RDCK FLOODPLAIN AND STEEP CREEK STUDY

Wilson Creek

Final
March 31, 2020

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

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TABLE OF REVISIONS

ISSUE	DATE	REV	REMARKS
DRAFT	March 20, 2020		Interim draft. Drawing 07 excluded and model results included for discussion purposes.
FINAL	March 31, 2020		Final issue.

LIMITATIONS

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EXECUTIVE SUMMARY

This report and its appendices provide a detailed hydrogeomorphic hazard assessment of Wilson Creek. Wilson 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 floods). This report provides comprehensive geomorphological and hydrological background and details the analytical techniques applied to create scenario and composite hazard rating maps for the Wilson Creek fan-delta. It is the foundation for possible future quantitative risk assessments or conceptualization and eventual design and construction of mitigation measures.

Wilson 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). Wilson Creek is a debris-flood prone creek.

Multiple hazard scenarios were developed for specific event return periods. These included bulking of flow to allow for higher organic and mineral sediment concentrations and bridge blockage scenarios.

A numerical hydro-dynamic model was employed to simulate debris flood hazard scenarios on the fan-delta. 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 Wilson Creek debris floods.

Process	Key Observations
Clearwater Inundation (HEC-RAS results for all return periods)	• Wilson Creek flows overbank from its current channel for return periods 20 years and higher east of Rosebery Campsite Road. • Downstream of Highway 6, water will likely inundate the Nakusp and Slocan Railway Trail (NSRT) as well as some properties on the east end of Derosa Drive. Properties on Stanley Street and the north side of Stewart Drive would also be inundated. • Flood extent and depth are similar for the 20 and 50-year return period floods. • Access and egress to Derosa Drive, Stanley Street and Stewart Drive would likely be severed by inundation near 6th Street for the 20-year and higher return period floods. Without egress, these properties will likely be isolated in case of a flood. • The 200-year flood extent is similar to the 50-year flood. However, East Wilson Road would likely be flooded north of Highway 6. • The 500-year flood extent is similar to the 200-year flood with a larger portion of the Rosebery Parklands Regional Parks north of the Wilson Creek delta being inundated.

Process	Key Observations
Bank Erosion	• Bank erosion reaches a maximum of 32 m for the 500- year return period in the vicinity of the NSRT. • Bank erosion could impact the bridge foundations at Highway 6 and the NSRT though BGC did not evaluate the possibility of abutment failures. • Properties along the right (west) side of Wilson Creek between Highway 6 and the NSRT are likely to lose substantial portions of land (i.e., up to 151 m) in a severe flood. • Given the comparatively high flow velocities (> 3 m/s) it is also likely that portions of the East Wilson Road embankment would erode from the 20-year and higher return period floods, thus severing access northward into the Wilson Creek watershed.
Auxiliary Hazards	• None of the numerical modelling accounts for collapses of any of the high slopes on the upper fan, possibly resulting in an outbreak flood surge or the possibility of exacerbated bank erosion in case of a partial creek blockage and flow concentration on the opposite side of the slope failure. • NSRT and Highway 6 embankment failures have not been modelled.

The numerical modelling demonstrates the key hazards and associated risks stem from inundation of presently developed areas in the south-central portions of the Wilson Creek fan-delta and the potential isolation of properties along Derosa Drive due to egress cutoff via Rosebery Road.

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. 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 combines all hazard scenarios into one map and incorporates the respective debris flood and debris flow frequencies. It provides a sense of the areas that could possibly be impacted by future events up to the highest modelled return period. The composite hazard rating map can serve to guide subdivision and other development permit approvals. It requires discussions and regulatory decisions on which hazard zone is attributed to specific land use prescriptions, covenants, bylaws or other limiting clauses for both existing and proposed development. The categories range from very low to very high hazard. Very low hazard is defined as areas likely to not be affected by any of the modeled scenarios up to the 500-year return period debris floods, but which are not free of hazard. Very low hazard zones could be impacted by flows of higher return periods, or if, over time, the channel bed of Wilson Creek aggrades, or the channel or fan surface is artificially altered. All other hazard categories are classified via the impact force intensity. The composite hazard rating map shows that the majority of the north side of the Wilson Creek fan-delta (north of the Wilson Creek channel) is subject to very low and low hazards. The south side of the Wilson Creek fan-delta (south of the Wilson Creek channel) is subject to very low to low hazards at the southern end and increases to moderate hazard north of Stewart St. The Wilson Creek channel from the fan apex to the outlet has high to very high hazards.

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): Improvement to existing and install of further bank protection with riprap to better protect from bank erosion in multiple locations adjacent to the main channel; building-specific flood proofing and erosion protection to properties shown to be inundated by modelling; a berm equipped with culverts to protect development downstream of Rosebery Rd and DeRosa Dr from flow and erosion; and a ring dike or property-specific flood proofing to protect development adjacent to the main channel and on the Slocan Lake shoreline from inundation and erosion. In addition to physical mitigation, other measures should be considered such as development restrictions and emergency preparedness as development on the fan-delta may be cut off from evacuation routes during an event.

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 developments, debris floods, formation or reactivation of existing large landslides in the watershed that could impound Wilson Creek, bridge re-design or alteration to bank armouring or other mitigation works. 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 modelled as each process displays some chaotic behaviour. For example, unforeseen log jams may alter flow directions and create avulsions into areas not specifically considered in the individual hazard scenarios. Substantial changes of Slocan Lake levels could 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 and mapping for Wilson Creek, located approximately 30 km north of Slocan, BC in Electoral Area H. The site lies on the west side of the Slocan Lake and Wilson Creek flows through the center of the community of Roseberry and into the lake.

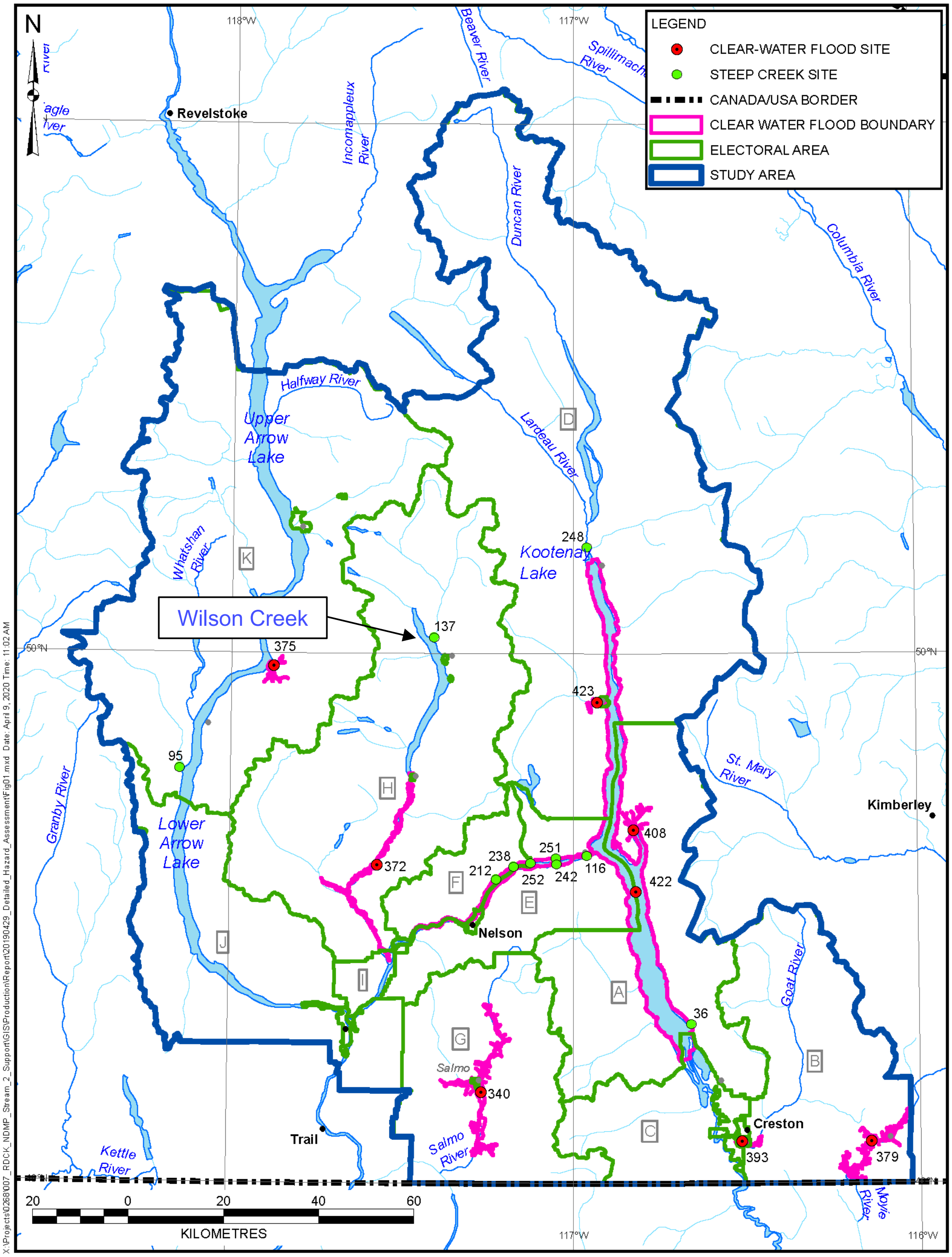

Figure 1-1. Hazard areas prioritized for detailed flood and steep creek mapping. Site labels correspond to hazard identification numbers in Cambio Communities. Wilson Creek (No. 137) is labelled on the figure.

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

At Wilson Creek, the scope of work included:

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

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[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 BGC's Cambio™ web application and as geospatial data provided to RDCK.

This report is best read with access to Cambio. Cambio displays the results of both the Stream 1 and Stream 2 studies. The application can be accessed at *www.cambiocommunities.ca,* using either Chrome or Firefox web browsers. A Cambio user guide is provided in the Summary Report (BGC, March 31, 2020a). As outlined in Section 1.1, the report is best read with the Summary Report and Methodology Report (BGC, March 31, 2020b).

1.4. Study Team

This study was multidisciplinary. Contributors are listed below, and primary authors and reviewers are listed in Table 1-3.

- Kris Holm, M.Sc., P.Geo., Principal Geoscientist
- Sarah Kimball, M.A.Sc., P.Eng., P.Geo., Senior Geological Engineer
- Matthias Jakob, Ph.D., P.Geo., Principal Geoscientist
- Hamish Weatherly, M.Sc., P.Geo., Principal Hydrologist
- Lauren Hutchinson, M.Sc., P.Eng., Intermediate Geotechnical Engineer
- Beatrice Collier-Pandya, B.A.Sc., EIT, Geological Engineer
- Matthias Busslinger, M.A.Sc., P.Eng., Senior Geotechnical Engineer
- Carie-Ann Lau, M.Sc., P.Geo., Intermediate Geoscientist
- Jack Park, B.A.Sc., EIT, GIT, Junior Geological Engineer

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[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.

- 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
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- 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.

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Midori Telles-Langdon</td><td>Sarah Davidson</td></tr>
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Beatrice Collier-Pandya</td><td>Lauren Hutchinson;
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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.

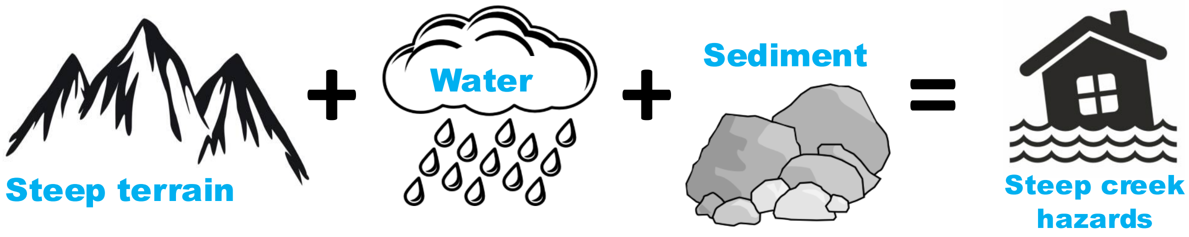

Figure 2-1. Illustration of steep creek hazards.

Steep creek hazards span a continuum of processes from 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.

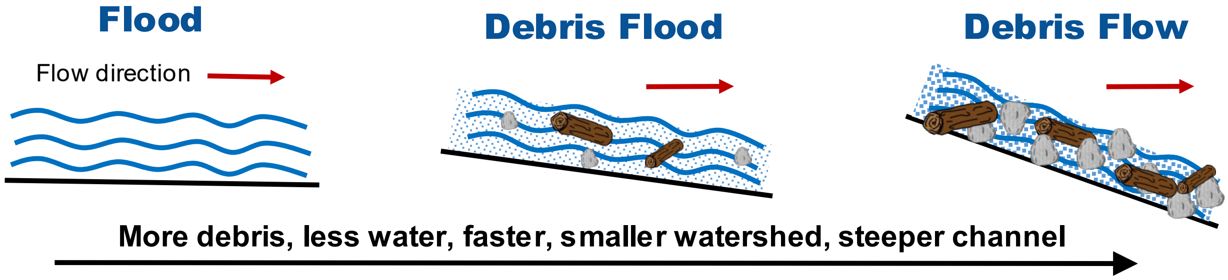

Figure 2-2. Continuum of steep creek hazards.

2.2. Floods and Debris Floods

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

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

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

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

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

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

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

2.3. Debris Flows

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

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

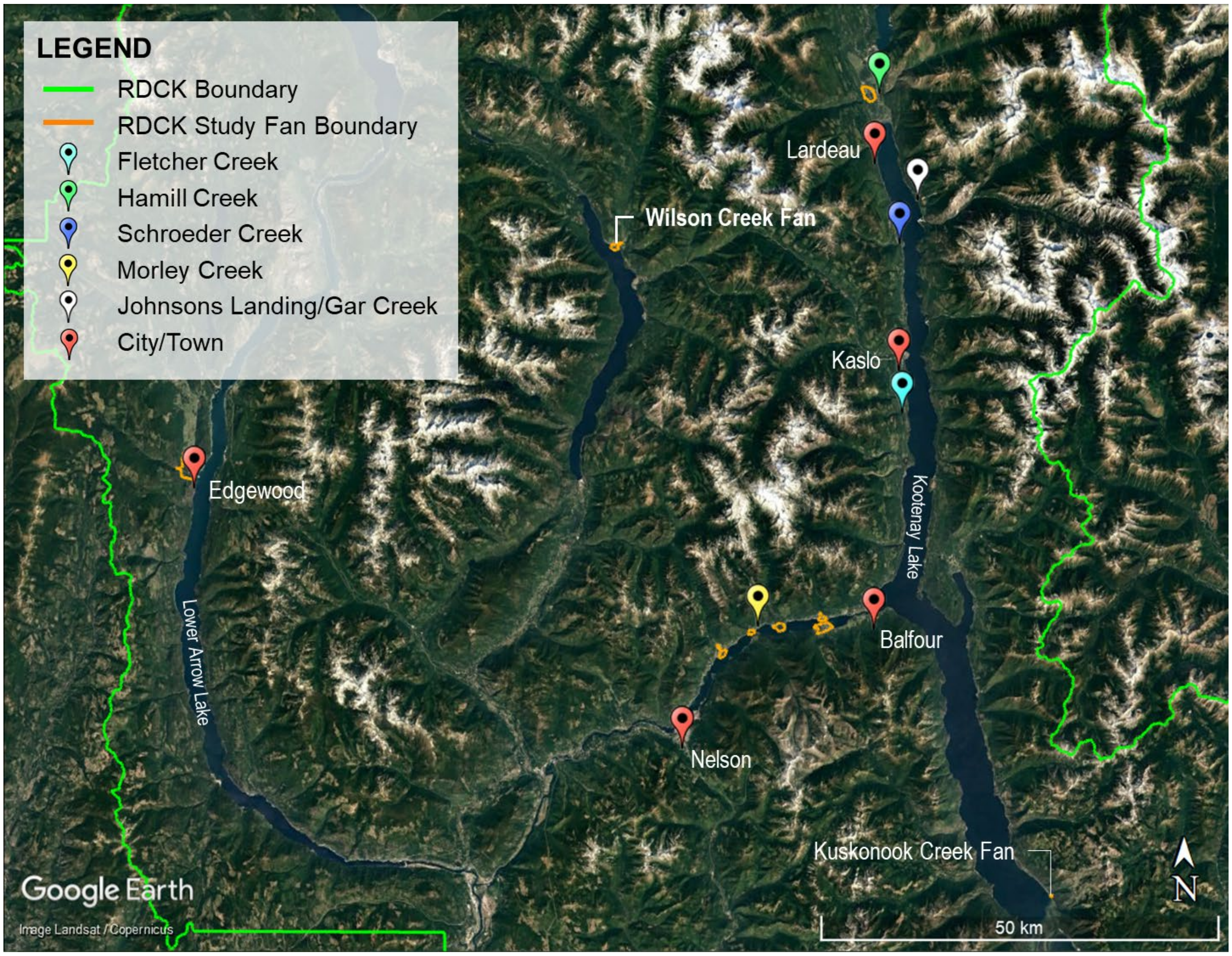

Figure 2-3. **Locations of RDCK fans and recent floods, debris flows, and debris floods (Google Earth Pro, 2016).**

2.4. Contextualizing Steep Creek Processes

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

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

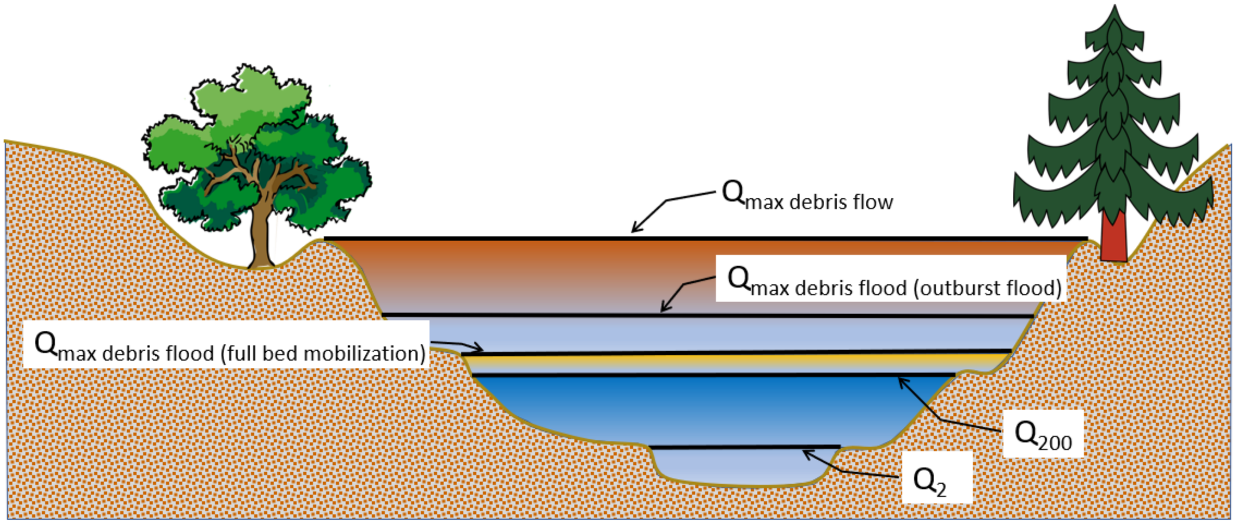

Figure 2-4. Conceptual steep creek channel cross-section showing peak discharge levels for different events. Note that for some outburst floods or debris flows the discharge may well exceed what is shown here.

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 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 bridge or toppled building redirects flow away from the present channel. The channel an avulsion 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. These channels differ from paleochannels because those are not expected to experience flows other than by surface runoff or groundwater flow during contemporary events.

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. It is shown in dashed blue lines as avulsions only occur during severe floods. On high resolution topographic maps generated from LiDAR of detailed field surveys, avulsion channels are 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 hinterland. The hillsides flanking the fan apex are also preferential locations for remnants of so-called 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 it is 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.

