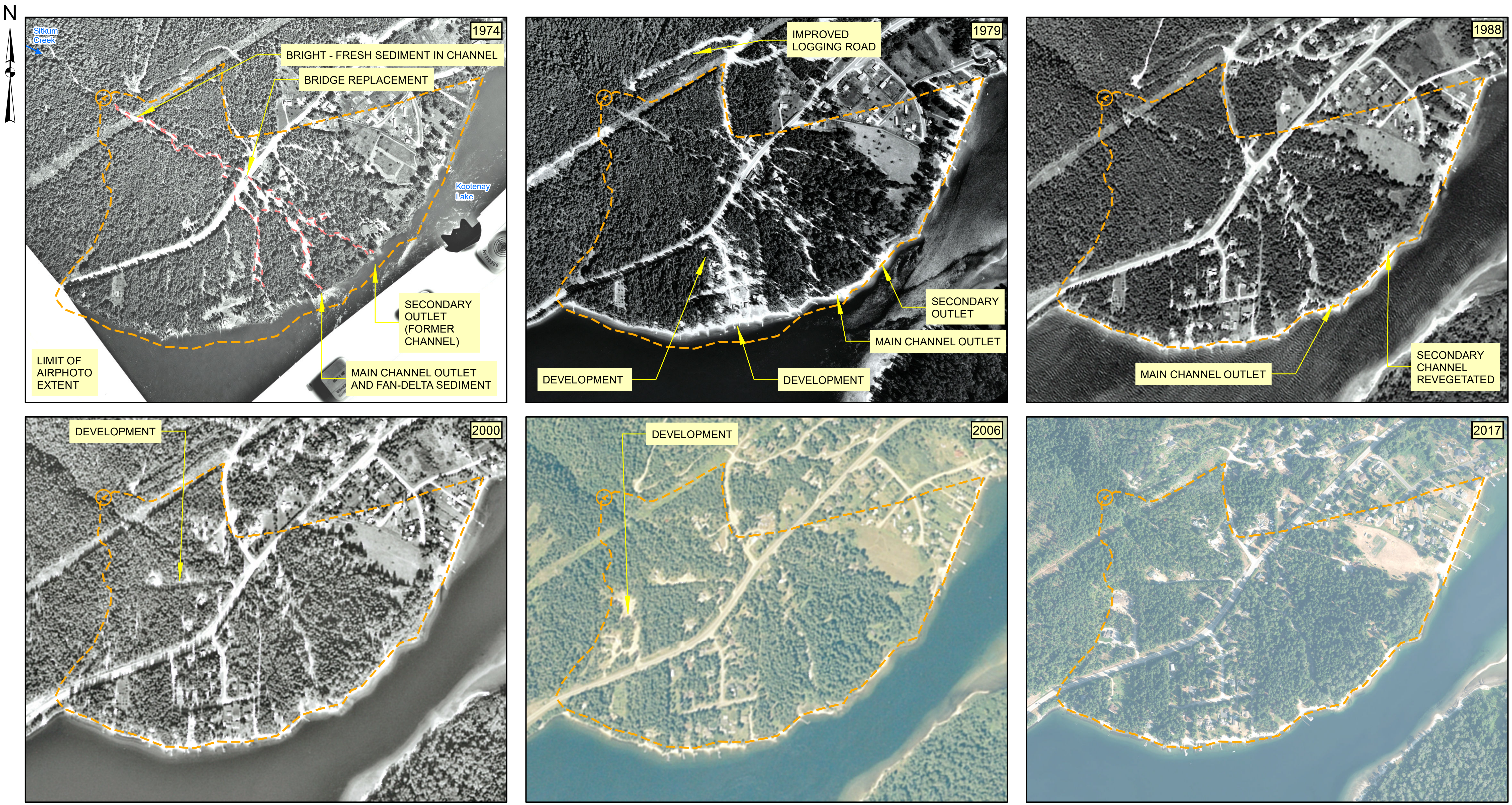
LEGEND

▭	APPROXIMATE FAN-DELTA BOUNDARY 2017	- - -	APPROXIMATE EXTENT OF 1950's EVENT
○	FAN APEX	- - -	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 - SITKUM 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 YEARS 1952 AND 1958 WERE 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: 1:10,000	BGC ENGINEERING INC. AN APPLIED EARTH SCIENCES COMPANY	PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY	
DATE: MAR 2020		TITLE: SITKUM CREEK AIR PHOTO COMPARISON	
DRAWN: MIB, LL	CLIENT: REGIONAL DISTRICT CENTRAL KOOTENAY		
CHECKED: JJHP, LCH		PROJECT No.: 0268007	DWG No: 04A
APPROVED: MJ			

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



SCALE 1:10,000

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

- - - APPROXIMATE EXTENT OF 1972 EVENT

○ 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 - SITKUM 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:	1:10,000
DATE:	MAR 2020
DRAWN:	MIB, LL
CHECKED:	JJHP, LCH
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

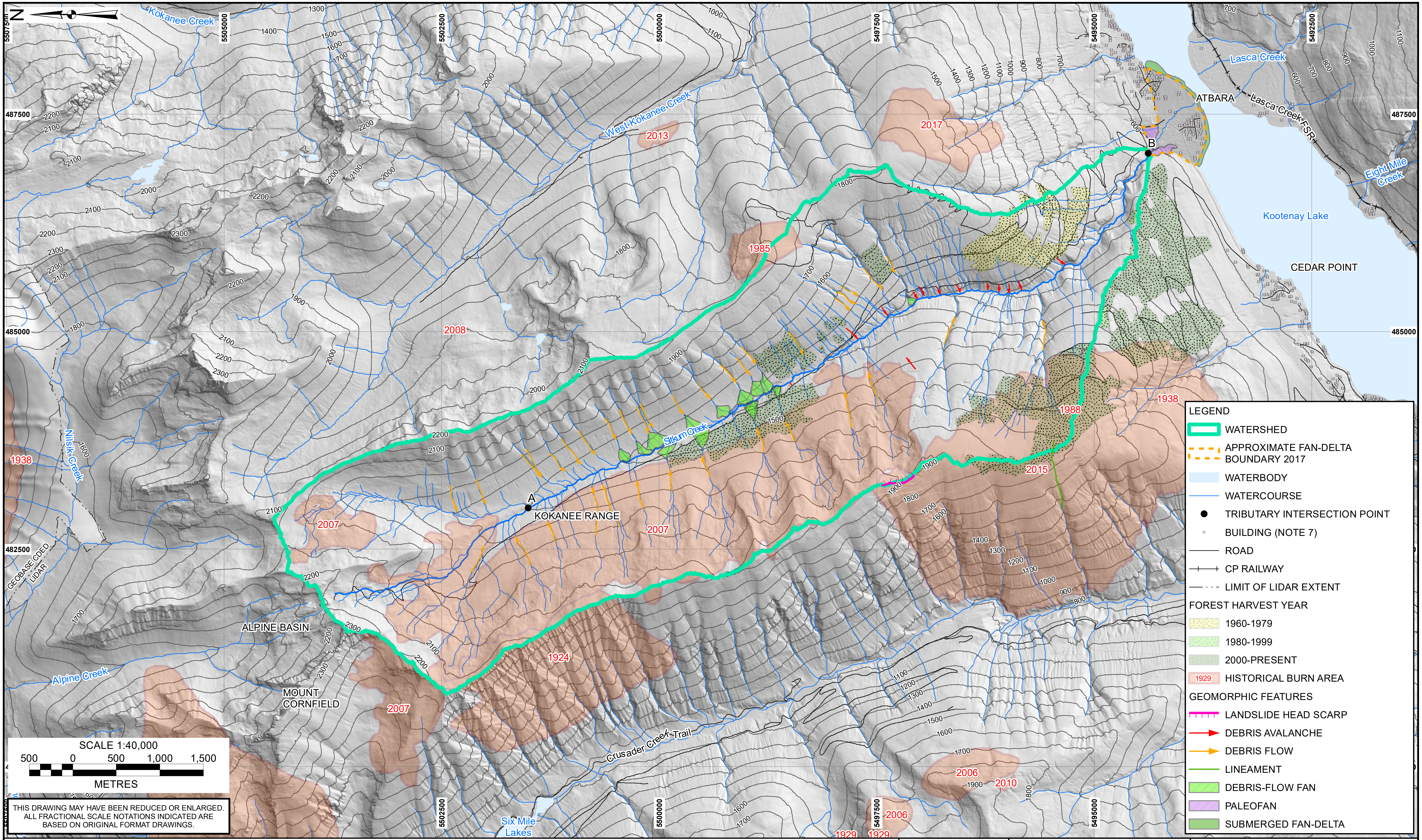
PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE:
SITKUM CREEK
AIR PHOTO COMPARISON