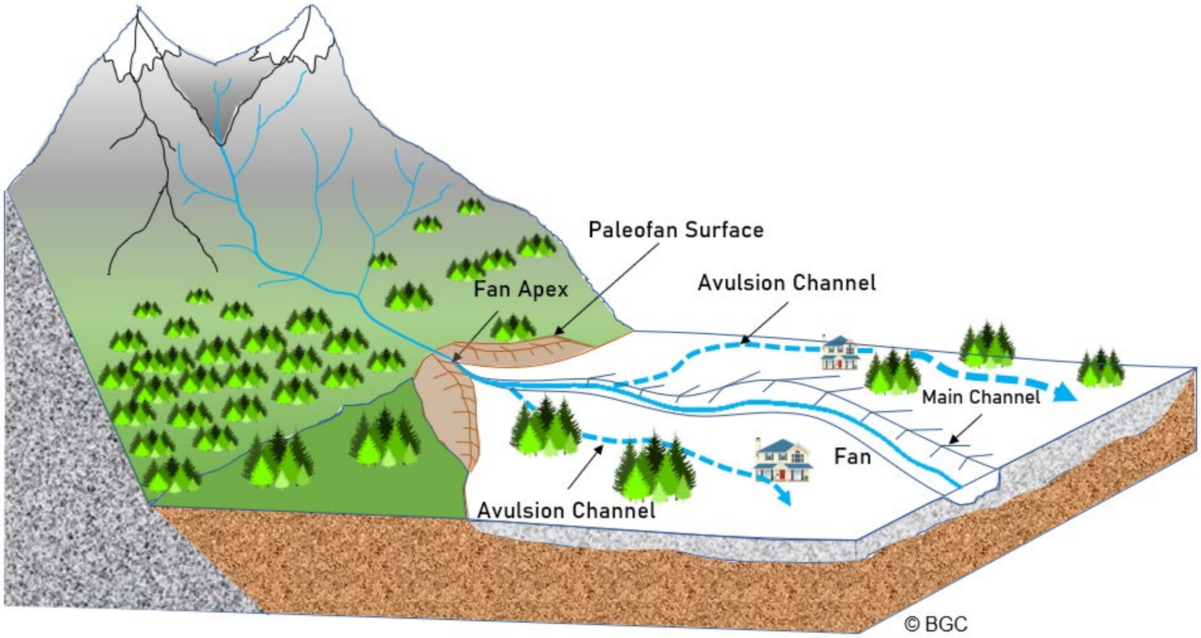

Figure 2-5. Schematic of a steep creek channel with avulsions downstream of the fan apex. Artwork by BGC.

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

3.1. Site Visit

Fieldwork on Wilson Creek was conducted from July 26, 2019, July 30, 2019 and on November 20, 2019 by the following BGC personnel Rob Millar, Marc Olivier Trottier, Anna Akkerman, Beatrice Collier-Pandya and Hilary Shirra). Field work included channel hikes to observe bank conditions, erosion and protection; locate previous creek alignments; measure grain size diameters (Wolman sampling) at the fan apex, the Highway 6 Bridge and the mouth (Appendix C); and, measure cross-sections at the bridge and other infrastructure crossing locations. Numerous photographs of field conditions were taken for later analysis and reference (Appendix B).

3.2. Physiography

Wilson Creek is located approximately 5 km north of New Denver, BC and flows through the community of Roseberry. Drawings 01, 02A, and 02B show the watershed and fan-delta boundaries of Wilson 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.

The site lies within the Selkirk Mountains, which is 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 Pacific moisture arrives from the south and west, bringing high humidity and rain in summer, and deep snow in winter (Demarchi, 2011). Typical vegetation includes Western Red Cedar and Western Hemlock trees at lower elevations (from 500 m) and Engelmann Spruce and Subalpine Fir trees along the mid-mountain slopes. The highest peaks in the Central Columbia ecosection reach up to approximately 3200 m and consist of barren rock.

3.3. Geology

3.3.1. Bedrock Geology

The bedrock geology of the Wilson Creek watershed can be divided into three main sub-regions: the southern portion is underlain by the Slocan Group, which is composed of sedimentary limestone, slate, siltstone, and argillite rocks that formed in the upper Triassic period; the northwestern portion is underlain by the Kuskanax Batholith, which is composed of granitic intrusive rocks that intruded upon the Slocan Group in the Mid-Jurassic period; the northeastern portion is underlain by a mixture of basaltic volcanics (Kaslo Group) and sedimentary rocks (Millford Formation) that formed in the Carboniferous to Permian periods, and were later intruded upon by several stocks of the Kuskanax Batholith (Parrish & Wheeler, 1983; Thompson et al., 2006). Multiple reverse faults have been mapped within the northeastern portion of the watershed, including the Whitewater Fault and the Stubbs Fault. These lineaments serve as preferential flow pathways for many of the tributary streams of Wilson Creek.

3.3.2. Surficial Geology

Along the valley bottoms of the Wilson Creek watershed, the surficial materials are dominantly glaciofluvial and fluvial, with some colluvium in the upper tributaries (Figure 3-1, Province of BC, 2016). The valley walls are characterized by colluvium and minor till overlying bedrock. The highest ridges and peaks are mostly composed of bedrock, partially overlain by colluvium (Wittneben, 1980). The abundant colluvium in the watershed, as well as the rockfall-prone bedrock outcrops indicate that the watershed is likely largely supply unlimited, which implies a quasi-unlimited amount of sediment available in the watershed to be mobilized during extreme hydroclimatic events.

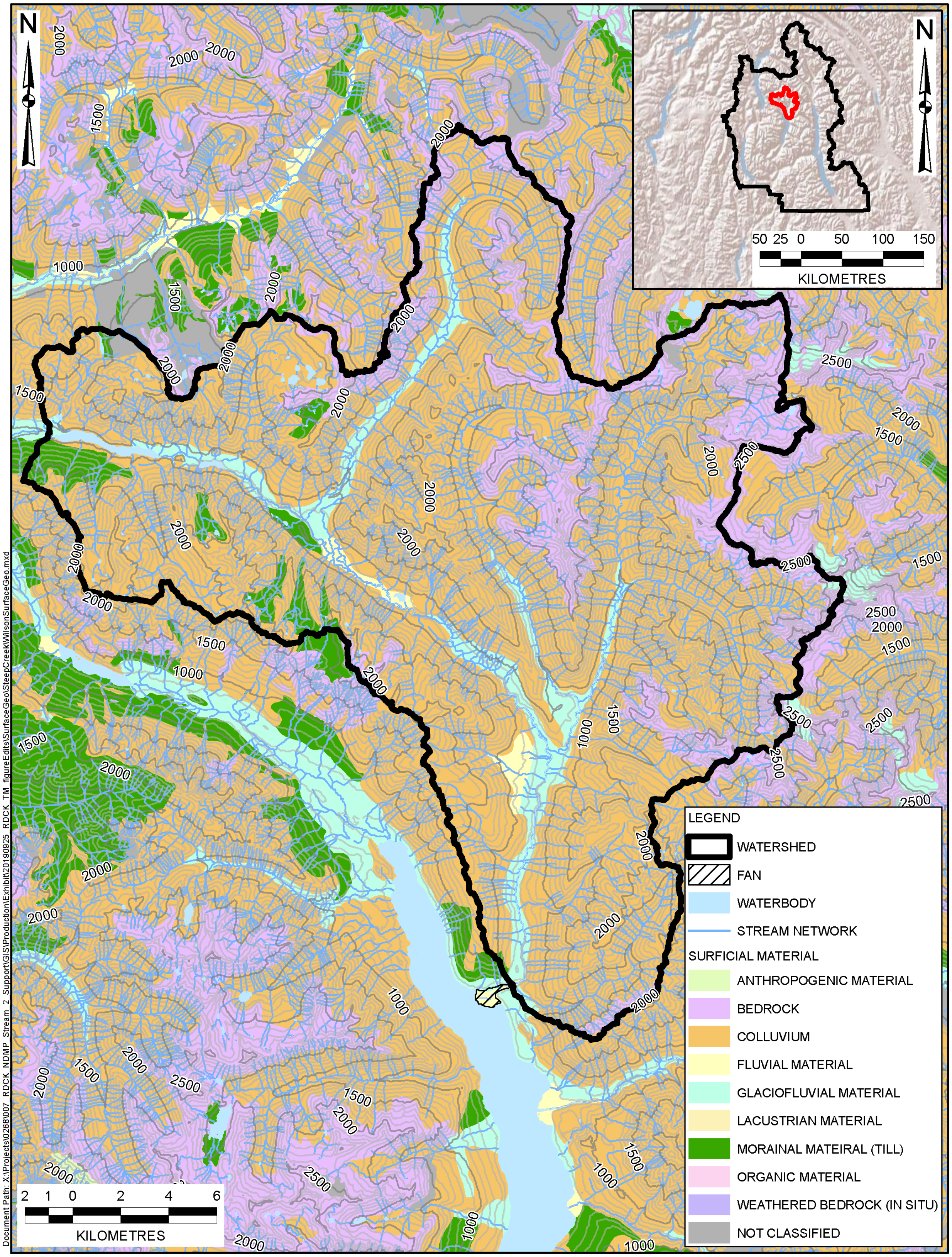

Figure 3-1. Surficial geology of the Wilson Creek watershed (from Province of BC, 2016).

3.4. Geomorphology

3.4.1. Watershed

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

The Wilson Creek watershed covers an area of 580 km^2, making it the largest of any of the steep creeks assessed as part of this Stream 2 study (Table 3-1). The watershed is branched and follows multiple tributary creeks that drain mountainous slopes of the Goat Range (Drawings 03, 05). The headwaters of the Wilson Creek mainstem are located on the mountainous slopes of Cascade Mountain (approximate elevation of 2,930 m) and Mount Marion (2,900 m). Moving downstream from the headwaters, Wilson Creek is joined by Keene Creek, which in combination with Rossland Creek drain the western slopes of Mount Stubbs (2780 m) and Mount Cooper (3,090 m) (A on Drawings 03, 05). Downstream, Burkitt Creek joins form the west (B on Drawings 03, 05). Approximately 1.5 km downstream of the confluence with Burkitt Creek, Monitor Creek that, together with Dixie Creek, drains the western slopes of Mount Dolly Varden (2625 m), joins the Wilson Creek mainstem (C on Drawings 03, 05).

A further 1 km downstream, Fitzstubbs Creek joins from the west (D on Drawings 03, 05). Fitzstubbs Creek is an approximately 30 km long tributary west of the Wilson Creek mainstem that connects Kimbol Lake, Horseshoe Lake, Wilson Lake, and Little Wilson Lake on the far western reaches of the watershed. Hamling Creek connects Hamling Lakes to Fitzstubbs Creek farther east. Bremner Creek drains the southern slopes of an unnamed mountain and joins Fitzstubbs Creek. The north-facing slopes of Mount Ferrie (2370 m) drain towards Fitzstubbs Creek. Downstream of Fitzstubbs Creek, Ranch Creek joins the Wilson Creek mainstem from the west (E on Drawings 03, 05). Immediately downstream of the Wilson Creek fan-apex, Dennis Creek joins from the east (F on Drawings 03, 05).

The upper portions of the Wilson Creek watershed are characterized by an alpine environment that transitions to wide U-shaped valleys. Several small lakes (e.g., Wilson Lake, Little Wilson Lake) are present on flatter portions of the tributary valleys. Smaller lakes are present in the upper reaches of tributary creeks (e.g., Hamling Lakes, Kimbol Lake). Wilson Creek and its main tributaries (Fitzstubbs Creek and Burkitt Creek) have wide alluvial channels throughout the watershed. There are areas of active rock fall and slope instability that contribute sediment to the main channel as well as debris flow tributaries coming down the steep valley walls (Drawing 05). The main channel throughout the watershed has a low gradient (<10°) with an average gradient of 6.5% (Table 3-1) (Drawing 03). BGC categorizes it as a supply unlimited system.

Large portions of the upper watershed are part of the Goat Range Provincial Park and the Hamling Lakes Wildlife Management Area (Drawing 01). The lower half of the watershed has been extensively logged (Drawing 05), accounting for approximately 9% of the total watershed area having been logged since 1900. There is evidence of logging road failures throughout the logged portion of the watershed. Approximately 34% of the watershed area has burned since 1919, with the largest forest fire recorded in 1940 (FLNRORD, 2019a; 2019b).

Table 3-1. Watershed characteristics of Wilson Creek.

Characteristic	Value
Watershed area (km^2)	580
Fan-delta area (km^2)	0.64
Active fan-delta area (km^2)[1]	0.70
Maximum watershed elevation (m)	3,090
Minimum watershed elevation (m)	560
Watershed relief (m)	2,530
Melton Ratio[2]	0.1
Average channel gradient of mainstem above fan apex (%)	6.5
Average channel gradient on fan (%)	2.0
Average fan gradient (%)	10

Notes:

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

3.4.2. Wilson Creek Fan-Delta

An overview of the Wilson Creek watershed and fan-delta is shown on Drawings 02A, and 02B. Drawing 06 shows geomorphic features on the fan-delta. Locations referred to in the text below are labelled on these drawings. The fan areas delineated in the drawings have been interpreted by BGC based on lidar and field data.

Wilson Creek flows westerly across the fan that extends into Slocan Lake. The northern side of the fan contains Rosebery Provincial Park and the north west distal fan contains the Rosebery Parklands Regional Park. The remaining lower portion of the fan contains the unincorporated community of Rosebery. The active channel ranges from 25 to 30 m wide on the fan. The average channel gradient decreases from approximately 4% at the fan apex to approximately 2% near the channel outlet.

Just downstream of the fan apex, Dennis Creek, a sediment heavy tributary, joins the main channel increasing the sediment load to the fan. Wilson Creek is a braided channel with several bars in the main channel on the fan. The upper fan is flanked by steep sided glacial terraces that the channel is eroding into where the channel flows along the slope toe. On the left (south) bank, the terraces have a stepped structure where the first terrace is approximately 9 m above the channel, followed by a second terrace approximately 20 m above the channel and then a larger steep sided glaciofluvial terrace approximately 60 m above the channel. On the right (north bank) the channel has eroded the lower terraces and the upper terraces is approximately 40 m above the channel. Wilson Creek flows into Slocan Lake in an approximately 130 m wide reach.

There are multiple avulsion channels from the proximal to distal fan where overland flow is possible in clearwater and debris-flood events. At mid-fan, there are several avulsion channels representing abandoned meander bends (Drawing 06) where there is potential for channel bank overtopping.

BGC looked for evidence of submerged fan-delta (historical air photos and ortho imageries) but did not observe any. However, to be conservative, the 10% allowance for submerged fan-delta aerial extent applied to all steep creeks in the RDCK is applied here as well (Table 3-1).

3.4.3. Steep Creek Process

Figure 3-2 illustrates the Melton ratio and watershed geomorphic measurements for Wilson Creek against a larger dataset of steep creeks in B.C. and Alberta. These parameters can indicate the tendency of a creek to produce floods, debris floods or debris flows. Wilson Creek plots in the data cluster prone to floods. Based on this data and from historical and field evidence, BGC assessed potential hazards arising from a range of possible steep creek processes, including floods and debris floods.

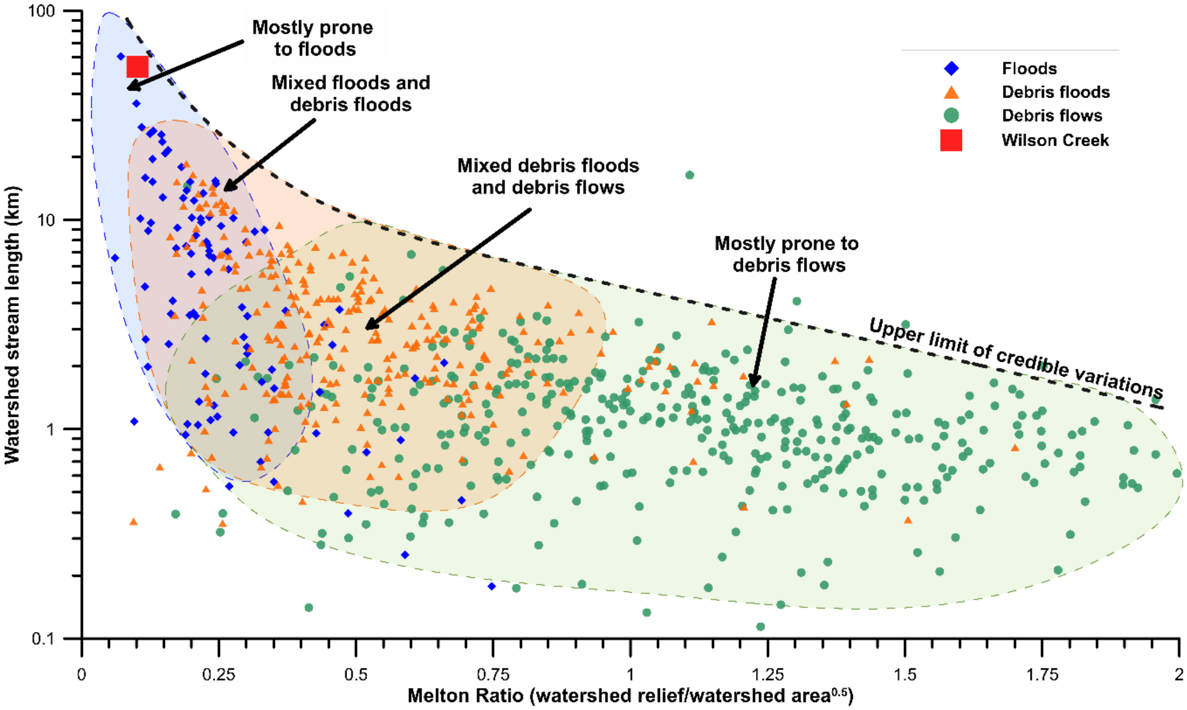

Figure 3-2. Tendency of creeks to produce floods, debris floods and debris flows, as a function of Melton Ratio and stream length (data from Holm et al., 2016 and Lau, 2017). See Section 3.4.1 for Wilson Creek watershed data.

Debris floods can be subdivided into three types, those triggered by the exceedance of a critical bed shear stress threshold (Type 1), those through transitions from debris flows (Type 2), and those triggered from outbreak floods (Type 3) (Section 1 of Methodology Report (BGC, March 31, 2020b). This differentiation is not included in the above plot as such nuances are unknown for the data included above; however, it is included in this detailed assessment. See Section 6.1 for further details on selection of hydrogeomorphic process for hazard analysis.

3.5. Existing Development

Development on the Wilson Creek fan-delta comprises a small community on both sides of the creek, north and south of Highway 6 (Drawings 02A, 02B). Roseberry Provincial Park is located on the west side of Wilson Creek, north Highway 6. Rosebery Parklands Regional Park is located north of Wilson Creek on the distal fan.

The community is described as a lakeside community of summer homes, retiree's and a few locals (Slocan Valley Economic Development Commission, 2020). The 2016 census does not have a population estimate for Rosebery and instead groups the community into the RDCK electoral area (Statistics Canada, 2016). The estimated total improvement value of parcels intersecting the Wilson Creek fan based on the 2018 BC Assessment Data is $10,094,500 (BGC, March 31, 2019).

3.5.1. Bridges

Wilson Creek passes under two bridges on the fan-delta. (Table 3-2, Figure 3-3). Bridge locations are shown on Drawings 02A, 02B. The Highway 6 bridge (Figure 3-3A to C) is at mid-fan. The Wilson Creek channel gradient decreases from approximately 4% upstream of the bridge to approximately 2% when the river turns west towards the outlet.

Approximately 0.5 km downstream of the Wilson Highway Bridge, Wilson Creek passes under an old rail bridge that is now part of the Nakusp and Slocan Railway Trail (Figure 3-3 D-E, Drawings 02A, 02B). The bridge has a concrete abutment on the left bank and wooden cribbing on the right bank at the approximate width of the active channel.

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

Bridge	Span	Height Above Channel Center (m)	Notes
Wilson Highway Bridge	55	4.6	Highway 6
Nakusp and Slocan Railway Trail Bridge	24	4.8	Downstream of Wilson Highway Bridge

Note: The bridge dimensions were either taken in the field or estimated from site photographs and lidar using typical dimensions for the size of road, if required.

A) Looking downstream at Wilson Highway Bridge.

B) Mid channel, looking at left bank at rip rap armouring.

C) Looking downstream at right bank at rip rap armouring.

D) On right bank looking upstream at the Nakusp and Slocan Railway Trail bridge.

E) Nakusp and Slocan Railway Trail bridge deck.

F) On right bank looking at the Nakusp and Slocan Railway Trail Bridge left bank abutment.

G) On right bank looking at the Nakusp and Slocan Railway Trail Bridge right bank abutment.