PROJECT No.: 0268007

DWG No: 04B

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



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

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY - SITKUM 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 FROM GEOBC DATASET DATED 2019 AND ONLY REPRESENTATIVE OF AREAS THAT INTERSECT WATERSHED BOUNDARY. HISTORICAL BURN AREA FROM GEOBC DATASET DATED 2019.
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: 1:40,000
DATE: MAR 2020
DRAWN: MW
CHECKED: JJHP
APPROVED: MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

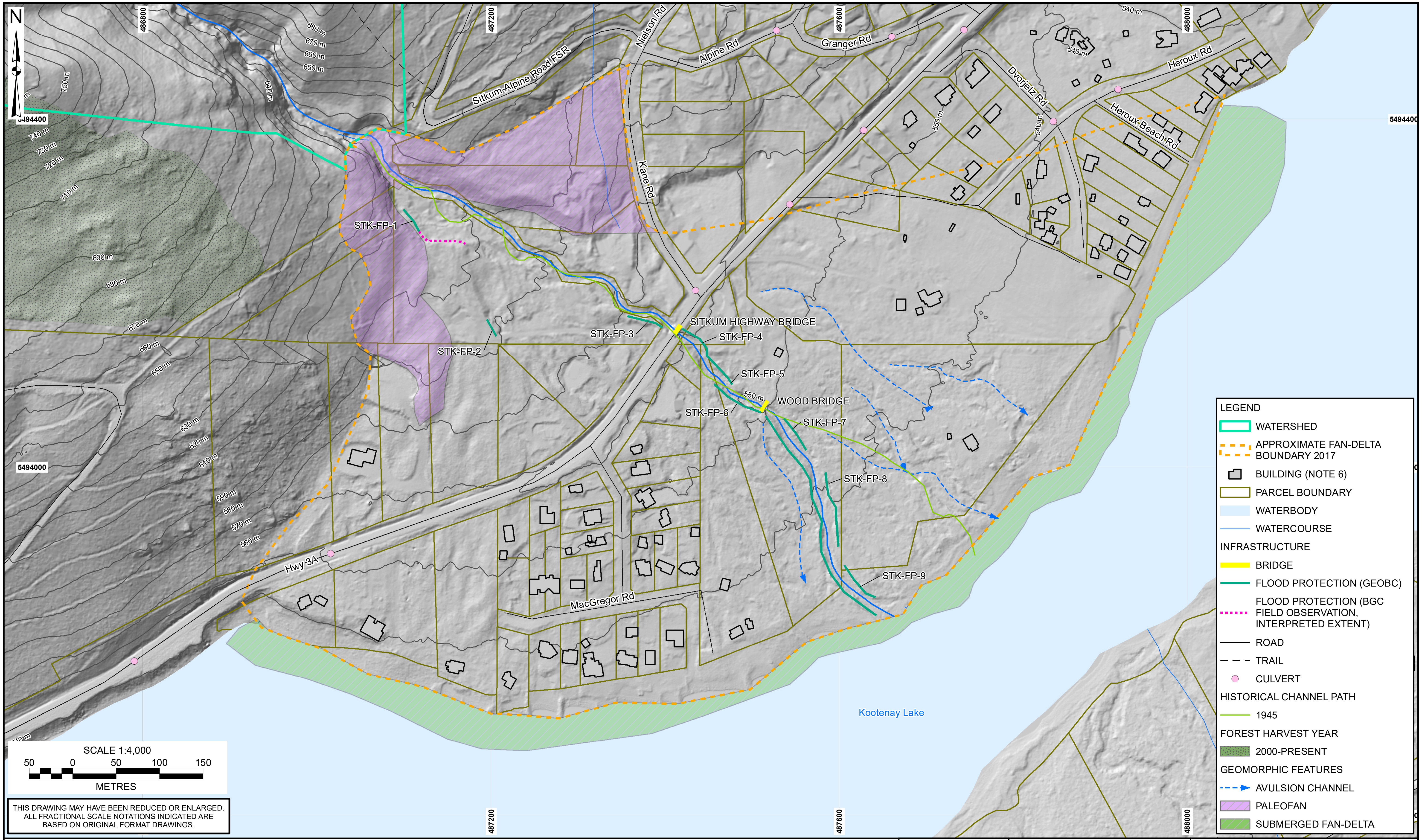
CLIENT:
REGIONAL DISTRICT CENTRAL KOOTENAY

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE:
SITKUM CREEK
WATERSHED GEOMORPHOLOGY

PROJECT No.: 0268007
DWG No.: 05

X:\Projects\0268007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20191112_RDCK_Floodplain_and_Steep_Creek_Study_STEEPCREEK\FINAL_COPIES\05_SitkumCreek_GeomorphicMappingWatershed.mxd Date: April 13, 2020 Time: 3:50 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 - SITKUM 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. 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. FLOOD PROTECTION DATA FROM GEOBC AND BGC FIELD OBSERVATIONS.
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:	1:4,000
DATE:	MAR 2020
DRAWN:	MW
CHECKED:	JJHP
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

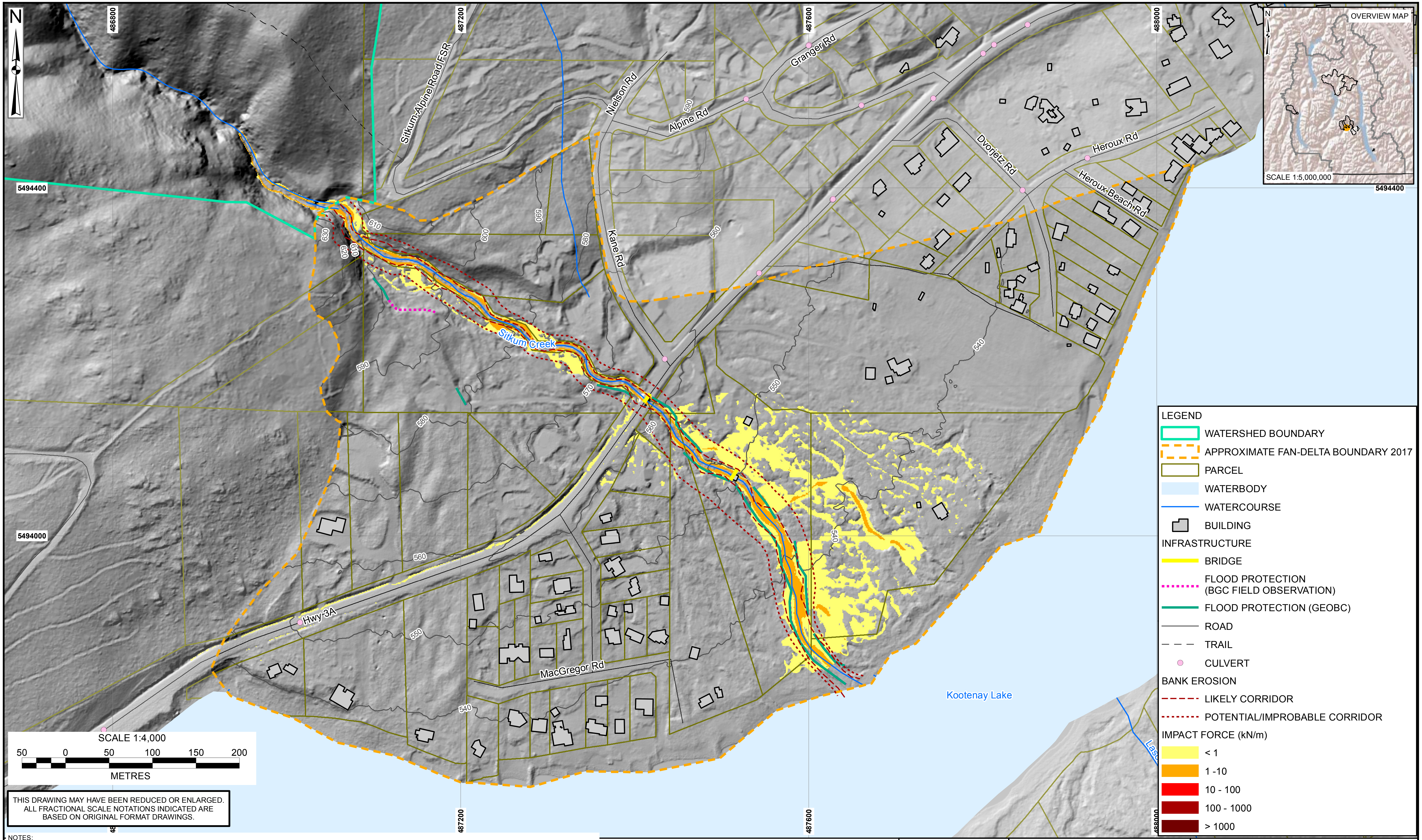
CLIENT:

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE:
SITKUM 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_SitkumCreek_GeomorphicMappingofFan.mxd Date: April 14, 2020 Time: 2:19 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 - SITKUM 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. BANK PROTECTION FROM GEOBC AND BGC FIELD OBSERVATIONS. PARCEL MAP FROM PARCELMAP BC.
6. SCENARIO MAP SHOWS CLEARWATER IMPACT FORCE BASED ON HEC-RAS MODEL RESULTS FOR THE 200-YEAR RETURN PERIOD COMPLETED BY BGC. THIS IS A REPRESENTATIVE MAP AND DOES NOT SHOW THE FULL SUITE OF MODELLED SCENARIOS. SCENARIO DETAILS ARE OUTLINED IN BGC REPORT.
7. THIS MAP REPRESENTS A SNAPSHOT IN TIME. FUTURE CHANGES (DEVELOPMENT, DEBRIS FLOOD MITIGATION, GEOHAZARD EVENTS) MAY WARRANT RE-DRAWING OF CERTAIN AREAS.
8. PROJECTION IS NAD 1983 UTM ZONE 11N. VERTICAL DATUM IS UNKNOWN.
9. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE:	1:4,000
DATE:	MAR 2020
DRAWN:	LL, MIB, STT
CHECKED:	LCH
APPROVED:	HW