Figure 3-3. Highway 6 bridge (A – C) and old rail bridge (D-G) over Wilson Creek. BGC photos taken July 26, 2019.

Upstream of the Nakusp and Slocan Trail Railway Bridge, the right bank is elevated on a terrace as evident in the lidar (Drawings 02A, 02B).

3.5.2. Flood Protection Structures

The iMapBC Flood Protection Structural Works layer, as well as the field visit in July 2019, concluded that there is no flood protection, only bank protection at the highway bridge abutments the railway bridge abutments and approximately 185 m upstream of the bridge on the left bank. Drawings 02A, 02B show the approximate extent of the upstream protection, determined from field observations and assumed from alignment of East Wilson Creek Road. Rounded material up to approximately 0.7 m in diameter has been placed along the left bank to prevent erosion for approximately 100 m where the road runs along the creek (Appendix B-Photo 8 & 9). This material appears to be slumping in sections. The abutments of both bridges also provide bank protection along Wilson Creek (Figure 3-3A to F). Failure of any of these structures was not included in the numerical modelling scenarios, described in Section 6.5.

In the late 1970s to early 1980s, a 300 m berm was constructed as a condition of subdivision approval to protect properties on the southern distal fan and extensive fill was used to raise the ground level on several lots to accommodate the lake flood construction level (Dwain Boyer, personal communication, April 23, 2020). BGC inspected this berm to determine if any erosion protection was in place that would merit inclusion in the numerical modelling; however, none was observed.

3.6. Hydroclimatic Conditions

3.6.1. Existing Conditions

Climate normal[3] data were obtained from Environment and Climate Change Canada's New Denver weather station (568 m), located approximately 5 km south of the Wilson Creek outlet (Environment and Climate Change Canada, n.d.). Daily precipitation and temperature data are available from 1924 to 2015. Figure 3-4 shows the average monthly temperature and precipitation for this station from the 1981 to 2010 climate normals. Precipitation (rain and snow) peaks in November, though average rainfall values are slightly lower in June. The total annual precipitation is 873 mm, as summarized in Table 3-3.

The measured precipitation at the New Denver weather station is lower than the actual precipitation in the Wilson Creek watershed, where the mountaintops extend more than 2500 m above Slocan Lake. This is due to orographic effects, which occur when an air mass is forced up over rising terrain from lower elevations. As it gains altitude it quickly cools down, the water vapour condenses (forming clouds), ultimately resulting in precipitation

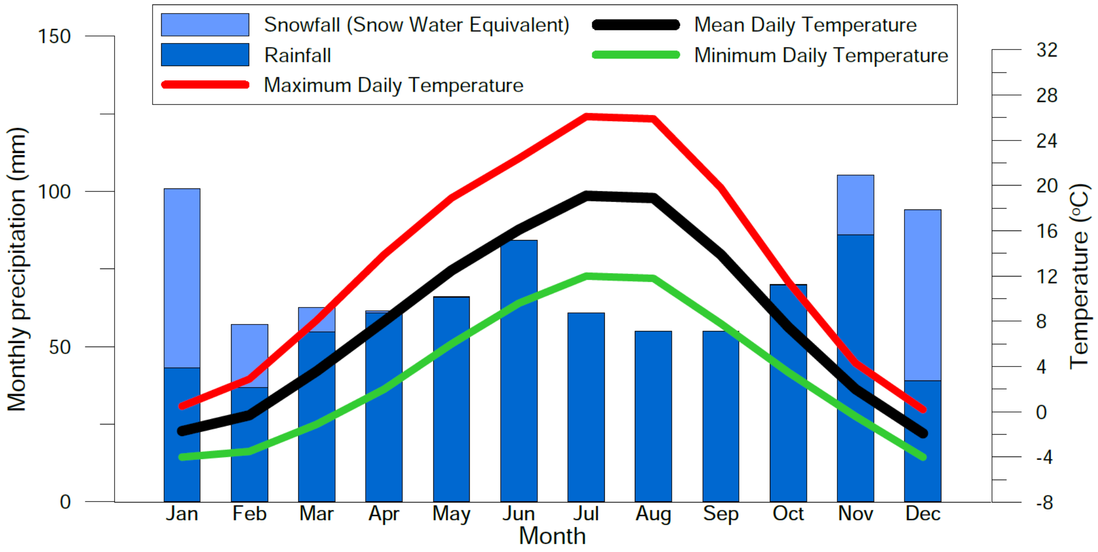

Figure 3-4. Climate normal data for New Denver station from 1981 to 2010.

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

Table 3-3. Annual total of climate normal data for New Denver weather station from 1981 to 2010.

Variable	Annual Total	Percent of total annual precipitation (%)
Rainfall (mm)	712	81
Snowfall (cm)	161	19
Precipitation (mm)	873	100

To understand the regional distribution of precipitation and snowfall patterns and supplement the data from the New Denver station, BGC obtained climate data based on the CRU-TS 3.22 dataset (Mitchell & Jones, 2005) for the period 1961-1990. This dataset was generated with the ClimateNA v5.10 software package, available at *http://tinyurl.com/ClimateNA*, based on methodologies described by Wang et al. (2016). The historical Mean Annual Precipitation (MAP) over the watershed is 1400 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 823 mm. PAS increases with elevation; therefore, Wilson Creek watershed accumulates greater precipitation falling as snow compared to the New Denver weather station.

3.6.2. Climate Change Impacts

The watershed lies within the Central Columbia Mountain ecosection of the Northern Columbia Mountains ecoregion. Extreme flood events in this region are often associated with rain-on-snow events in the spring (Harder et al., 2015). Although the effects of climate change on precipitation are not clear, projected increases in temperature are expected to have the largest impact on annual minimum temperatures occurring in the winter months (Harder et al., 2015).

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

The Climate NA model provides downscaled climate projections for future conditions (Wang et al., 2016). The projections based on the Representative Carbon Pathway (RCP) 8.5 indicate that the mean annual temperature (MAT) in the Wilson Creek watershed is projected to increase from 2.1ºC (historical period 1961 to 1990) to 5.7ºC by 2050 (average for projected period 2041 to 2070). The MAP is projected to increase from 1400 mm to 1489 mm while PAS is projected to decrease from 823 mm to 577 mm by 2050 in the Wilson Creek watershed. Projected change in climate variables from historical conditions for the Wilson Creek watershed are presented in Table 3-4.

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

Table 3-4. Projected change (RCP 8.5, 2050) from historical (1961 to 1990) conditions for the Wilson Creek watershed (Wang et al., 2016).

Climate Variable	Projected Change
Mean Annual Temperature (MAT)	+3.5 ºC
Mean Annual Precipitation (MAP)	+89 mm
Precipitation as Snow (PAS)	-246 mm

4. SITE HISTORY

4.1. Introduction

Wilson Creek flows through the community of Rosebery and into Slocan Lake. Residents have lived on the fan-delta since the late 1800s. The townsite has historically served as an important railway link between Slocan Lake and Lower Arrow Lake (Nakusp).

4.2. Document Review

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

- Archival records from the BC Archives, Nelson Touchstone Museum, and Lower Arrow Lake Historical Society.
- Reports provided to BGC by RDCK (Table 4-1), including:
    - Precondition applications (building permit, subdivision, and site-specific exemptions, etc.).
    - Hazard assessments (flooding, post-fire, etc.).
- Reports provided to BGC by Ministry of Forests, Lands, Natural Resource Operations and Rural Development (MFLNRORD) (Table 4-1).
- Historical flood and landslide events from the following sources:
    - Social media and online media reports.
    - Septer (2007).
    - DriveBC historical events (2009 to 2017), (MoTI, 2019).
    - Canadian Disaster Database (Public Safety Canada, n.d.).
    - MFLNRORD.
- 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. 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 Wilson Creek.

Year	Month/Day	Source	Purpose
1972	June	Water Resources Branch (BC Government)	Flood survey report
1988	June	Integrated Hydropedology	Debris flow report
1994	January	Northwest Hydraulic Consultants Ltd.	Flooding and erosion assessment
1999	May 4	Nelson Forest Region	Hazard Assessment
2001	July 23	Fletcher Associates Engineering	Precondition for Subdivision
2002	December 12	Intermountain Engineering & Surveying Ltd.	Precondition for Building Permit
2005	June 21	Intermountain Engineering & Surveying Ltd.	Precondition for Building Permit
2006	July 24	Klohn Crippen Berger Ltd.	Precondition for Site-specific Exemption
2006	November 6	WSA Engineering Ltd.	Precondition for Site-specific Exemption
2006	November 16	WSA Engineering Ltd.	Precondition for Site-specific Exemption
2011	April 30	Deverney Engineering Services Ltd.	Precondition for Building Permit
2014	November 26	Perdue Geotechnical Services	Precondition for Building Permit
2016	September 19	Lasca Group Technical Services Ltd.	Precondition for Subdivision
2018	September	Austin Engineering	Precondition for Subdivision

4.2.1. NHC (1994)

In 1994, Northwest Hydraulics Consultants (NHC) completed an assessment of flooding and erosion on the Wilson Creek fan-delta for a property (Lot #39). The property is located on the north side of Wilson Creek near the Nakusp and Slocan Railway Trail Bridge. NHC assessed that the railway bridge had sufficient capacity to pass a 200-year return period clearwater flood without overtopping the bridge or the railway embankment. NHC did not note any bulking for sediment or woody debris. BGC notes that NHC (1994) used a larger bridge span than BGC measured in the field and verified from lidar (Table 3-2).

Upstream of the railway bridge, NHC assessed that avulsions to the left (south) was likely between the highway bridge and railway bridge but that flow would likely return to the channel. BGC's estimate of peak discharges is included in Section 6.3.

4.2.2. Intermountain Engineering & Surveying (2002)

A previous assessment of a property located on the north side of Stewart Creek downstream of the Nakusp and Slocan Railway Trail Bridge in the distal fan-delta evaluated that a "debris torrent" was unlikely due to the location on the fan and the gentle slope of the property. Moreover, this assessment concurred or used NHC's (1994) evaluation that the railway bridge would pass the 200-year return period event (Intermontain Engineering & Surveying, 2002).

4.2.3. Intermountain Engineering & Surveying (2005)

A previous assessment of a property located on the Derosa Drive (Lot 1, Plan 10379) on the south side of the Wilson Creek fan-delta downstream of the Nakusp and Slocan Railway Trail Bridge evaluated that a "debris torrent" was unlikely due to the location on the fan and the gentle slope of the property. Moreover, this assessment concurred or used NHC's (1994) evaluation that the railway bridge would pass the 200-year return period event (Intermountain Engineering & Surveying, 2005). Any overland flow was expected on the east side of the property.

4.2.4. Klohn Crippen Berger (2006)

As part of a site-specific flood hazard assessment for a property on the north side of Wilson Creek between the two bridges on the fan, Klohn Cripper Berger (KCB) completed a site visit and reviewed past reports for Wilson Creek. Their findings include that Wilson Creek has remained in its present channel with relatively stable banks for the past 80 years. They also noted erosion on the north bank of the creek upstream of the former highway crossing (Drawing 04A). The assessment also referred to the potential for Wilson Creek to overtop the banks on the south side into avulsion channels (mapped on Drawing 06) (KCB, 2006).

4.2.5. WSA Engineering (2006), Deverney Engineering Services Ltd (2011)

In 2006, WSA Engineering completed two geotechnical site assessments for properties along Wilson Creek where applications to relax the setback from 15 m to 30 m were submitted. The first property is on the left (southern) bank of Wilson Creek upstream of the Nakusp Slocan Railway Trail Bridge. The assessment deemed that the lot was not subject to a significant erosion hazard form Wilson Creek and a 15 m setback was deemed appropriate (WSA, November 6, 2006).

The second property is located along the left (east) bank of Wilson Creek immediately downstream of Highway 6. At the time of inspection, no significant signs of bank erosion nor was evidence of bank observed in the air photo record by WSA. WSA (November 16, 2006) assessed the likelihood of Wilson Creek breaching its left (eastern) bank and inundating as Moderate (greater than 10% chance of occurrence within a 50-year period). WSA recommended that the 30 m setback be maintained and building foundations on the property be designed by a Geotechnical Engineer to withstand shallow flooding and low to moderate flow velocities (WSA, November 16, 2006).

The latter property was re-assessed by Deverney Engineering Services Ltd. in 2011 (Deverney, 2011). Deverney assessed that channel changes in Wilson Creek could be expected during an event with a return period of approximately 100 years given the maturity of trees and vegetation in the abandoned channel east of the main channel downstream of Highway 6. Deverney recommended installation of erosion protection in the form of rip rap on the west, north and south sides of the proposed building site. Further, Deverney assessed that high flows in Wilson Creek could generate low velocity overbank flooding up to a depth of 3 m above the natural boundary of

Wilson Creek and thus re-iterated WSA's recommendation for floodproofing of the foundation (WSA, November 16, 2006).

BGC's bank erosion assessment results are outlined in Section 6.6.

4.2.6. Perdue Geotechnical Services (2014)

Perdue Geotechnical Services (Perdue) completed a geotechnical site inspection of the west-most triangular shaped property on the lakeshore of Slocan Lake south of Stewart St (Drawings 02A, 02B, 06). Perdue identified a man-made berm built with coarse material that measures approximately 300 m long and 4 m higher than the adjacent terrain on the north side of the berm that protects properties on the southern distal fan. At the time of writing, the age and method of construction of the berm was unknown. Perdue also determined that Rosebery Rd, that runs approximately north-south downstream of Highway 6, acts as a berm to contain flows to the west side. However, Perdue identified an approximately 50 m long opening between these two berms at the junction of the old Nakusp and Slocan Railway and Rosebery Road where flows could travel in a large event.

Perdue evaluated the potential for the property in question to be affected by debris-flood and clearwater flood events. Based on the size of the Wilson Creek fan-delta relative to the Wilson Creek watershed and the Melton Ratio, Perdue assessed that debris-flood events and bed migration occur at a low frequency, and consequently the likelihood of a debris flood affecting the property in question was considered to be unlikely. Clearwater flood impacts were assessed using a climate-adjusted peak discharge of 416 m^3/s. Perdue determined that the property in question was likely to be affected by clearwater floods at the 200-year return period. BGC's assessment of peak discharges is outlined in Section 6.3 and modelling results are included in Section 6.5.

4.2.7. Lasca Group (2016), Austin Engineering (2018)

In 2016, Lasca Group completed a geotechnical site visit on 153 Rosebery Road. The property is comprised of three unconnected parcels: on the triangular parcel immediately west of Rosebery Road and south of Highway 6, and the two parcels immediately west of Rosebery Road (Drawings 02A, 02B, 06). The results of the assessment indicated that no flood events would overflow on to the property. Moreover, Lasca categorized the risk of an "alluvial fan flood" on Wilson Creek to be "very low" due to the "causeway dam effect" of Highway 6 and Rosebery Road on the property in question (Lasca, 2016).

A second assessment of the property was completed by Austin Engineering in 2017 (Austin, 2018). As part of the assessment, Lasca described test trenches on the property. The descriptions do not make reference to past hydrogeomorphic event deposits, but this does not appear to have been the focus of the assessment at the time and therefore cannot be conclusively relied upon. Austin completed a multi-hazard assessment including hazards from Slocan Lake, Wilson Creek and instability from the slope above Highway 6, and the highway embankment including stability modelling, and earthquakes. Overall, Austin determined that flooding, landslides, and debris flow hazards are extremely unlikely hazards at this location.

4.3. Historic Timeline

Figure 4-1 provides a timeline summary of floods and mitigation history for Wilson 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:

- One notable hydrogeomorphic event was recorded in 1972. BGC notes that other hydrogeomorphic events may have occurred that may not be documented by the available records.
- Log jams have been reported in Wilson Creek on the fan-delta.
- The channel location has historically been relatively stable on the fan-delta.
- Extensive logging has occurred in the watershed. These activities are concentrated within approximately 15 km of the fan apex and in the northeast portion of the upper watershed. Landslides have occurred from forestry roads and cut blocks.
- Several large forest fires have burned large areas of the watershed.

Geohazard History

Wilson Creek north of Rosebery, May 23, 1971 (Courtesy of Arrow Lakes Historical Society, 1999.019.1065)

Bridge over Wilson Creek, Canadian Pacific (Nakusp & Slocan) Railway, Rosebery, ca. early 20th century (Courtesy of Arrow Lakes Historical Society, 2000.035.45)

June 8, 2011 - Log jam and possible avulsion downstream from Wilson Highway Bridge (FLNRO hazard report database). Location appears to be near right bank of Nakusp and Slocan Railway Trail Bridge

July 16, 2007 - Moderate log jam downstream of Wilson Highway Bridge caused significant undercutting of stream right bank immediately downstream of Wilson Highway Bridge

October 2002 - Log jam in creek (FLNRO Hazard report database). Location appears to be approximately 250 m upstream from Wilson Highway Bridge

April 26, 1999 - Debris flow originated from Jeanette Road (forestry road) that deposited sediment into Wilson Creek

April 18, 1988 - Debris flow originated from logging road on "Ranch Ridge" (approximately 5 km upstream of fan apex); sediment entered Wilson Creek

1973 - Lightning-caused wildfire burned approximately 2,800 ha in watershed

June 1972 - Flooding caused erosion on north bank of creek between old bridge (constructed 1907 and new bridge (Wilson Highway Bridge) under construction at the time of the flood

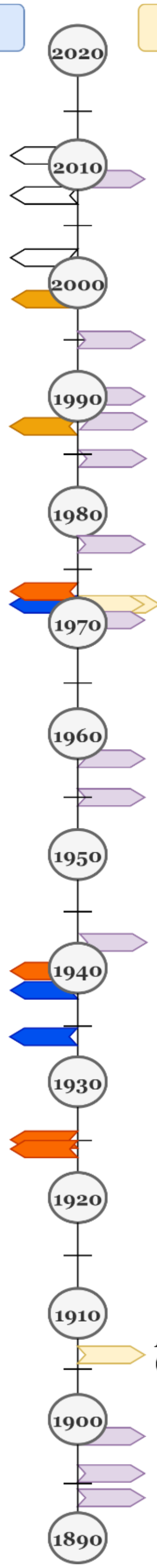
1940 - Lightning-caused wildfire burned approximately 7,700 ha in watershed

Pre-1939s - Fresh sediment deposit is visible in the 1939 air photo

1934 - Flood event on Wilson Creek

July 1925 - Sparks from CP Rail train ignited fire near Summit Lake, spreading to Wilson Creek causing damage to property, logging equipment, and railcars

1924 - Lightning-caused wildfire burned approximately 4,000 ha in watershed



Mitigation

1972 - Highway straightened and new Wilson Highway Bridge constructed across channel

June 1972 - BC Hydro poles riprapped during flood

April 1907 - Steel bridge constructed over Wilson Creek (approx. 320 m upstream from current Wilson Highway Bridge)

Development

2009 - Rosebery Parklands property transferred to RDCK and Rosebery Parklands Regional Park established at the mouth of Wilson Creek

July 1995 - Goat Range Provincial Park established in the upper watershed

1990 - Rosebery Parklands Development Society created the Rosebery Parklands at the mouth of Wilson Creek

Late 1980s - Rail service between Nakusp and Rosebery discontinued and rail barge dock at Rosebery deconstructed

Mid 1980s to Mid 2000s - Logging in lower watershed

Mid to Late 1970s - Logging in northeast upper watershed

Early 1970s - Logging in lower watershed

July 27, 1959 - Rosebery Provincial Park established on the banks of Wilson Creek

1955 - SS Rosebery sailed last trip between Rosebery and Slocan

1940s - Rosebery interment camp established on the Wilson Creek fan during WWII; held more than 350 Japanese Canadians

August 1899 - Construction of new government-built trail up Wilson Creek completed