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

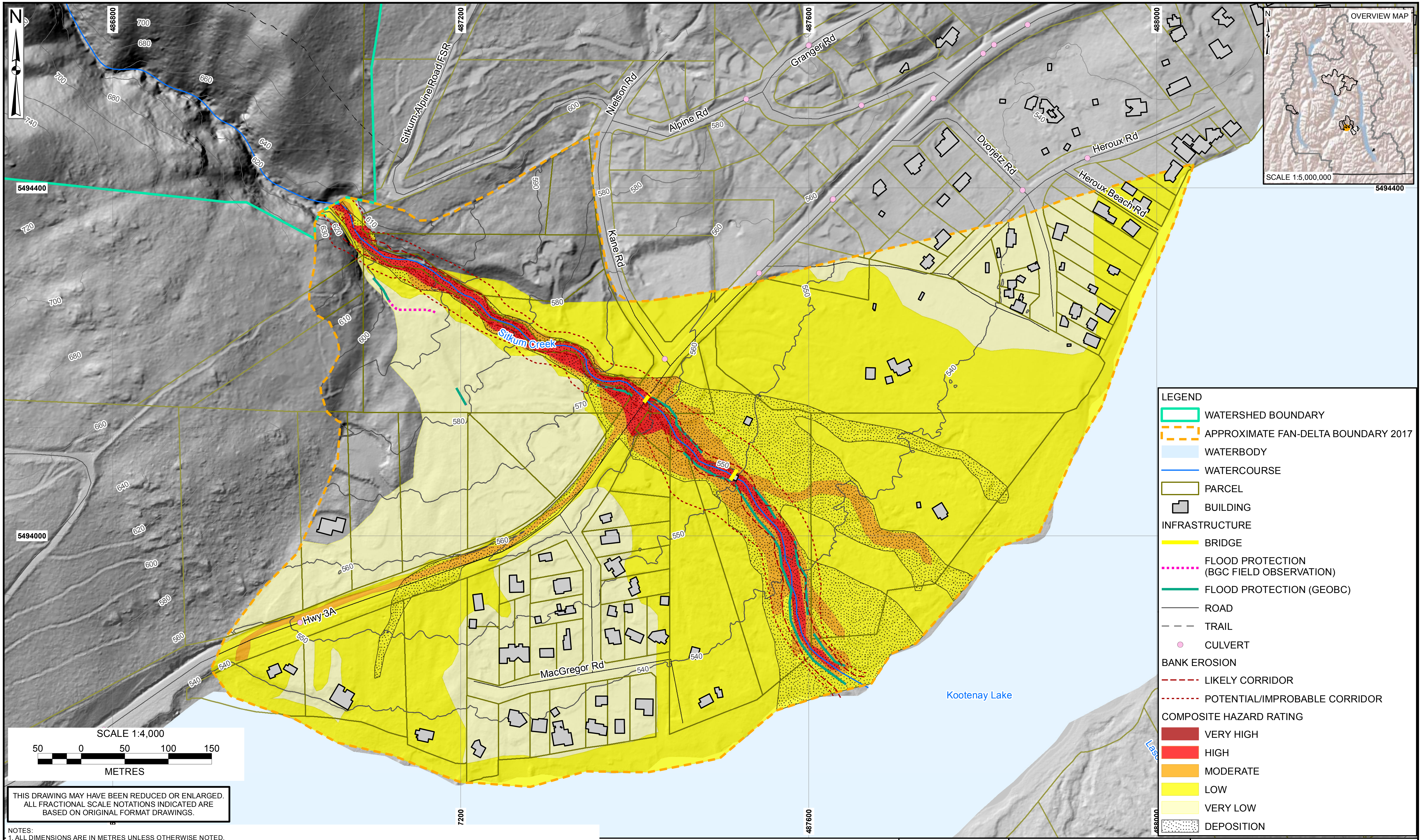
CLIENT:
REGIONAL DISTRICT CENTRAL KOOTENAY

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE:
SITKUM CREEK 200 YEAR MODEL SCENARIO STK-3

PROJECT No.: 0268007
DWG No: 07

X:\Projects\0268\007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20200207_RDCK_Steep_Creek_Hazards\07 Sitkum 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 - DUHAMEL 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. COMPOSITE HAZARD RATINGS PORTRAYED ON THIS DRAWING ONLY REPRESENT HAZARDS STUDIED WITHIN THE FAN-DELTA BOUNDARY.
5. SURFACE FLOW ON PALEO SURFACES WITHIN THE FAN-DELTA BOUNDARY HAVE NOT BEEN ASSESSED IN THIS STUDY.
6. MODELLED BANK EROSION IS SHOWN AS A LIKELY CORRIDOR (DIVIDED BETWEEN CHANNEL BANKS BASED ON CHANNEL GEOMETRY) AND POTENTIAL/IMPROBABLE CORRDIOR (APPLIED EQUALLY TO BOTH BANKS).
7. THIS MAP REPRESENTS A SNAPSHOT IN TIME. FUTURE CHANGES (DEVELOPMENT, DEBRIS FLOOD MITIGATION, GEOHAZARD EVENTS) MAY WARRANT RE-DRAWING OF CERTAIN AREAS.
8. BUILDING FOOTPRINTS DIGITIZED BY BGC. CULVERT LOCATIONS FROM BC MINISTRY OF TRANSPORTATION. PARKS DATA FROM GOVERNMENT OF BC. ROADS DATA FROM BC DIGITAL ROAD ATLAS. RAILWAY DATA FROM GEOBASE NATIONAL RAILWAY NETWORK. ELECTRICAL, PETROLEUM, COMMUNICATION AND WATER INFRASTRUCTURE FROM INTEGRATED CADASTRAL INFORMATION SOCIETY. BANK PROTECTION FROM GEOBC AND BGC FIELD OBSERVATIONS. PARCEL MAP FROM PARCELMAP BC.
9. PROJECTION IS NAD 1983 UTM ZONE 11N.
10. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

X:\Projects\0268007_RDCK_NDMP_Stream_2_Support\GIS\Production\Report\20200207_RDCK_Steep_Creek_Hazards\08 Composite Hazard Map Sitkum.mxd

SCALE: 1:4,000
DATE: MAR 2020
DRAWN: STT, LL, MIB
CHECKED: LCH
APPROVED: HW

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: REGIONAL DISTRICT CENTRAL KOOTENAY

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE: SITKUM CREEK
COMPOSITE HAZARD RATING MAP

PROJECT No.: 0268007
DWG No: 08