Mid 1890s - Rail barge dock constructed at Rosebery

1894 - Wilson Creek townsite surveyed and renamed Rosebery

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

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

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

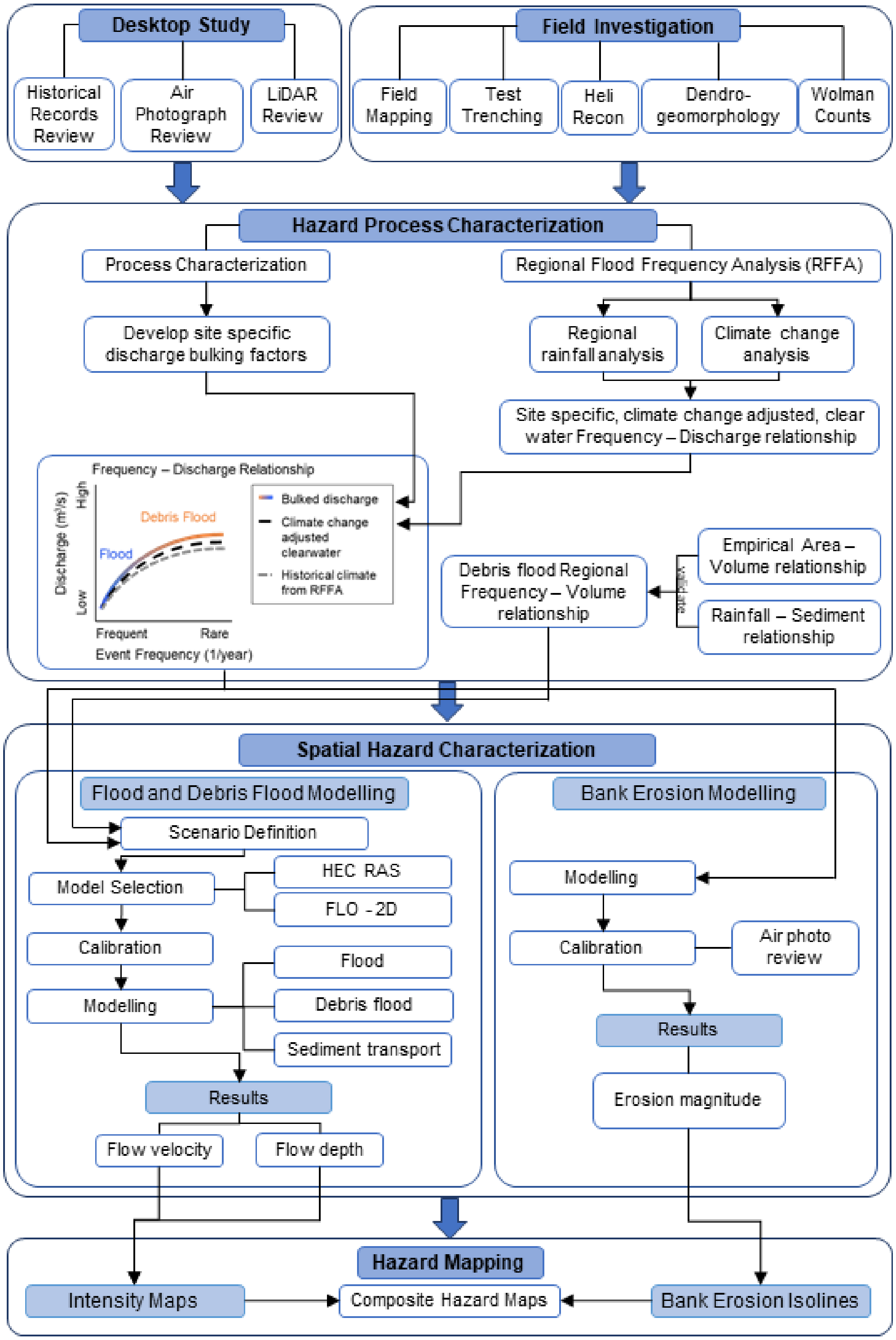


Figure 5-1. Flood and debris flood prone steep creeks workflow used for developing frequency-magnitude relationships, modelling, and preparing hazard maps.

5.1. Debris Flood Frequency Assessment – Air Photo Interpretation

At Wilson Creek, air photo interpretation was used to estimate debris-flood frequencies. Air photos dated between 1939 and 2015 were examined for evidence of past sediment transport events on Wilson Creek. A complete list of the air photos reviewed is included in Appendix D. Events were identified from the appearance of bright areas and disturbed vegetation relative to previous air photos. Smaller events that did not deposit sediment outside the channel or significantly change the course of the channel are not captured in this analysis. Similarly, events that occurred during large gaps between air photos or successive events that overlap may not be captured. Air photo interpretation was supplemented by historical records of past events (Figure 4-1).

5.2. Peak Discharge Estimates

5.2.1. Clearwater Peak Discharge Estimation

There are no hydrometric stations on Wilson 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., Intermountain Engineering & Services Ltd. 2005, Klohn Crippen Berger Ltd. 2006, Perdue Geotechnical Service Ltd. 2014, and Austen Engineering Ltd. 2018). Based on its watershed characteristics, the Wilson Creek watershed was assigned to the '1 West hydrologic region for watersheds more than 500 km^2'. Details of the Regional FFA are presented in Section 3 of the Methodology Report (BGC, March 31, 2020b).

5.2.2. Climate-Change Adjusted Peak Discharges

The Engineers and Geoscientists British Columbia (EGBC) offer guidelines that include procedures to account for climate change when flood magnitudes for protective works or mitigation procedures are required (EGBC, 2018). The impacts of climate change on peak discharge estimates in Wilson 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 (MAP, MAT, and PAS) 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[4], 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 Wilson 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 (see Section 6.1). Because the debris-flood events will carry sediment and woody debris, the climate adjusted clearwater discharges need to be bulked accordingly. To produce a bulked frequency-discharge relationship, a bulking factor was applied to the peak discharge for each return period, based on sediment availability and debris-flood process type. The bulked frequency-discharge relationship was then used in numerical runout modelling.

Another measure for magnitude is sediment volume. While sediment volume is less useful as input to numerical modelling, it is helpful to verify sediment deposition predicted by the model. Therefore, a regional frequency-volume relationship was applied to compare to numerical modelling results and a well-known empirical sediment transport equation for steep creeks (Jakob et al., 2016; Jakob et al., submitted; Rickenmann, 2001). 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 modelled 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). Hydraulic modelling was done with HEC-RAS 2D (Version 5.0.7). HEC-RAS is a public domain hydraulic modelling program developed and supported by the United States Army Corps of Engineers (Brunner & CEIWR-HEC, 2016). It was used to model clearwater floods.

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

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

Table 5-1. Summary of numerical modelling inputs.

Variable	HEC-RAS
Topographic Input	Lidar (2018)
Grid cells	Variable (5- 10 m)
Manning' n	0.06 (channel), 0.02 (main roads), 0.1 (fan)
Upstream boundary condition	Steady Flow (Q_{20} and Q_{50})
Downstream boundary condition	Steady stage at Slocan Lake (538.0 m)

Note: The downstream boundary condition is a 20-year lake elevation based on daily maximums, determined from data at Slocan Lake at Slocan City (08NJ137)

The base topographic data used to develop a digital elevation model (DEM) for the HEC-RAS 2D model was lidar data acquired on July 21, 2018. BGC reviewed topographic data to evaluate the streamflow at the time of lidar acquisition. This was done as the lidar returns bounce off water surfaces and in the absence of a supplementary channel survey, the resultant DEM would have a reduced channel capacity. On review of the topographic data, streamflow in Wilson Creek appeared to have been low at the time of lidar acquisition.

A series of modelling scenarios were developed for Wilson 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.

Modelling results show inundation areas for various return periods and scenarios. As per the methods outlined in Section 2 of the Methodology Report (BGC, March 31, 2020b), sediment transport modelling in FLO-2D (Version 19.07.21).) was applied where sediment concentrations were 10%. Sediment transport models for the 200- and 500-year events were completed, however, given the size of the watershed and peak discharges the sediment volumes transported in the models were found to be unrealistic given available geological and historical records for the area. For this reason, the HEC-RAS results were relied upon for the 200- and 500-year return periods. As for other creeks studied in detail as part of the Stream 2 study, the hazards maps will need to be updated after major floods as those could lead to severe aggradation and/or bank erosion.

As the objective of this study was a hazard assessment, BGC did not attempt to assign conditional probabilities to each hazard 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 five creek cross-sections between the fan apex and the mouth of the creek. The assessment methods are outlined in Section 2 of the Methodology Report (BGC, March 31, 2020b). Sediment size sample results used as inputs to the modelling are included in Appendix C. The location of each bank erosion cross-section is delineated on Drawings 02A, 02B. Refer to Appendix D for the full list of air photos consulted during the calibration process.

5.6. Hazard Mapping

BGC prepared hazard maps based on the combined results from the numerical debris flood modelling and bank erosion assessment. Specifically, BGC prepared two types of steep creek hazard maps for Wilson 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 modelling.
2. Potential bank erosion extents.

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 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:

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

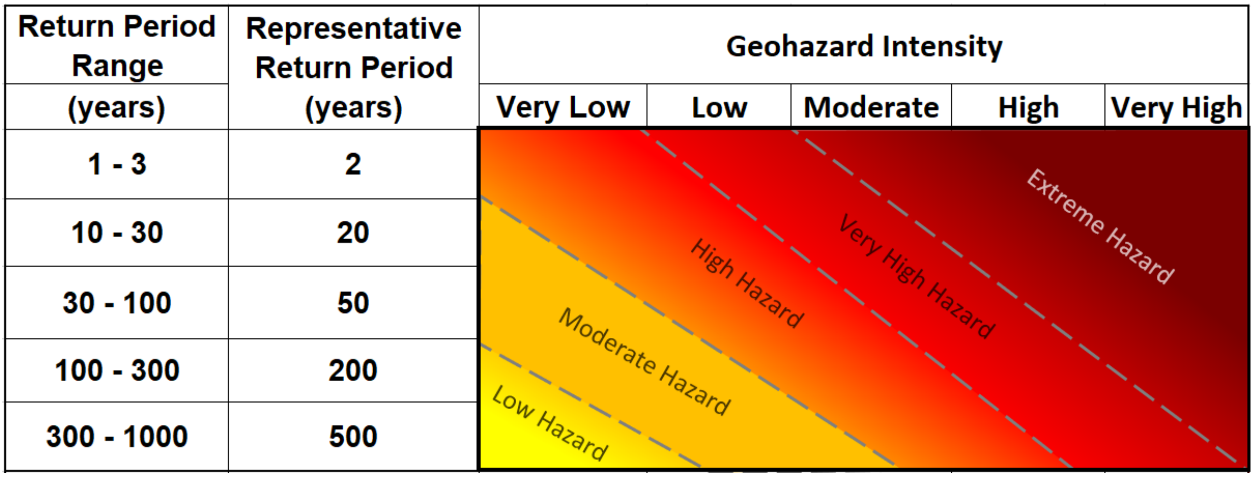
where v is flow velocity (m/s), ρ_f is the fluid density (kg/m^3) and d_f is the fluid's flow depth (m), to obtain a unit of force per metre flow width for the three left terms in Equation 5-1. $P(H)$ is the annual probability of the geohazard. The unit of IIF is then Newton or kilo Newton per metre per year (kN/m per yr). 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 Wilson 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	Representative Return Period	Geohazard Intensity				
(years)	(years)	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, it is expected that in most cases, orange, red and dark red zones will be confined to the channel where the highest flow depths and flow velocities will be encountered; however, with sufficient flows, avulsions and overbank flows with high flow depths and velocities are possible.

6. RESULTS

6.1. Hydrogeomorphic Process Characterization

Figure 3-2 indicates that Wilson Creek is mostly prone to floods. In evaluating the process type at Wilson Creek, BGC considered the following evidence:

- The average channel gradient of the Wilson Creek mainstem above the fan apex is 6.5% (Drawing 03), which is insufficient for sustained debris flow transport.
- Dennis Creek is a sediment laden tributary to Wilson Creek that joins the mainstem immediately downstream of the fan apex. Landslide headscarps, and debris avalanche and debris flow paths are evident along the channel walls. Dennis Creek is interpreted to have the potential to deliver substantial sediment to the Wilson Creek fan-delta.
- The average fan gradient of 10% is typical of creeks prone to debris floods.
- Accounts of previous flood events and analysis of historic air photos (see Section 6.2) are consistent with debris-flood activity due to associated erosion and observed movement of sediment in air photos.

Together, this evidence indicates that Wilson Creek is subject to supply-unlimited Type 1 debris floods for low return periods (20-year). At the 50-year return period, Wilson Creek is listed as Type 1/Type 2 given the ample sediment in the Dennis Creek tributary (Drawings 03, 05) and the uncertainty associated with the return period for a debris flow on that tributary. For higher return periods (50-, and 200-year), Type 2 (debris-flow transitional) debris floods are believed to be the dominant process. These can inject substantial volumes of debris leading to surging flow and higher sediment concentrations compared to Type 1 debris floods. BGC assesses that Type 3 debris floods may evolve where tributary debris flows impound Wilson Creek leading to outbreak floods when the fan at the bottom of tributaries are breached through overtopping and incision. There was no evidence of a contemporary fan or deposits associated with such an event, for this reason, BGC interprets that the peak discharge associated with such an event would not exceed the bulked discharge for the 500-year return period.

Should there be a large stand-replacing moderate to high intensity fire in the watershed, Type 3 debris floods are also conceivable, as moderate and high severity wildfires increase the likelihood and magnitude of tributary debris flows. Due to their higher magnitude, debris flows that are a result of forest fires are substantially more likely to impound Wilson Creek or one if its tributaries and form a temporary landslide dam followed by an outbreak flood. Given the size of the Wilson Creek watershed, the debris flow would need to be of sufficient size and sufficiently close to the Wilson Creek fan-delta. This potential scenario ought to be considered in the context of a detailed post-fire hazard assessment which BGC has not attempted

6.2. Debris Flood Frequency Assessment – Air Photo Interpretation

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

One notable hydrogeomorphic event was observed in the air photo record (1939 – 2015). The evidence was observed in the first air photo (1939) so the exact date of the event is unknown. An additional event in 1972 is known from historical records (Figure 4-1) but was not delineated in the air photos. Drawings 04A and 04B show air photos with the pre-1939 event delineated. The interpreted deposition area and characteristics of the sediment transport event are described in Table 6-1. BGC interprets that the pre-1939 event was likely a Type 1 debris flood due to the observed sediment deposition in the 1939 air photo. Using the Scheidl and Rickenmann (2010) relationship, BGC estimated that the depositional thickness of the pre-1939 event was approximately 0.6 m resulting in the estimated event volume of 48,000 m^3.

Table 6-1. Summary of Wilson Creek sediment transport events in air photo record (1939-2015).

Event Year[1]	Air Photo Year	Deposition Area (m^2)	Estimated Event Volume (m^3)	Event Characteristics
Pre-1939	1939	74,100	48,000	Fresh sediment in channel from fan apex to 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.

The two hydrogeomorphic events identified from air photo interpretation and historic records are summarized in Table 6-2. The air photo record also shows that Wilson Creek has held a relatively constant position over the past 80 years. A previous assessment (NHC, 1994) hypothesized that the Nakusp and Slocan Railway Trail Bridge has prevented channel avulsions and served to maintain the downstream path of Wilson Creek.

Table 6-2. Summary of past flood and debris flood events on Wilson Creek.

Event Year	Description
Pre-1939	Fresh sediment in channel from fan apex to outlet.
1972	Flooding caused erosion on north bank of creek between the old Highway bridge and the one under construction at the time of the flood. Evidence of this event was not observed in the air photo record (closest air photo date 1976).

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 6-3 and Figure 6-1. With respect to these results, the reader should note the following:

- Because there are no hydrometric stations on Wilson Creek, non-adjusted peak discharges (flood quantiles) were estimated using a Regional FFA. The regional index-flood model was selected because it is produced slightly higher peak flows than the provincial model.

- The historic peak discharge estimates based on the Regional FFA were adjusted by 20% to account for the projected impacts of climate change as per the Section 4 of the Methodology Report (BGC, March 31, 2020b).
- The climate-adjusted, bulked peak discharges were used in the numerical modelling.

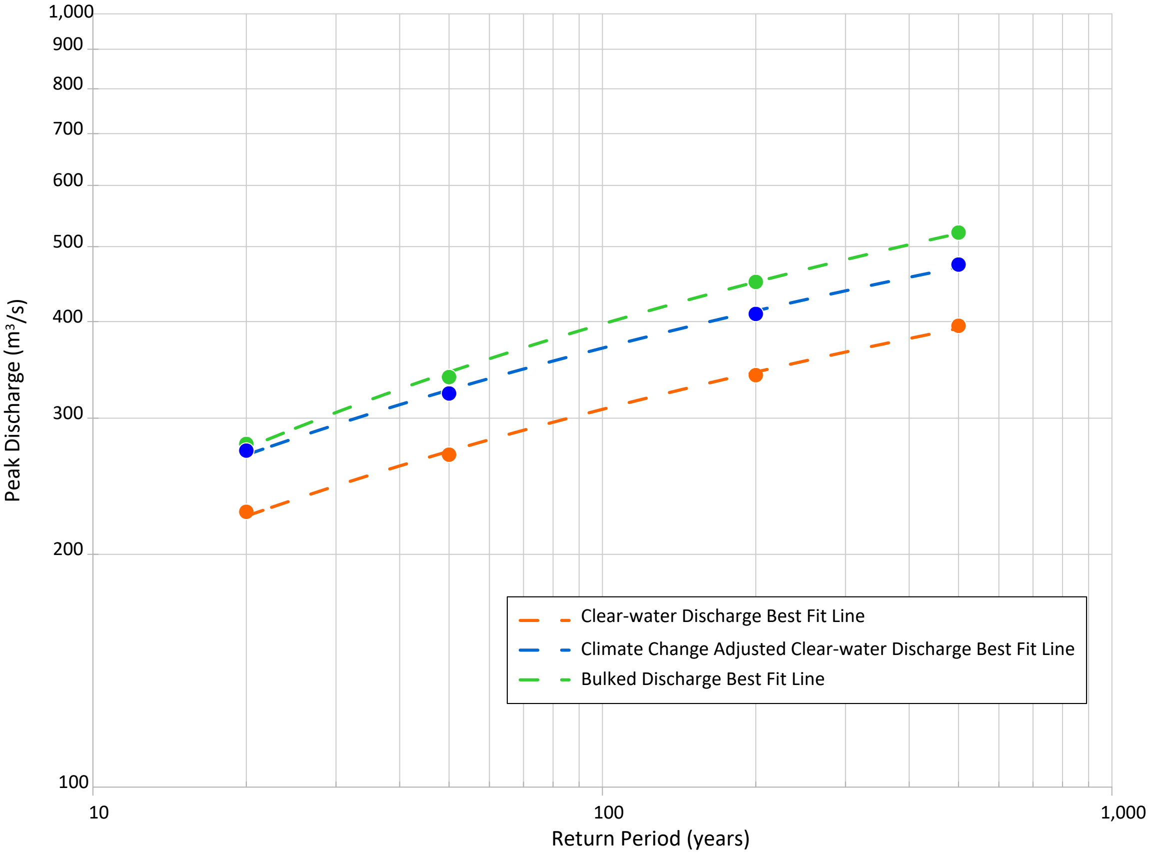


Figure 6-1. Frequency-discharge relationship for Wilson Creek.

Table 6-3. 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
20	0.05	227	272	1.02	280	1	Low activity along mainstem
50	0.02	260	323	1.05	340	1/2	Type 1 or Type 2 originating from Dennis Creek.
200	0.005	341	409	1.1	450	2	Dennis Creek tributary has potential for debris flows.
500	0.002	395	474	1.1	520	2	Dennis Creek tributary has potential for debris flows. The dearth of evidence from past Type 3 debris floods (outbreak floods) suggest that such events occur on return periods outside the range investigated.

Notes:

1. Refer to Section 2 of the Methodology Report (BGC, March 31, 2020b) for details on bulking method.
2. Although Wilson Creek is subject to Type 2 debris floods, BGC anticipates that due to the high discharge on the mainstem that the debris flows would be more diluted than other creeks in this study, hence the lower bulking factor for Type 2 debris floods.

6.4. Frequency-Volume Relationship

6.4.1. General

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

Debris volume results from the air photo analysis are shown in Table 6-1 and the results of the regional relationship and sediment transport equations are shown in Table 6-4. The volume estimates from the regional relationship are not credible given that they significantly overestimate event volumes that have not been replicated in the air photo record and are 4 to 5 times higher than those obtained from the Rickenmann (2001) sediment transport analysis.

This overestimate could be attributable to the regional relationship being developed from creeks that have watershed sizes less than 100 km^2. The application of this relationship to Wilson Creek (watershed area of 580 km^2) could also be inappropriate due to lack of data from creeks that have similar geomorphology.

Therefore, to compare to numerical modelling, the Rickenmann (2001) sediment transport analysis was applied as it appears to provide more reasonable results. These sediment volumes for the 20- and 50-year return period events are associated with Type 1 debris floods, while the sediment volumes for the 200- and 500- year return period events are associated with Type 2 debris floods.

Table 6-4. 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	298,000	62,000
50	384,000	74,000
200	512,000	95,000
500	597,000	111,000

Note: this relationship was 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 Wilson 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 6-5. 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 6-5. Summary of modelling results.

Process	Key Observations
Clearwater Inundation (HEC-RAS results for all return periods)	• Wilson Creek flows overbank from its current channel for return periods 20 years and higher east of Rosebery Campsite Road. • Downstream of Highway 6, water will likely inundate the Nakusp and Slocan Railway Trail (NSRT) as well as some properties on the east end of Derosa Drive. Properties on Stanley Street and the north side of Stewart Drive would also be inundated with up to 1 m depth and flow velocities up to 2.2 m/s. • Flood extent and depth are similar for the 20 and 50-year return period floods. • Access and egress to Derosa Drive, Stanley Street and Stewart Drive would likely be severed by inundation near 6th Street for the 20-year and higher return period floods. Without egress, these properties will likely be isolated in case of a flood. • The 200-year flood extent is similar to the 50-year flood. However, East Wilson Road would likely be flooded north of Highway 6. • The 500-year flood extent is similar to the 200-year flood with a larger portion of the Rosebery Parklands Regional Parks north of the Wilson Creek delta being inundated.
Auxiliary Hazards	• None of the numerical modelling accounts for collapses of any of the high slopes on the upper fan, possibly resulting in an outbreak flood surge or the possibility of exacerbated bank erosion in case of a partial creek blockage and flow concentration on the opposite side of the slope failure. • NSRT and Highway 6 embankment failures have not been modelled

6.6. Bank Erosion Assessment

The air photo assessment compared available air photos from 1939 to 2015 to determine the historical changes in channel width at the five cross-sections considered in the bank erosion assessment (see Drawings 02A, 02B for cross-section locations). Table 6-6 summarizes the channel changes in channel width between air photo years. Potential error or uncertainty in these measurements may be introduced by shadows from vegetation, poor image quality, or distortion during rectification. BGC estimates the total error associated with the above factors is less than 5 m.

Table 6-6. Summary of channel width increases from 1939 to 2015.

Air Photo Interval	Maximum Channel Width Increase Between Photos (m)	Cross-Section of Maximum Channel Width Increase (Drawing 02)
1939-1945	0	-
1945-1952	0	-
1952-1966	0	-
1966-1978	4	5
1978-1979	1	3
1979-1986	2	5
1986-1990	6	4
1990-2006	0	-
2006-2015	0	-

Table 6-6 shows that minimal erosion occurred over time throughout the reach. However, channel conditions did differ significantly in the earliest photo (1939) from other years. The channel was 60 m wider in the 1939 imagery than in 2015 at cross-section 4 (located at a meander bend), and 10 m wider at cross-section 3. The 1939 photo appears to have been obtained soon after a debris-flood event (Table 6-2), and Figure 6-2 shows that the channel progressively narrowed at cross-section 3 and 4 over the period of air photo record as the reach recovered from the disturbance through vegetation colonization.

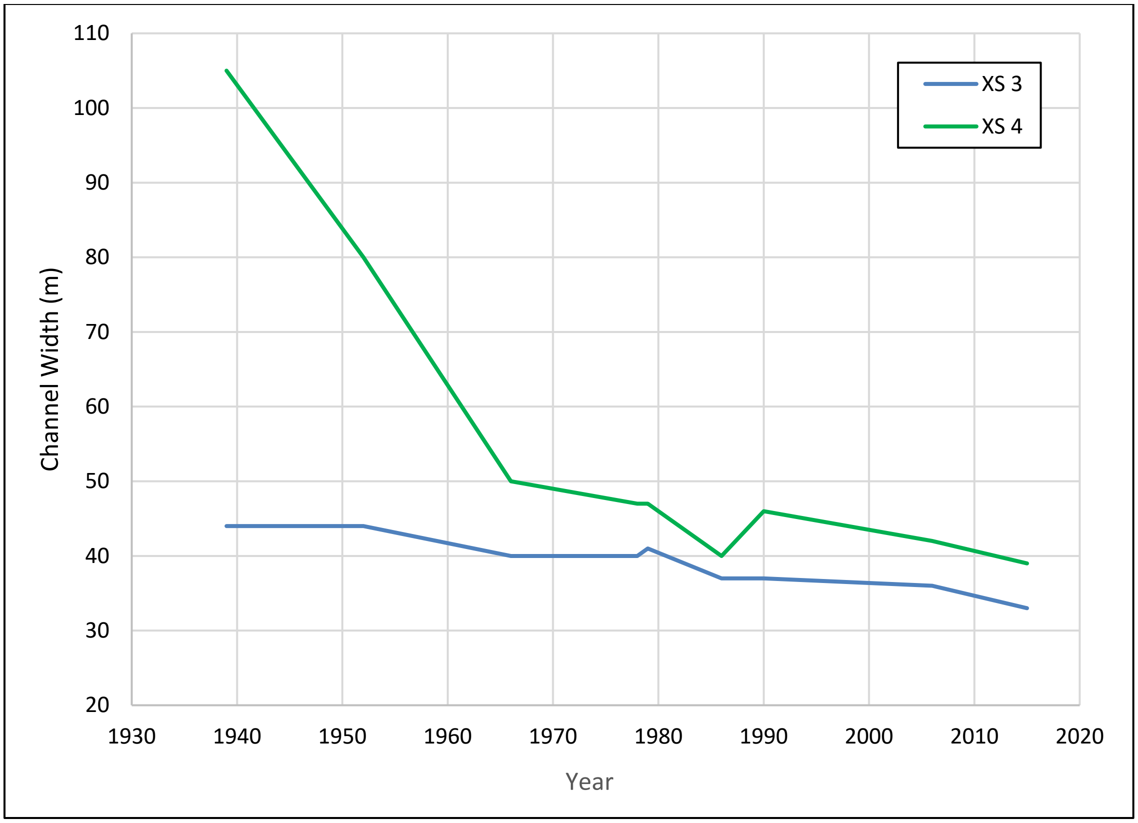


Figure 6-2. Channel widths from 1939 to 2015 at cross-section 3 and 4.

The air photo assessment was used to calibrate a physically based bank erosion model. BGC assumed that the maximum event magnitude during the 76-year air photo record was a 50-year event and calibrated the model to produce minimal erosion during for that event. A summary of the bank erosion model results by return period is outlined in Table 6-7. This table displays the minimum, maximum, and average erosion modelled across all cross-sections considered at each of the four return periods modelled.

Table 6-7. Summary of bank erosion model results by return period.

Return Period (years)	Minimum Erosion (m)	Average Erosion (m)	Maximum Erosion (m)
20	1	3	9
50	5	9	12
200	11	15	22
500	15	24	32

Figure 6-3 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 5 for all return periods (see Drawings 02A, 02B). The abutments of the Highway 6 bridge may be at risk from progressive erosion.

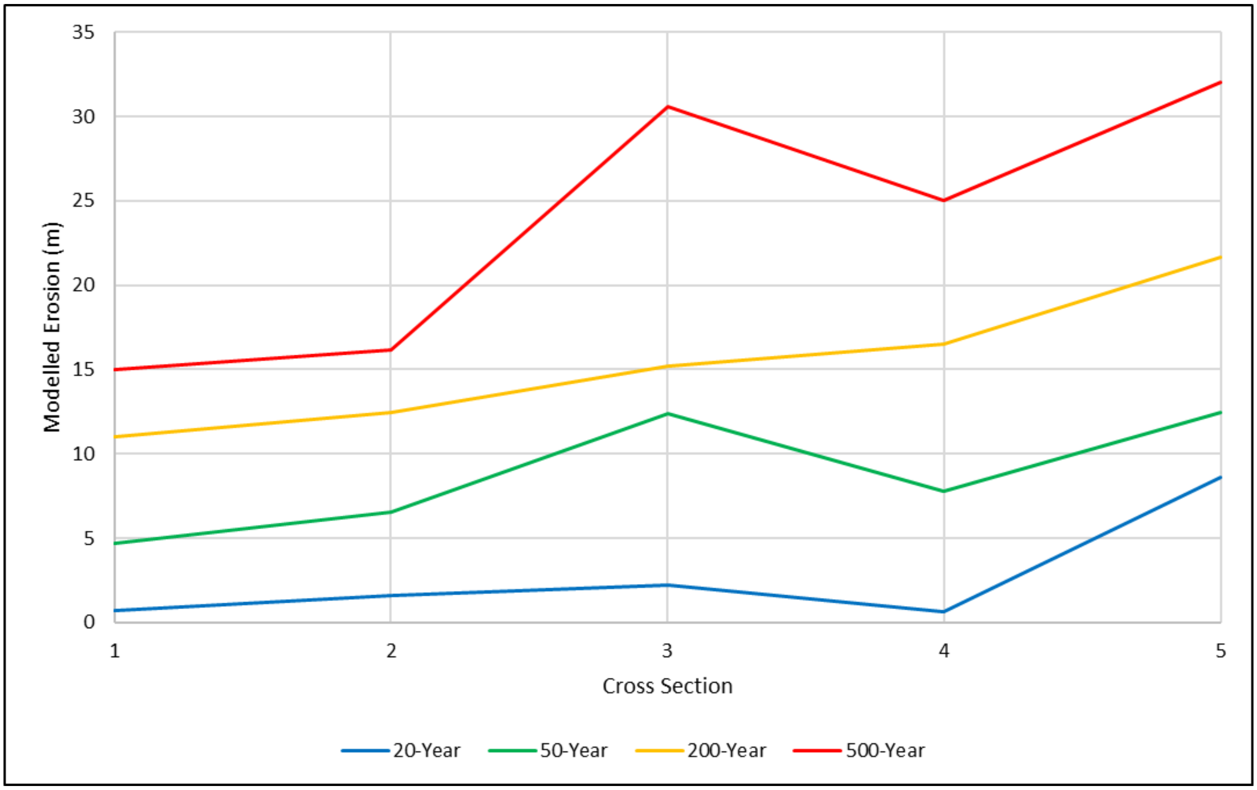


Figure 6-3. Wilson Creek 50th percentile bank erosion model results at each cross-section.

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.

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

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

The composite hazard rating map demonstrates that significant hazards exist outside the active channel sections both upstream and downstream of the Highway 6 crossing. Given the large watershed area (580 km^2), Wilson Creek behaves more like a river and is characterized by high flow depth (up to 5 m upstream of the Highway 6 crossing) and flow velocities (up to 5 m/s in narrow channel sections). These factors also result in potential bank erosion on both sides of Wilson Creek. About one third of the lower fan (downstream of Highway 6) is subject to either “high” or “moderate” hazards, zones that will likely witness substantial damage during major floods.

7. SUMMARY AND RECOMMENDATIONS

7.1. Introduction

This report provides a detailed hazard assessment of the Wilson Creek fan-delta. Wilson 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 Wilson Creek.

A variety of analytical desktop and field-based tools and techniques were combined to decipher Wilson 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, Wilson Creek is subject to supply-unlimited Type 1 debris floods for the 20-year return period, and Type 1/Type 2 for the 50-year return period. For higher return periods (200- and 500-year), Type 2 debris floods are believed to be the dominant process due to the presence of sediment-laden Dennis Creek that joins the Wilson Creek fan-delta immediately downstream of the fan apex (Drawing 05). Type 3 debris floods are believed to be possible but at return periods (>500-year) greater than considered in this assessment.

7.2.2. Air Photo Interpretation

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

- Only one hydrogeomorphic event was identified in the air photo record (1939 – 2015). The event is visible in the 1939 air photo and shows an area of freshly deposited debris of approximately 74,100 m^2. The exact date of this event is unknown.
- The 1972 flood event identified in the historical records (Figure 4-1) was not evident in the 1976 air photo. This could be due to bridge and highway construction marring evidence of the event which was recorded to include erosion on the right (north) bank where the new bridge was under construction (Water Resources Branch, Government of British Columbia, June 1972).

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 discharge was adopted as per Section 4 of the Methodology Report (BGC, March 31, 2020b).
- The climate-change adjusted peak discharges for Wilson Creek range from 272 m^3/s (20-year flood) to 474 m^3/s (500-year flood).
- Sediment bulking factors of 1.05 (5% increase for the 20-year debris flood) to 1.3 (30% increase for the 500-year return period event) were adopted as input to numerical modelling.
- Consideration of climate change and sediment bulking increase the clearwater discharge estimate from 272 to 286 m^3/s for the 20-year debris flood, and from 395 to 616 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. Wilson Creek debris flood frequency-magnitude relationship.

Return Period (years)	Adjusted Peak Discharge (m^3/s)
20	280
50	340
200	450
500	520

7.2.5. Numerical Flood and Debris Flood Modelling

Numerical models were employed to simulate the chosen hazard scenarios on the Wilson Creek fan-delta. Table 6-5 provided key observations derived from the numerical modelling.

The numerical modelling demonstrates that the key hazards and associated risks at Wilson Creek stem from the multiple avulsion paths as the main channel's capacity is exceeded at select locations in all return periods as well as the insufficient capacity of the Nakusp and Slocan Railway Trail Bridge.

7.2.6. Bank Erosion Assessment

A bank erosion assessment was completed because debris floods can be highly erosive, undercutting unstable banks. The key findings from the bank erosion assessment are:

- The bank erosion model was calibrated based on the air photo analysis to produce minimal erosion during a 50-year event.
- The maximum modelled erosion ranges from 9 m in a 20-year event to 32 m in a 500-year event. The likely erosion ranges from 0.4 m to 32 m during the 20-year to 500-year events.
- Bank erosion is unlikely to affect infrastructure along Wilson Creek, with the exception of the Highway 6 bridge abutments (see Drawings 02A, 02B).

7.2.7. Hazard Mapping

Model results are cartographically expressed in two ways:

- The individual debris flood model results are captured through an index of impact force that combines flow velocity, bulk density and flow depth flow path. These maps are useful for assessments of development proposals and emergency planning. A representative example from the 200-year return period is included on Drawing 07.
- A composite hazard rating map (impact intensity frequency map) that combines the debris flood intensity (impact force) and frequency up to the 500-year return period event. This map is useful to designate hazard zones. It is included as Drawing 08.

Both the individual scenario maps and the composite impact intensity frequency (hazard rating) 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 Wilson Creek represent a snapshot in time. Future changes to the Wilson Creek watershed or fan-delta including the following may warrant re-assessment and/or re-modelling:

- Future fan development
- Substantial flood or debris flood events
- Development of large landslides in the watershed with the potential to impound Wilson Creek
- Bridge re-design
- Substantial changes to Slocan Lake levels
- Significant wildfire events in the watershed in sufficiently proximal locations to the Wilson Creek fan-delta to affect hazards on the fan-delta
- Major earthworks within the active portion of the fan-delta.

The assumptions made on changes in runoff due to climate change and sediment bulking, while not unreasonable, are not infallible and will likely need to be updated occasionally as scientific understanding of 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 as they pertain to all studied RDCK creeks. This section notes Wilson 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 Wilson Creek fan-delta.

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

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

Wilson Creek fan-delta hosts a lower value of assets in comparison with the steep creek fan-deltas studied in detail (Table 1-1). Although it hosts the third lowest value of assets, the moderate hazard rating areas intersect many properties along Rosebery Park Rd and on the south side of Wilson Creek (Drawing 08). For this reason, consideration of measures for hazard management are warranted.

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

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

Option	Description	Effect on Steep Creek Hazard Reduction
a	Building-specific flood proofing and erosion protection.	Protection from inundation and sedimentation on properties.
b	Construction of ¾ ring dike greater than 2 m in height and/or property-specific flood proofing and erosion protection including raising buildings.	Protection from inundation from both Slocan Lake and Wilson Creek, and sedimentation from Wilson Creek.
c	Installation of a berm equipped with culverts to allow flow southeastward and erosion protection between Rosebery Rd and De Rosa Dr at 6th St.	Maintenance of access and egress from properties north of De Rosa Dr.
d	Installation of large, angular rip-rap and additional flood-proofing.	Erosion protection and protection from inundation and sedimentation.
e	Improvements to existing bank protection, including installation of additional large, angular rip-rap. Alternatively, acceptance of potential road loss during severe flood events and the associated repair costs.	Erosion protection and bank stabilization of East Wilson Creek Rd.

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

- Restrictions on development permits in areas of the composite hazard rating map (Section 5.6.2) where ratings exceed RDCK's tolerance standard.
- Restrictions on building permits (i.e. requirements for floodproofing measures) in areas of the composite hazard rating map where ratings exceeding RDCK's tolerance standard.
- Establishing development restrictions or requirements for bank erosion protection within the 50th percentile bank erosion lines, with consideration of the effects of such measures to upstream and downstream creek reaches.
- Emergency preparedness should account for the findings of the numerical modelling. For example, the realization that De Rosa Dr will be cut off by flooding means that evacuation plans be in place for properties along De Rosa Dr as well as Stewart and Stanley Streets. Similarly, forestry workers in the Wilson Creek watershed should be made aware that access to Rosebery via East Wilson Creek Road will likely be interrupted during major floods.
- Future developments should focus on areas of the fan-delta not impacted by bank erosion or hydrogeomorphic events or where the hazard is very low. Areas not impacted by hydrogeomorphic events are shown on the composite hazard rating map (Drawing 08) as un-coloured. Very low hazard areas are shown in light yellow on the composite hazard rating map. These very low hazard areas are not impacted by hydrogeomorphic events during the return periods investigated (20-, 50-, 200-, 500-year) but have the potential to be impacted during larger events or, if there are significant changes on the fan-delta. Appropriate bank setbacks (at least the 50th percentile bank erosion lines) should be considered even for these very low hazard and non-impacted areas.

- Signs could be erected warning residents and tourist from using trails and roads that will likely be severed, flooded or otherwise damaged during floods.

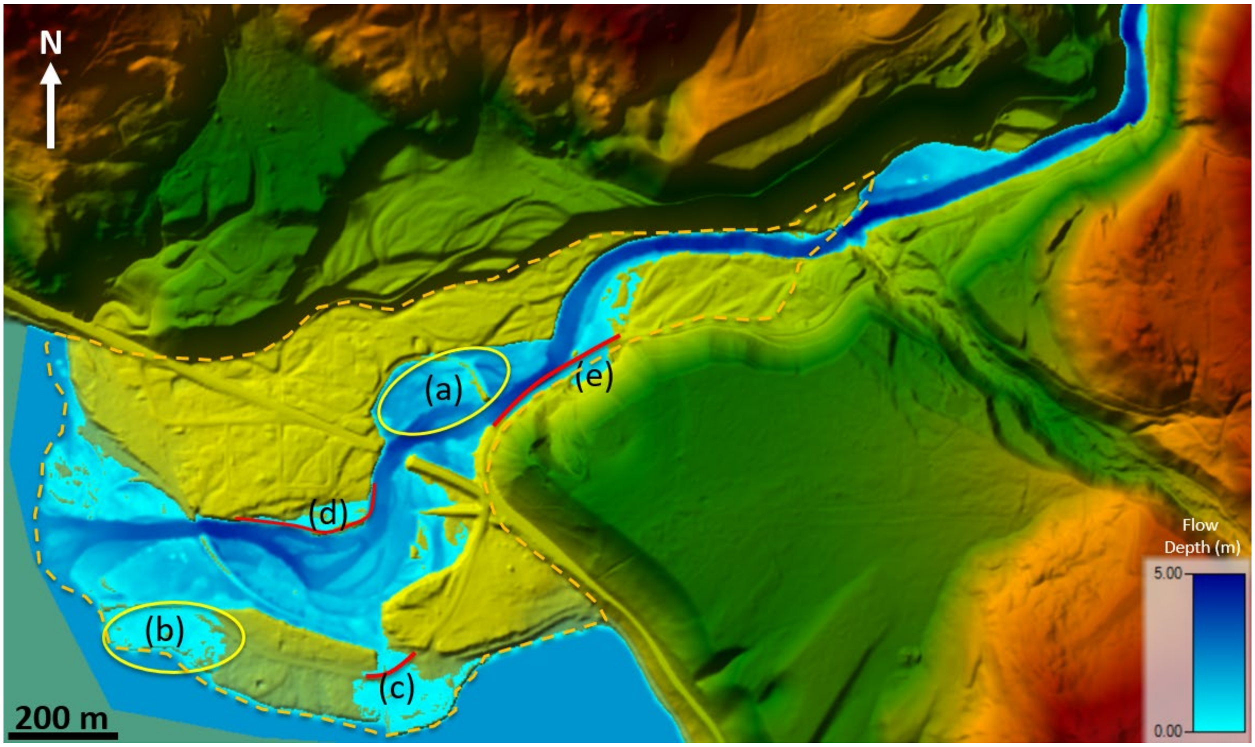


Figure 7-1. Flood inundation map showing flow depths for a 500-year return period clearwater flood on Wilson Creek and conceptual-level mitigation options for Wilson Creek fan-delta. Note that these options have not been tested by numerical modelling and only serve as an impetus for further discussion.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

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,

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

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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

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APPENDIX B
SITE PHOTOGRAPHS

Photo 1.

Standing on the right bank of Wilson Creek looking downstream, approximately 500 m upstream of the fan apex. Photo: BGC, July 26, 2019.

Photo 2.

Standing on Wilson Creek Road East bridge, looking at the left bank of Dennis Creek, a major tributary to Wilson Creek. Photo: BGC, July 26, 2019.

Photo 3.

Standing on the right bank of Wilson Creek in Roseberry Provincial Park, approximately 0.5 km upstream of the Highway 6 bridge. Looking at erosion of the right bank. Photo: BGC, July 26, 2019.

Photo 4.

Standing on the right bank of Wilson Creek in Roseberry Provincial Park, approximately 0.4 km upstream of the Highway 6 bridge. Looking at across to the left bank. Photo: BGC, July 26, 2019.

Photo 5.

Standing on the edge of Wilson Creek, looking at erosion of the right bank along Roseberry Provincial Park, approximately 0.4 km upstream of the Highway 6 bridge. Photo: BGC, July 26, 2019.

Photo 6.

Standing on the edge of Wilson Creek, looking at erosion of the right bank along Roseberry Provincial Park, approximately 0.4 km upstream of the Highway 6 bridge. Photo: BGC, July 26, 2019.

Photo 7.

Standing on the left bank of Wilson Creek looking at Roseberry Provincial Park, approximately 0.3 km upstream of the Highway 6 bridge. Photo: BGC, July 26, 2019.

Photo 8.

Standing on the left bank of Wilson Creek looking upstream, approximately 0.3 km upstream of the Highway 6 bridge. Bank protection along Wilson Creek Road East visible on left bank. Photo: BGC, July 26, 2019.

Photo 9.

Standing on the left bank of Wilson Creek looking downstream, approximately 0.3 km upstream of the Highway 6 bridge. Bank protection along Wilson Creek Road East visible on bank. Some protection material has moved and bank has slumped. Photo: BGC, July 26, 2019.

Photo 10.

Standing on the right bank of Wilson Creek looking upstream, just upstream of the Hwy 6 bridge. Photo: BGC, July 26, 2019.

Photo 11.

Standing on the right bank of Wilson Creek looking downstream at the Hwy 6 bridge. Photo: BGC, July 26, 2019.

Photo 12.

Looking downstream at Wilson Creek from on top of the Hwy 6 bridge. Photo: BGC, July 26, 2019.

Photo 13.

Standing on the left bank of Wilson Creek looking across at bank erosion on the right bank just downstream of the Hwy 6 bridge. Photo: BGC, July 26, 2019.

Photo 14.

Standing on the left bank of Wilson Creek looking downstream at low left bank, approximately 0.1 km downstream of the Hwy 6 bridge. Photo: BGC, July 26, 2019.

Photo 15.

Standing on the right bank of Wilson Creek looking downstream at Nakusp and Slocan Railway Trail, approximately 0.4 km downstream of the Hwy 6 bridge. Photo: BGC, July 26, 2019.

Photo 16.

Standing on the right bank of Wilson Creek looking across at the left bank and the railway bridge. Photo: BGC, July 26, 2019.

Photo 17.

Standing on the rail bridge looking downstream at the Wilson Creek outlet to Slocan Lake. Note mid-channel cobble deposit. Photo: BGC, July 26, 2019.

Photo 18.

Standing at the head of cobble deposit at Wilson Creek outlet to Slocan Lake looking downstream at the right bank. Photo: BGC, July 26, 2019.

Photo 19.

Standing at the Wilson Creek outlet to Slocan Lake looking upstream at the railway bridge in the distance. Photo: BGC, July 26, 2019.

Photo 20.

Standing at the head of mid-channel cobble deposit at Wilson Creek outlet to Slocan Lake looking downstream at the left bank. Photo: BGC, July 26, 2019.

Photo 21.

Standing at the Wilson Creek outlet on Slocan Lake on the left bank looking upstream at bank erosion. Photo: BGC, July 26, 2019.

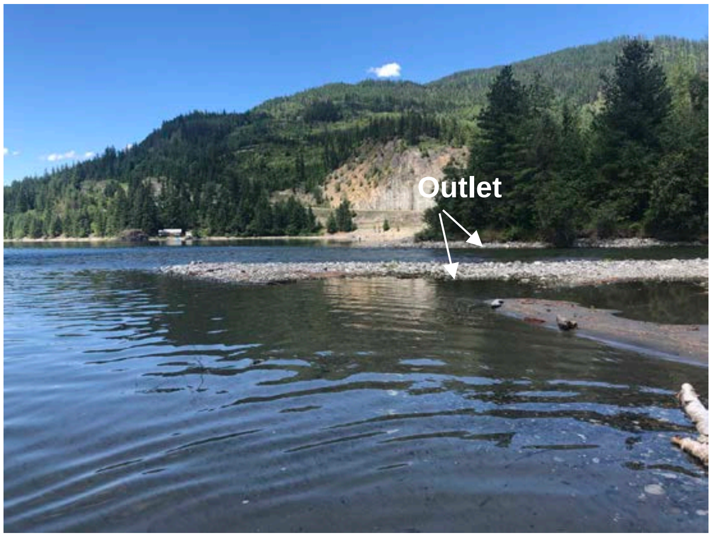


Photo 22.

Slocan Lake at the Wilson Creek outlet. Photo: BGC, July 26, 2019.

APPENDIX C
SEDIMENT SIZE SAMPLING

C.1. SAMPLING LOCATIONS

At Wilson Creek, three Wolman Samples were taken: one at the fan apex, one upstream of the Highway 6 bridge, and the other near the outlet to Slocan Lake. The sample from upstream of the Highway 6 bridge was discarded, as the presence of the bridge was likely artificially inflating results.

The remaining sampling locations at the fan apex and at the outlet to Slocan Lake (referred to as Wilson 1 and Wilson 2) are shown in Figure C-1 and in Table C-1. Bed material conditions at each site are shown on Figure C-2, and Figure C-3.

Table C-1. Wolman sampling locations.

Site Name	Wilson 1	Wilson 2
Location	Fan apex	Outlet to Slocan Lake.
Longitude	117°23'38.59"W	117°24'55.97"W
Latitude	50° 2'9.31"N	50° 1'48.43"N
Number of stones measured	101	113

Figure C-1. Wolman sampling locations along Wilson Creek. Google Earth image of September 28, 2015.

Figure C-2. Photograph taken of Wolman sampling location Wilson 1. BGC photograph of November 19, 2019.

Figure C-3. Photograph taken of Wolman sampling location Wilson 2. BGC photograph of July 25, 2019.

C.2. RESULTS

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

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

Grain Size	Wilson 1	Wilson 2
D95 (mm)	214	92
D84 (mm)	97	62
D50 (mm)	19	37
D15 (mm)	4	15
D5 (mm)	2	6

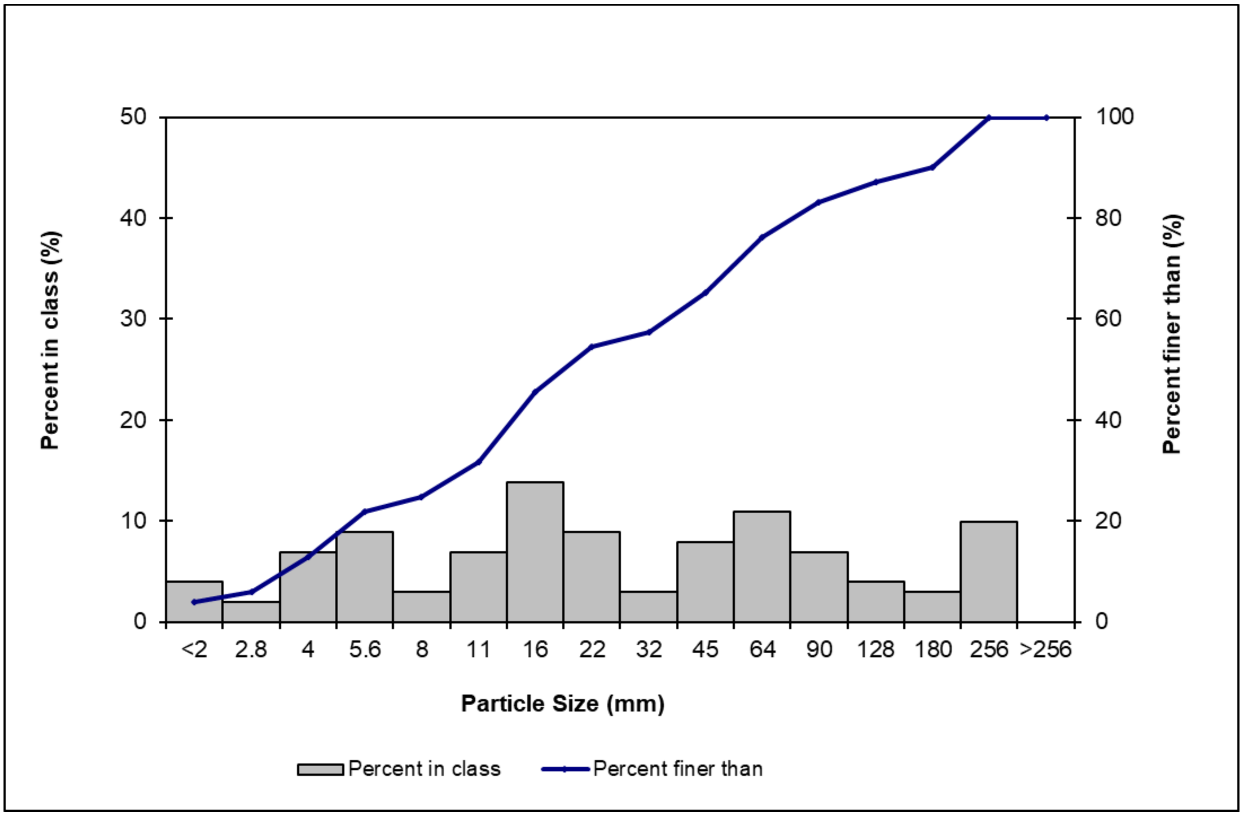


Figure C-4. Wilson Creek grain size distribution at Wilson 1 (at fan apex) from Wolman count.

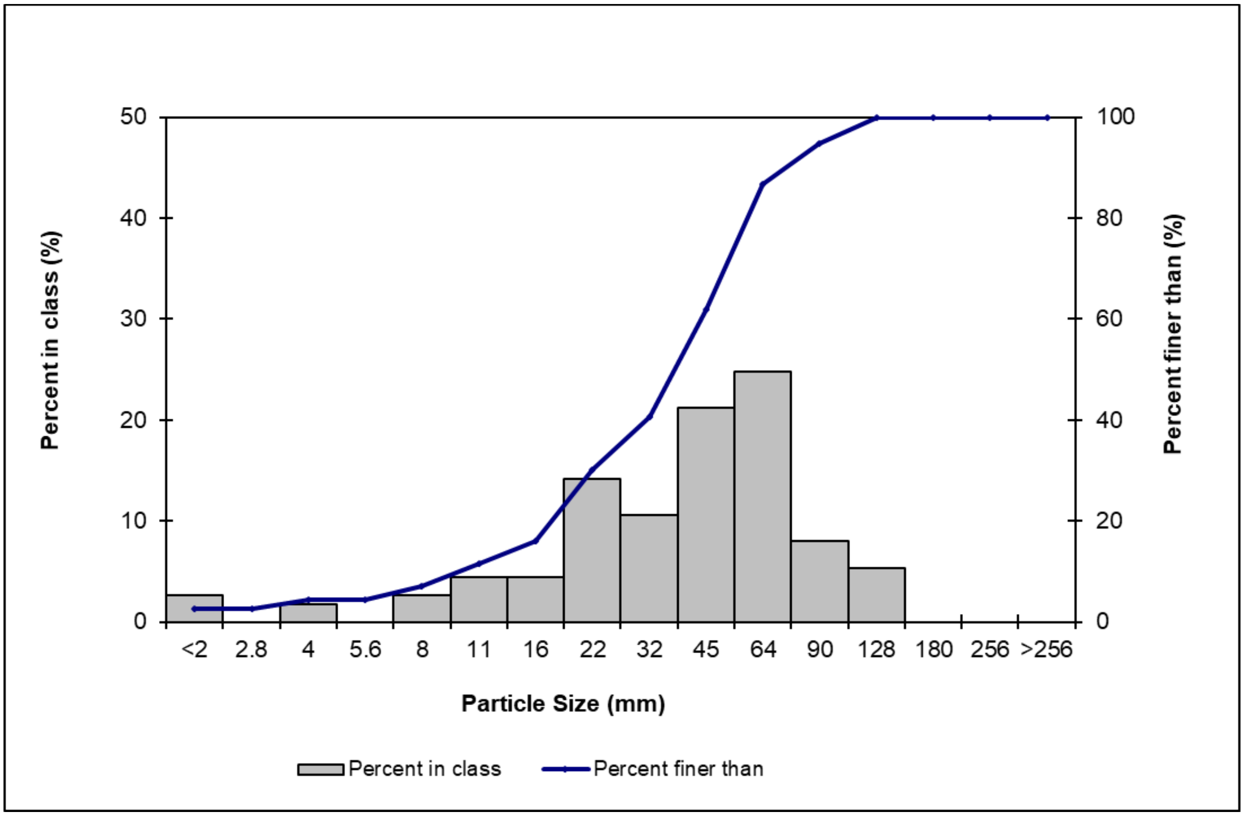


Figure C-5. **Wilson Creek grain size distribution at Wilson 2 (outlet to Slocan Lake) from Wolman count.**

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

APPENDIX D
AIR PHOTO RECORDS

Table D-1 presents air photo records from the Wilson Creek analysis. In addition to the air photos listed, RDCK provided BGC with an air photo from 2015. The original source of the 2015 image is unknown.

Table D-1. Wilson Creek air photo records.

Year	Date	Roll Number	Photo Number	Scale
2006	9/1/2006	BCC06135	104-106, 124-125	20,000
2000	8/22/2000	BCB00032	180-181	35,000
1997	9/23/1997	BCB97110	157, 231	15,000
1990	9/7/1990	BCB90143	111-113	15,000
1986	7/20/1986	BC86053	107-109	16,000
1979	6/12/1979	BC79037	304-306	20,000
1976	7/16/1976	BC7854	180-181	20,000
1966	8/3/1966	BC4383	21-22, 52-54	15,840
1952	7/7/1952	BC1465	13-14	31,680
1945	9/18/1945	A9424	125-126	25,000
1939	7/27/1939	BC154	68	31,680

APPENDIX E
MODELLING SCENARIOS

E.1. MODELLING SCENARIOS

The scenarios analyzed for Wilson 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.

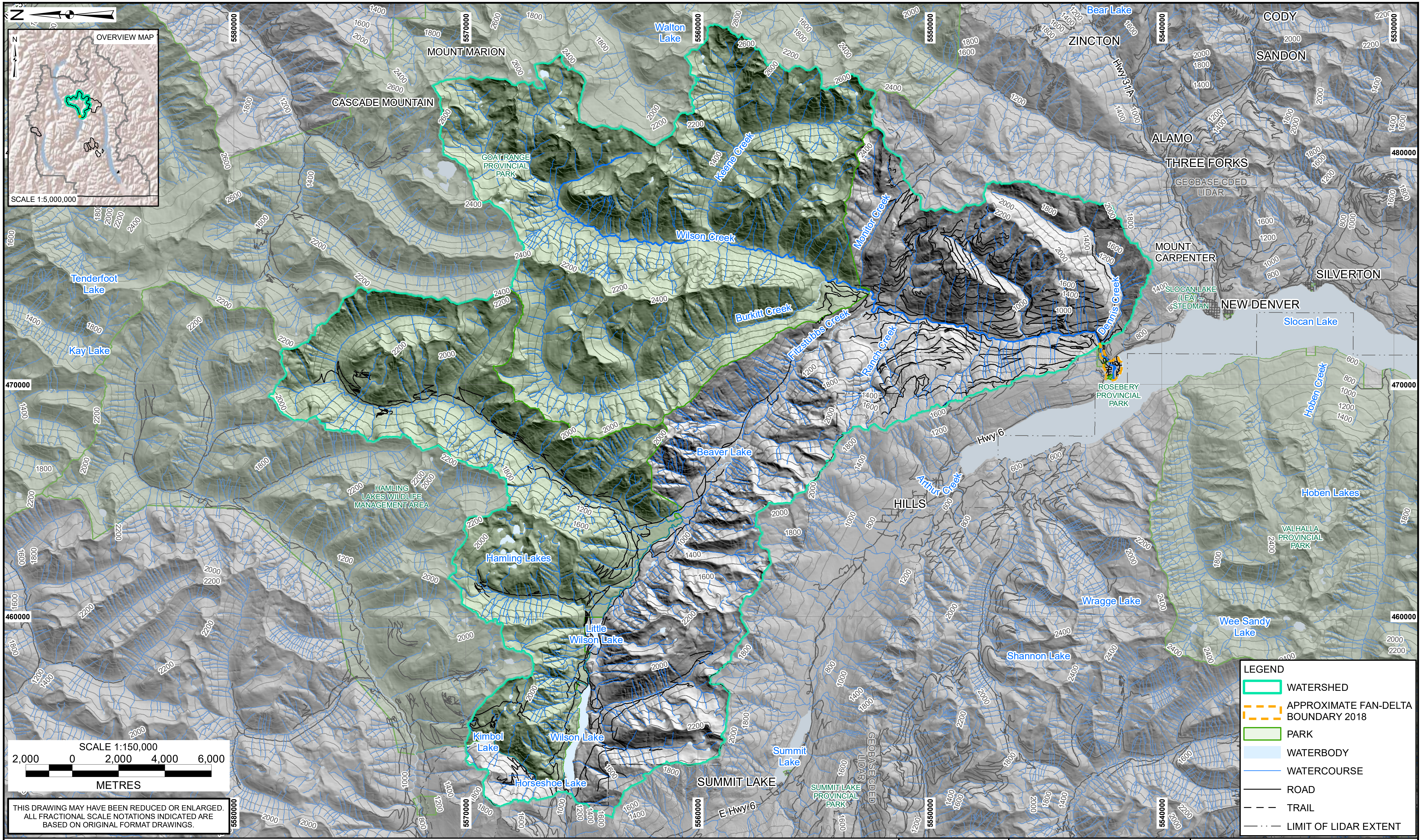
Table E-1. Modeling scenario summary for Wilson Creek.

Scenario Name	Return Period (years)	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**
WLS-1	20	Debris Flood (Type 1)	1.02	280	Wilson Highway Bridge	700	Functioning as intended.	N/A				
					Nakusp and Slocan Railway Trail Bridge	650	Functioning as intended.					
WLS-2	50	Debris Flood (Type 1/2)	1.05	340	Wilson Highway Bridge	700	Functioning as intended.	N/A				
					Nakusp and Slocan Railway Trail Bridge	650	Functioning as intended.					
WLS-3	200	Debris Flood (Type 2)	1.1	450	Wilson Highway Bridge	700	Functioning as intended.	N/A				
					Nakusp and Slocan Railway Trail Bridge	650	Functioning as intended.					
WLS-4	500	Debris Flood (Type 2)	1.1	520	Wilson Highway Bridge	700	Functioning as intended.	N/A				
					Nakusp and Slocan Railway Trail Bridge	650	Functioning as intended.					

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



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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 - WILSON CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2018, AND GEOBASE CDED. CONTOUR INTERVAL IS 200 m.
4. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM BASED ON LIDAR DATED 2018. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL FLOODING.
5. PARKS DATA FROM GOVERNMENT OF BC. ROADS DATA FROM BC DIGITAL ROAD ATLAS.
6. PROJECTION IS NAD 1983 UTM ZONE 11N.
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DATE:	MAR 2020
DRAWN:	LL
CHECKED:	JJHP
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

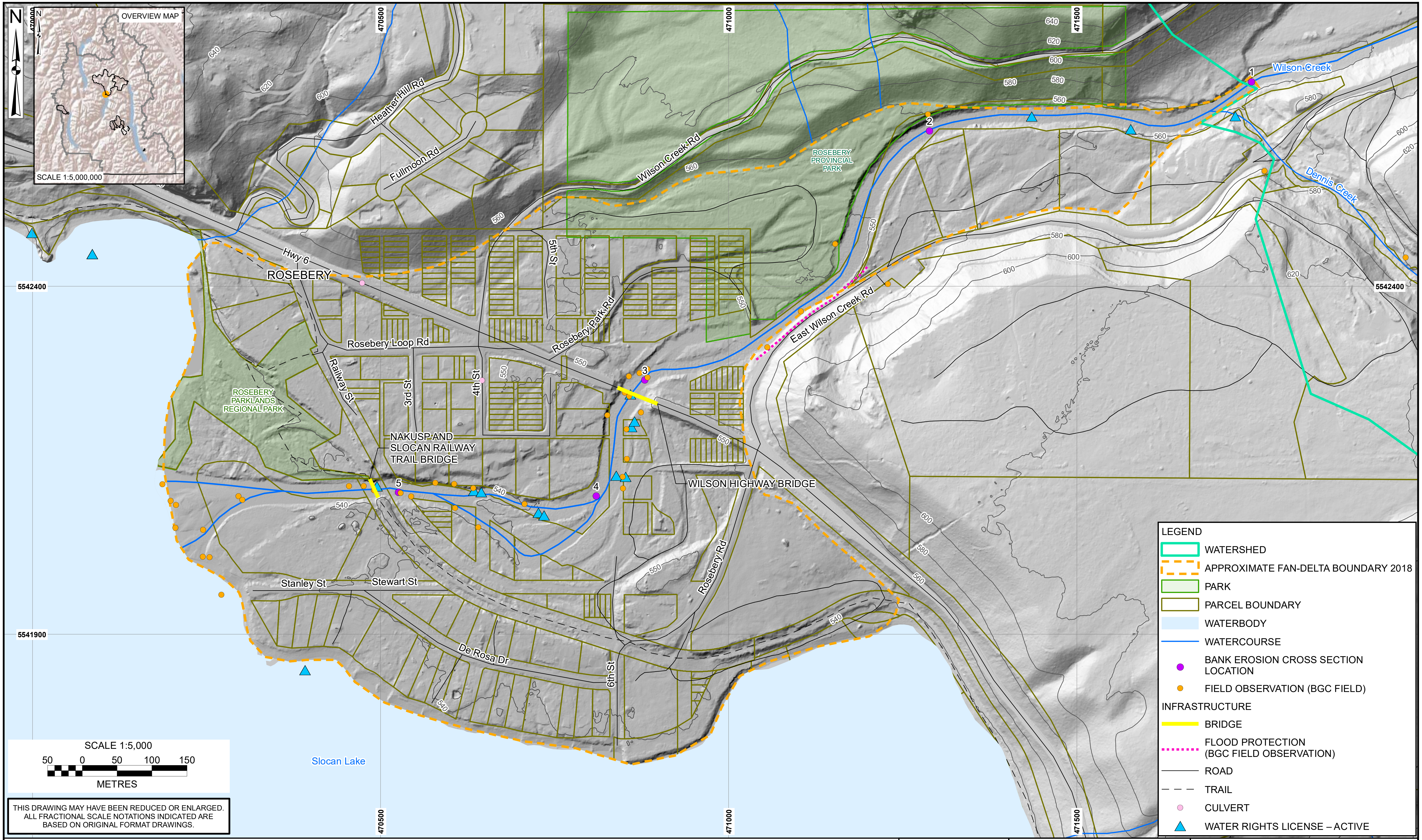
CLIENT:

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE:
WILSON CREEK
SITE LOCATION MAP

PROJECT No.:	DWG No:
0268007	01

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



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2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY - WILSON CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK, DATED 2018. 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 2018. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL FLOODING.
5. WATER DATA FROM CANVEC, UPDATED BASED ON BGC FIELD OBSERVATIONS, WHERE APPLICABLE. CULVERT LOCATIONS FROM BC MINISTRY OF TRANSPORTATION. FLOOD PROTECTION DATA FROM BGC FIELD OBSERVATIONS (APPROXIMATE). ROADS DATA FROM BC DIGITAL ROAD ATLAS. WATER RIGHTS LICENSE DATA FROM GEOBC. PARCELS FROM PARCELMAP BC. PARKS DATA FROM GOVERNMENT OF BC.
6. PROJECTION IS NAD 1983 UTM ZONE 11N.
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SCALE: 1:5,000
DATE: MAR 2020
DRAWN: LL
CHECKED: JJHP
APPROVED: MJ

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CLIENT: REGIONAL DISTRICT CENTRAL KOOTENAY

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE: WILSON CREEK
FAN-DELTA SITE MAP

PROJECT No.: 0268007
DWG No: 02A

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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 - WILSON CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK, DATED 2018. CONTOUR INTERVAL IS 20 m AND 10 m ON FAN. IMAGERY FROM WORLD_IMAGERY_BASEMAP.
4. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM BASED ON LIDAR DATED 2018. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL FLOODING.
5. WATER DATA FROM CANVEC, UPDATED BASED ON BGC FIELD OBSERVATIONS, WHERE APPLICABLE. CULVERT LOCATIONS FROM BC MINISTRY OF TRANSPORTATION. FLOOD PROTECTION DATA FROM BGC FIELD OBSERVATIONS (APPROXIMATE). ROADS DATA FROM BC DIGITAL ROAD ATLAS. WATER RIGHTS LICENSE DATA FROM GEOBC. PARCELS FROM PARCELMAP BC. PARKS DATA FROM GOVERNMENT OF BC.
6. PROJECTION IS NAD 1983 UTM ZONE 11N.
7. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE:	1:5,000
DATE:	MAR 2020
DRAWN:	LL
CHECKED:	JJHP
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE:
WILSON CREEK
FAN-DELTA SITE MAP

PROJECT No.:	DWG No:
0268007	02B

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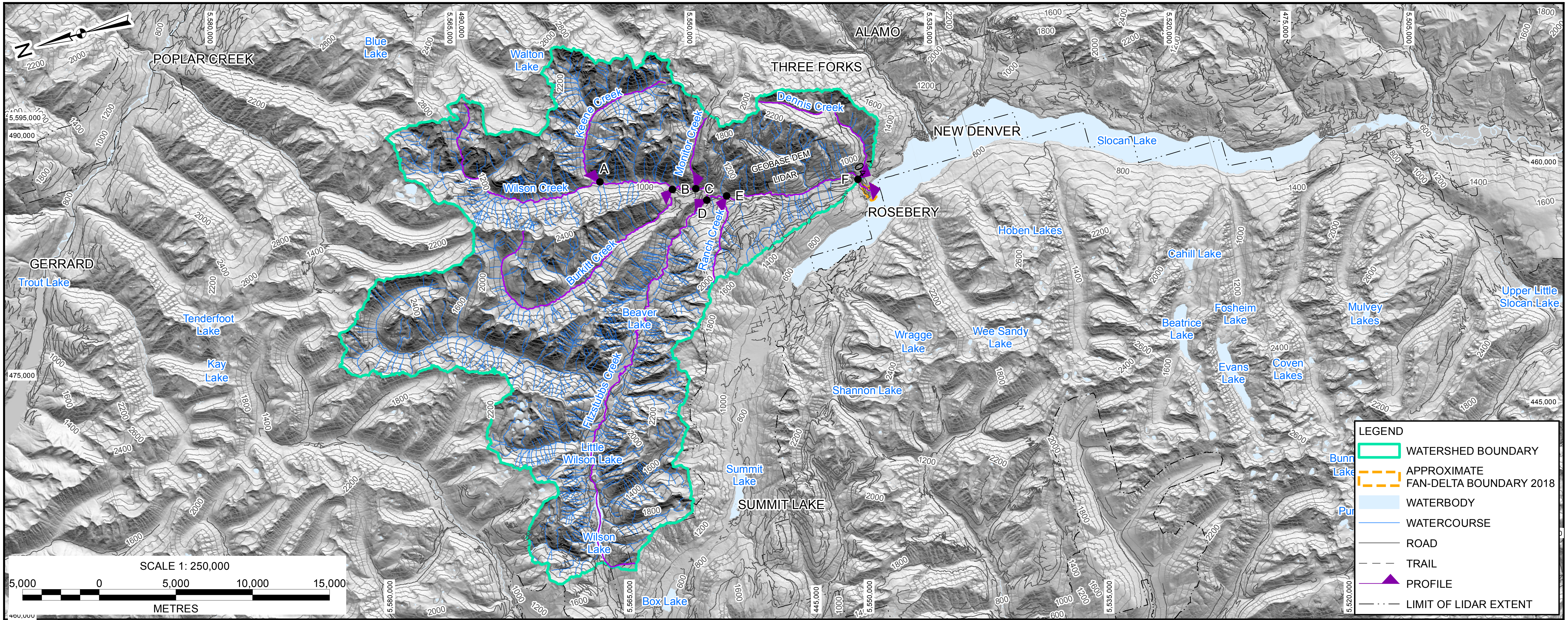

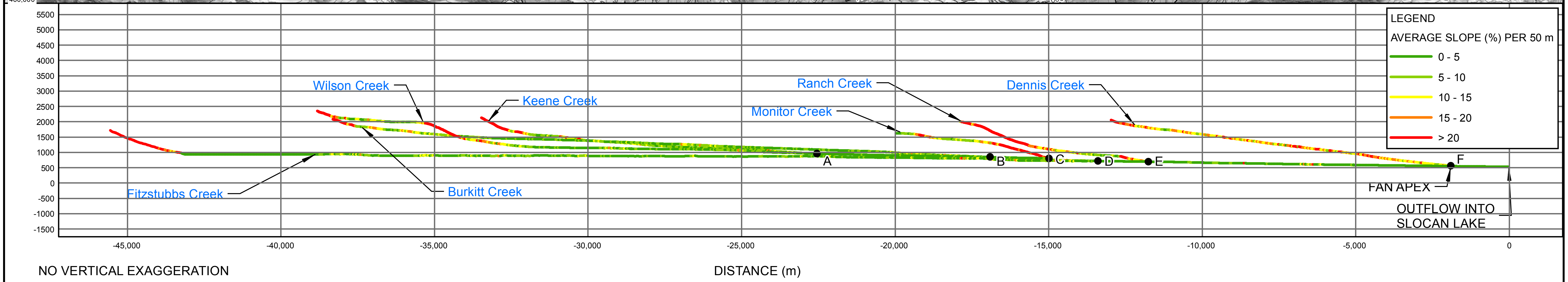

NO VERTICAL EXAGGERATION

DISTANCE (m)

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY – WILSON CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2018 AND GEOBASE CDED. CONTOUR INTERVAL IS 200 m.
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.
6. ELEVATION PROFILE SHOWS DISTANCE RELATIVE TO THE CREEK OUTLET ON X-AXIS AND ELEVATION DERIVED FROM THE BASE TOPOGRAPHIC DATA ON Y-AXIS
7. PROJECTION IS NAD 1983 UTM ZONE 11N.
8. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE:	1:250,000
DATE:	MAR 2020
DRAWN:	STT
CHECKED:	JJHP, LCH
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE:
WILSON CREEK PROFILE

PROJECT No.: 0268007
DWG No: 03

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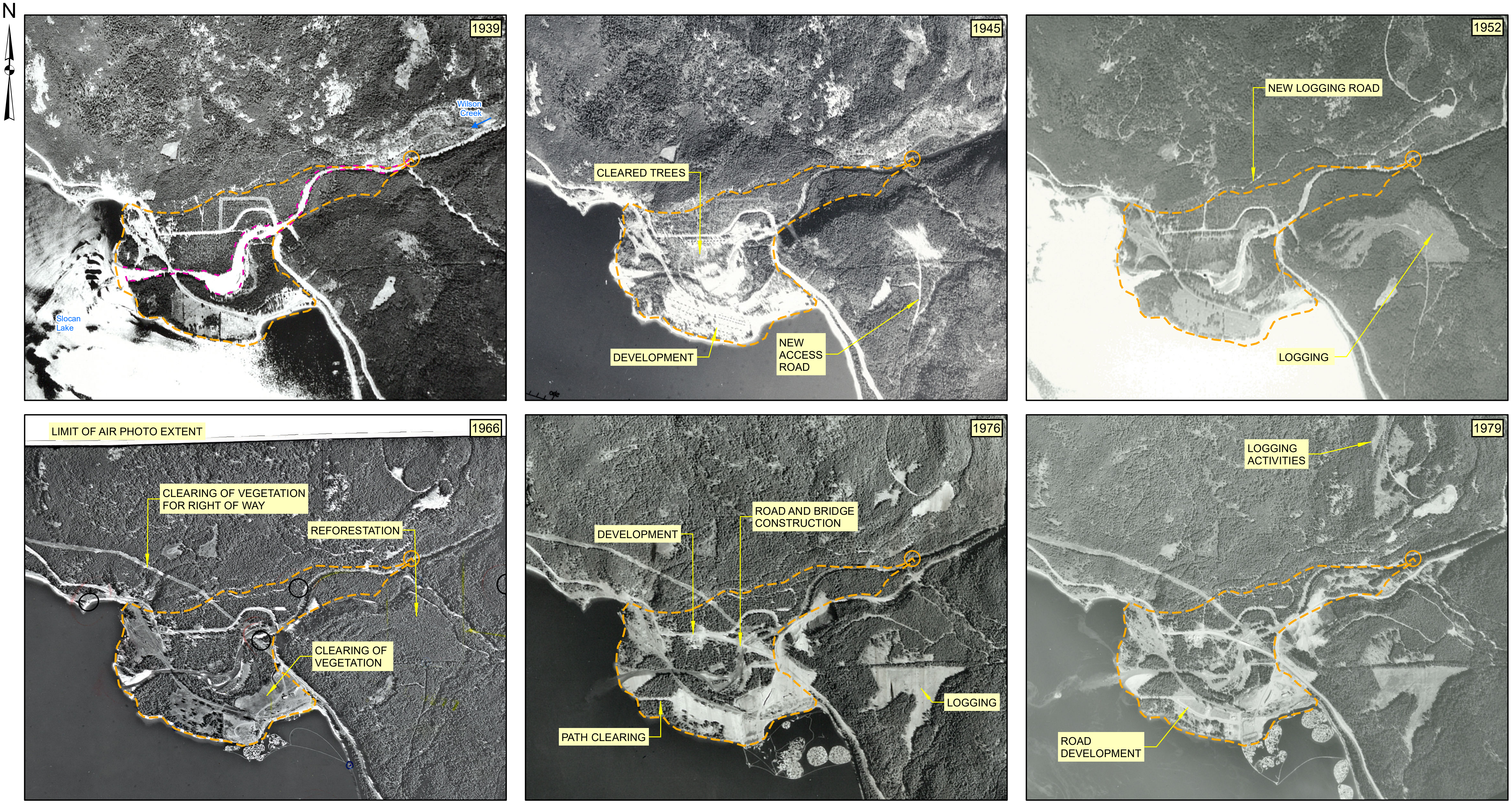

SCALE 1:20,000

200 0 200 400 600

METRES

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LEGEND

- ▭ APPROXIMATE FAN-DELTA BOUNDARY 2018
- - - - APPROXIMATE EXTENT OF PRE-1939 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 - WILSON 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 2018. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL FLOODING.
5. AIR PHOTO FROM YEAR 1966 WAS MARKED ON PHYSICAL COPIES PRIOR TO BGC'S AIR PHOTO INTERPRETATION.
6. COORDINATE SYSTEM IS UTM ZONE 11 NAD 1983. VERTICAL DATUM IS UNKNOWN.
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.

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SCALE: 1:20,000
DATE: MAR 2020
DRAWN: MIB, LL
CHECKED: JJHP, LCH
APPROVED: MJ

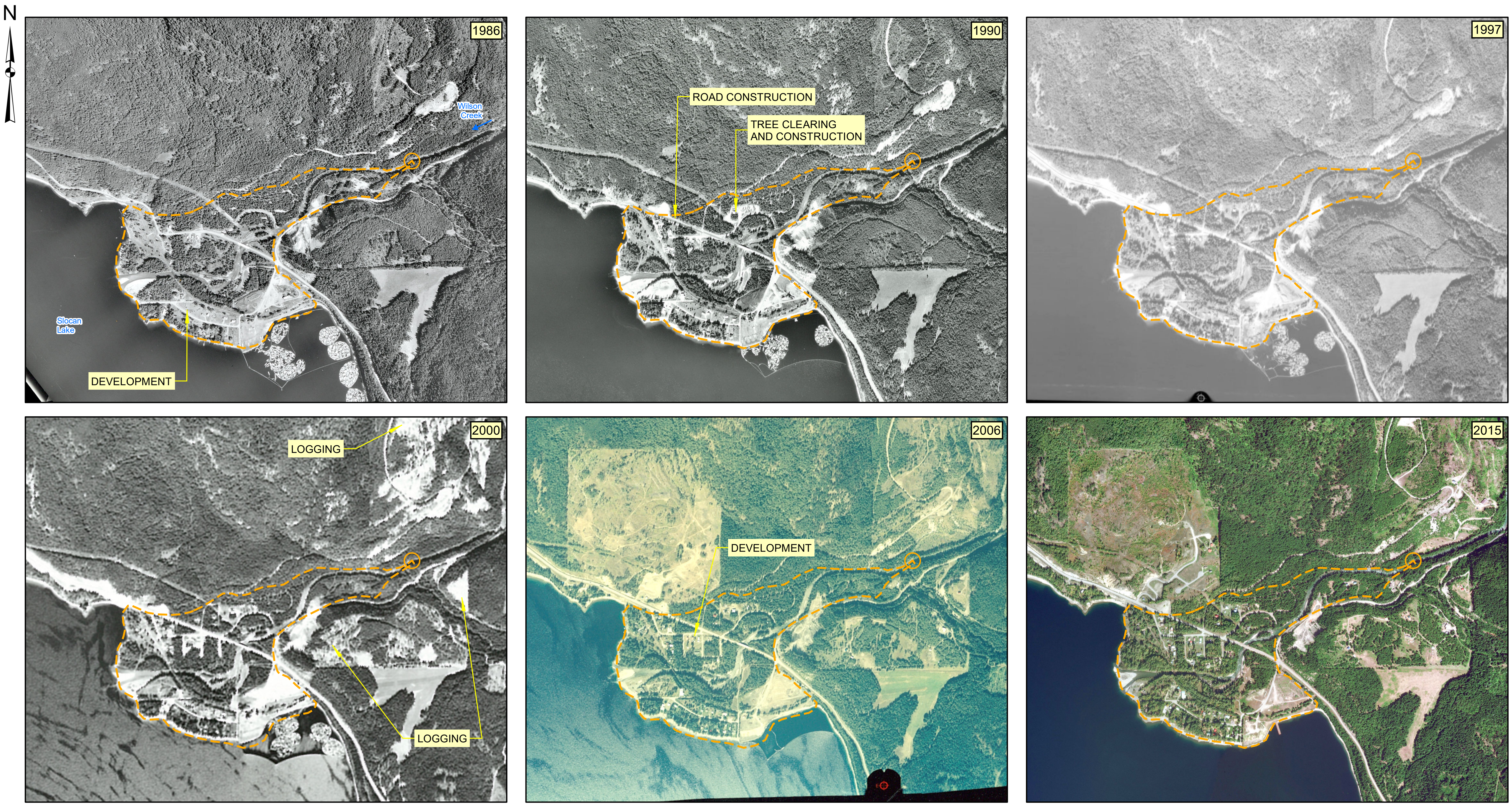
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE:
WILSON CREEK
AIR PHOTO COMPARISON

PROJECT No.: 0268007
DWG No: 04A



SCALE 1:20,000
200 0 200 400 600
METRES

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

LEGEND

▭	APPROXIMATE FAN-DELTA BOUNDARY 2018
○	FAN APEX

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 - WILSON 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 2018. 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. COORDINATE SYSTEM IS UTM ZONE 11 NAD 1983. VERTICAL DATUM IS UNKNOWN.
7. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE:	1:20,000
DATE:	MAR 2020
DRAWN:	MIB, LL
CHECKED:	JJHP, LCH
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE:
WILSON CREEK
AIR PHOTO COMPARISON

PROJECT No.:	DWG No:
0268007	04B

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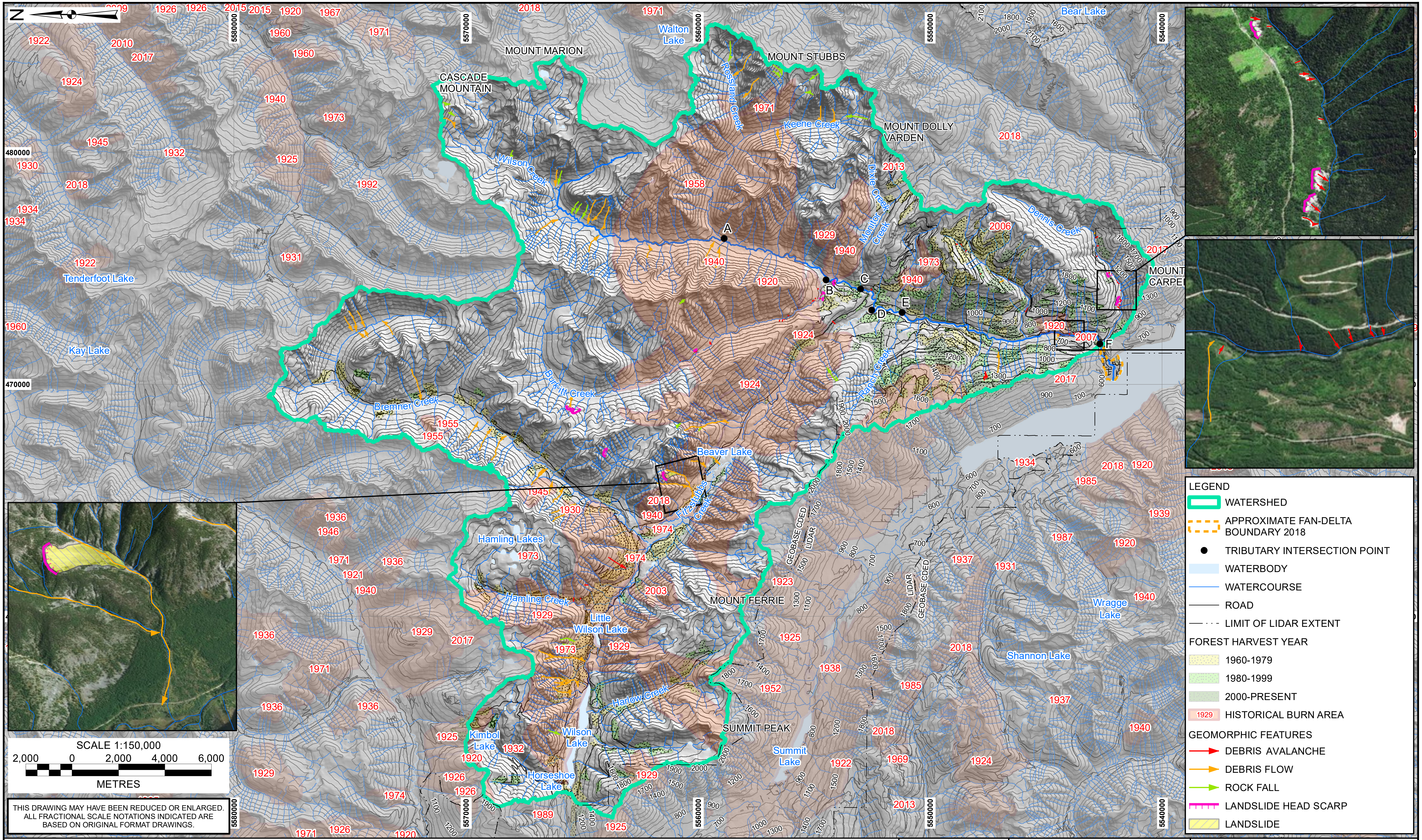

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NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY - WILSON CREEK ", AND DATED MARCH 2020.
3. BASE IMAGERY PROVIDED BY ESRI GLOBAL IMAGERY SERVICE AND DATED 2015. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2018, AND GEOBASE CDED. CONTOUR INTERVAL IS 100m.
4. THE WATERSHED AND FAN-DELTA BOUNDARY AS DRAWN ARE APPROXIMATE AND DELINEATE THE LANDFORMS BASED ON LIDAR DATED 2018. THE BOUNDARIES SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DO THEY SHOW THE SPATIAL EXTENT OF POTENTIAL FLOODING.
5. HISTORICAL CUT BLOCK DATA FROM GEOBC DATASET DATED 2019 AND ONLY REPRESENTATIVE OF AREAS THAT INTERSECT WATERSHED BOUNDARY. HISTORICAL BURN AREA FROM GEOBC DATASET DATED 2019.
6. SUBMERGED FAN-DELTA DELINEATED BASED ON LAKE LEVEL FROM LIDAR DATED 2018.
7. 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.

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DATE: MAR 2020
DRAWN: MW
CHECKED: JJHP
APPROVED: MJ

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CLIENT: REGIONAL DISTRICT CENTRAL KOOTENAY

PROJECT: RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE: WILSON CREEK
WATERSHED GEOMORPHOLOGY

PROJECT No.: 0268007
DWG No.: 05

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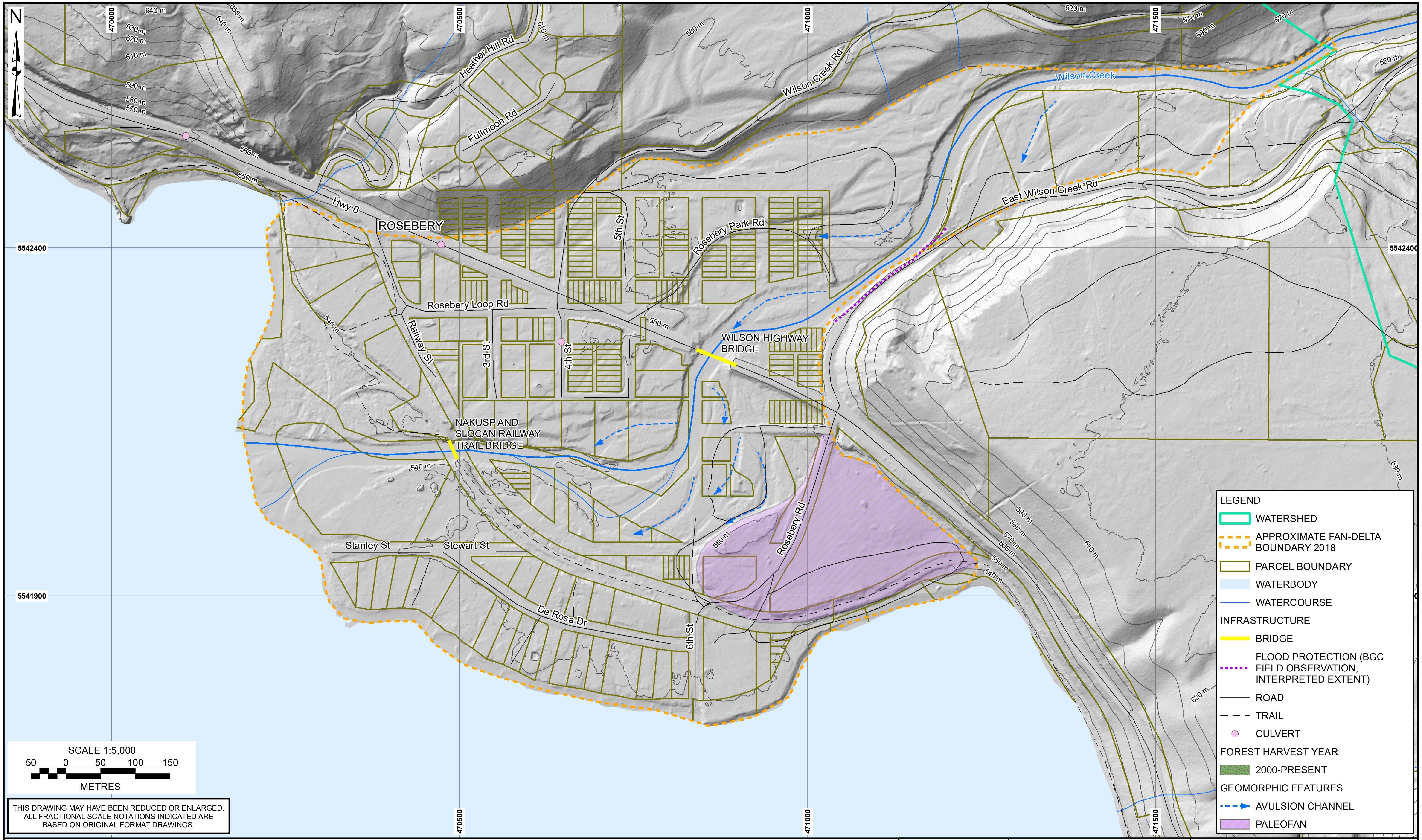

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NOTES:
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3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK DATED 2018, AND GEOBASE CDED. CONTOUR INTERVAL IS 10m.
4. THE WATERSHED AND FAN-DELTA BOUNDARY AS DRAWN ARE APPROXIMATE AND DELINEATE THE LANDFORMS BASED ON LIDAR DATED 2018. 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 2018.
6. CULVERT LOCATIONS FROM BC MINISTRY OF TRANSPORTATION. ROADS DATA FROM BC DIGITAL ROAD ATLAS. PARCELS FROM PARCELMAP BC. 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.

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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:
WILSON CREEK
FAN-DELTA GEOMORPHOLOGY

PROJECT No.: 0268007
DWG No: 06

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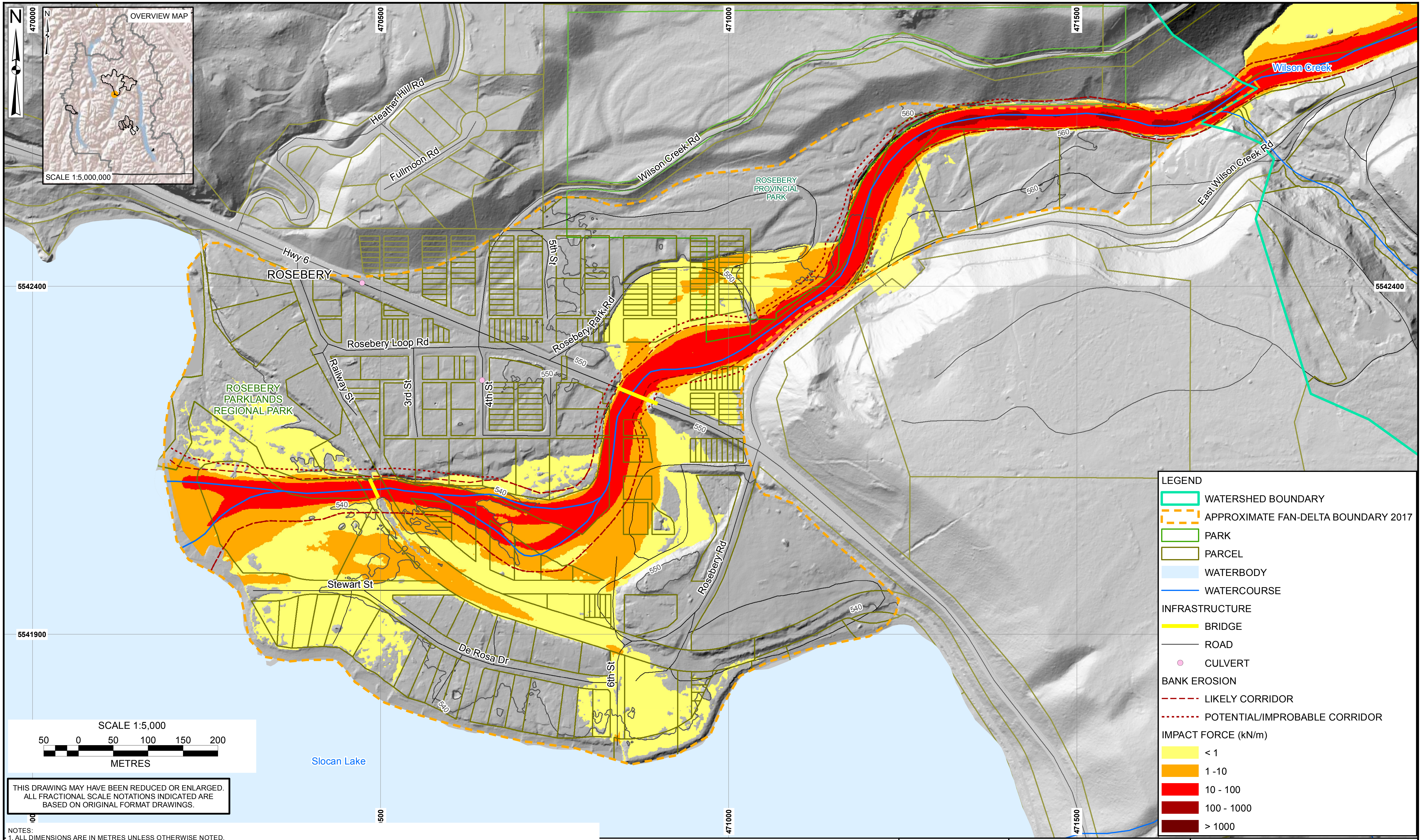

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NOTES:
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3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK, DATED 2018. CONTOUR INTERVAL IS 20 m AND 10 m ON FAN.
4. MODELLED BANK EROSION IS SHOWN AS A LIKELY CORRIDOR (DIVIDED BETWEEN CHANNEL BANKS BASED ON CHANNEL GEOMETRY) AND POTENTIAL/IMPROBABLE CORRDIOR (APPLIED EQUALLY TO BOTH BANKS).
5. BUILDING FOOTPRINTS DIGITIZED BY BGC BASED ON LIDAR AND REPRESENT ONLY A SUBSET OF TOTAL BUILDINGS ON THE FAN-DELTA. 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.

DRAFT

SCALE: 1:5,000
DATE: MAR 2020
DRAWN: LL, MIB, STT
CHECKED: LCH
APPROVED:

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AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
REGIONAL DISTRICT CENTRAL KOOTENAY

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE:
WILSON CREEK 200 YEAR MODEL SCENARIO WLS-3

PROJECT No.: 0268007
DWG No: 07

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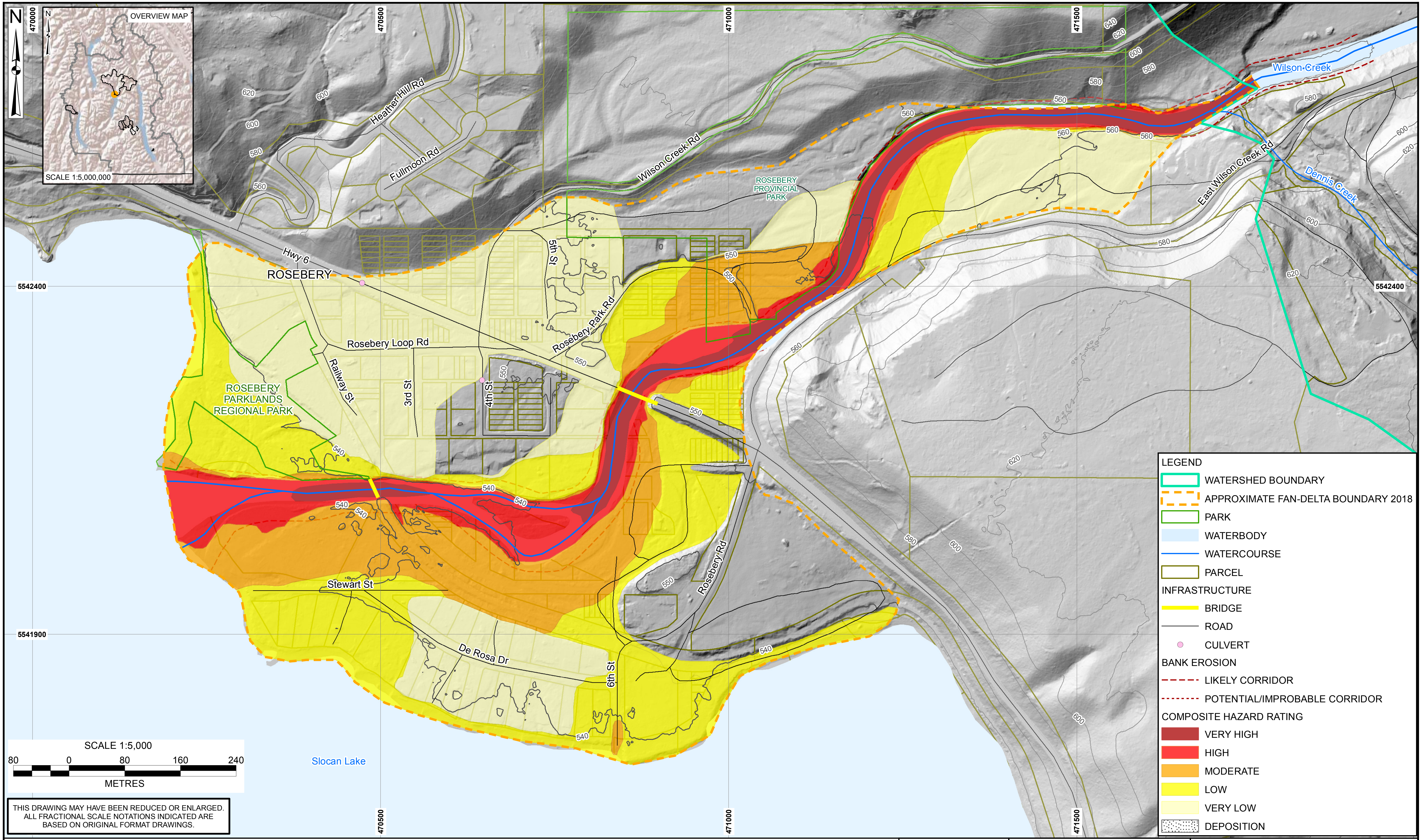

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NOTES:
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2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORTS TITLED "RDCK FLOODPLAIN AND STEEP CREEK STUDY - WILSON CREEK", AND DATED MARCH 2020.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY RDCK, DATED 2018. 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 2018.
4. MODELLED BANK EROSION IS SHOWN AS A LIKELY CORRIDOR (DIVIDED BETWEEN CHANNEL BANKS BASED ON CHANNEL GEOMETRY) AND POTENTIAL/IMPROBABLE CORRDIOR (APPLIED EQUALLY TO BOTH BANKS).
5. THIS MAP REPRESENTS A SNAPSHOT IN TIME. FUTURE CHANGES (DEVELOPMENT, DEBRIS FLOOD MITIGATION, GEOHAZARD EVENTS) MAY WARRANT RE-DRAWING OF CERTAIN AREAS.
6. BUILDING FOOTPRINTS DIGITIZED BY BGC. CULVERT LOCATIONS FROM BC MINISTRY OF TRANSPORTATION. PARKS DATA FROM GOVERNMENT OF BC. ROADS DATA FROM BC DIGITAL ROAD ATLAS. RAILWAY DATA FROM GEOBASE NATIONAL RAILWAY NETWORK. ELECTRICAL, PETROLEUM, COMMUNICATION AND WATER INFRASTRUCTURE FROM INTEGRATED CADASTRAL INFORMATION SOCIETY. BANK PROTECTION FROM GEOBC AND BGC FIELD OBSERVATIONS. PARCEL MAP FROM PARCELMAP BC.
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:	1:5,000
DATE:	MAR 2020
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CHECKED:	LCH
APPROVED:	MJ

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CLIENT:
REGIONAL DISTRICT CENTRAL KOOTENAY

PROJECT:
RDCK FLOODPLAIN AND STEEP CREEK STUDY

TITLE:
WILSON CREEK
COMPOSITE HAZARD RATING MAP

PROJECT No.: 0268007
DWG No: 08

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