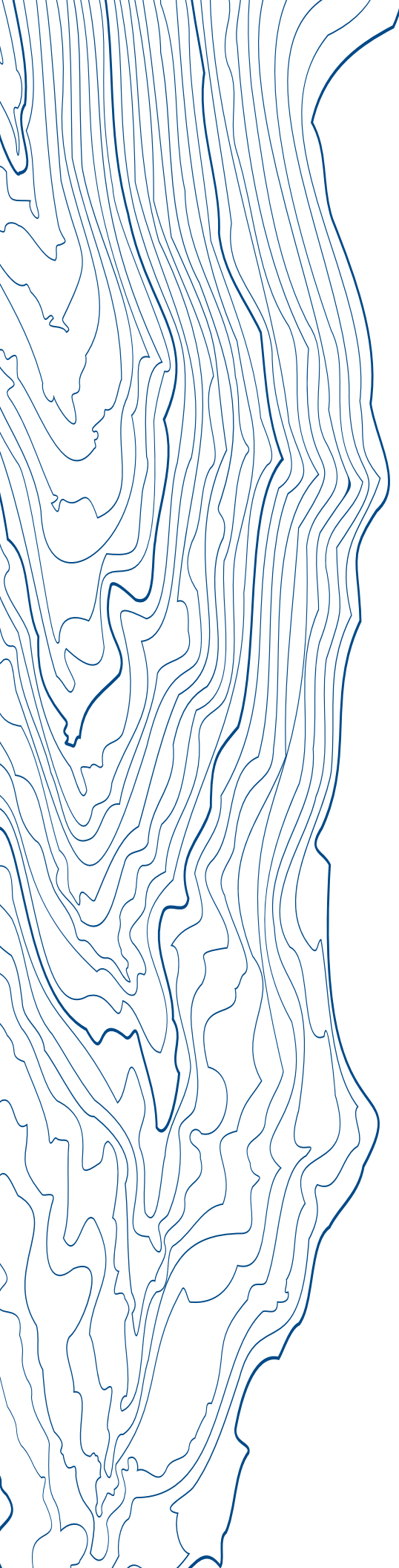


A detailed topographic map of the Fairmont Creek area, showing numerous contour lines that indicate the terrain's elevation and shape. The map is oriented vertically, with the creek's path visible on the left side.

Fairmont Creek Updated Hazard and Risk Assessment

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

October 24, 2025

Project 1127008



October 24, 2025

Project 1127008

Regional District of East Kootenay
19 – 24th Avenue
Cranbrook, BC V1C 3H8

Attention: Kara Zandbergen, Project Supervisor, Flood Mitigation and Water Resources

Fairmont Creek Updated Hazard and Risk Assessment

Please find the final report for the Fairmont Creek updated hazard and risk assessment attached. We appreciate the opportunity to collaborate with you on this challenging and interesting project.

Should you have any questions, please do not hesitate to contact the undersigned.

Yours sincerely,

BGC Engineering Inc.
per:

A handwritten signature in black ink that reads 'Beatrice Collier-Pandya'. The signature is written in a cursive, flowing style.

Beatrice Collier-Pandya, M.A.Sc., P.Eng.
Geological Engineer

EXECUTIVE SUMMARY

Fairmont Hot Springs, BC is situated on the Fairmont Creek alluvial fan, which is subject to debris-flood and debris-flow processes. A significant debris-flow event occurred on Fairmont Creek in 2012 which led to hazard and risk assessments, and the implementation of mitigative measures in phases. However, the existing mitigation may not be suitable for reducing risk from debris-flow events. BGC was retained to update the hazard and risk assessment and develop conceptual mitigation options.

The updated hazard assessment includes assessment of hazards up to the 3000-year return period. BGC interprets the dominant process type up to the 100-year return period to be debris floods, with debris flows dominating past the 100-year return period. BGC assessed debris-flood frequency-magnitude (F-M) by bulking flood peak discharges and using a sediment-rainfall empirical relationship. Debris-flow F-M was estimated using empirical models and comparing to known events. The estimated F-M values for Fairmont Creek are shown in Table E-1.

Table E-1 Debris-flood and debris-flow peak discharge and volume estimates for Fairmont Creek.

Return Period (Years)	Peak Discharge (m ³ /s)	Volume (m ³)	Process Type
10 to 30	11	9,000	Debris flood (Type 1)
30 to 100	20	28,000	Debris flood (Type 2)
100 to 300	240	72,000	Debris flow
300 to 1000	410	122,000	Debris flow
1000 to 3000	540	161,000	Debris flow

These values were then used as inputs into numerical modelling to estimate the extent and intensity of debris floods and debris flows. Modelling of the chosen hazard scenarios demonstrate that debris floods are conveyed in the channel until downstream of the golf course pond where the channel capacity is limited. Debris flows avulse from the channel at the bend downstream of Marble Canyon and downstream of the golf course pond.

The risk assessment estimated life safety and economic damage risk. The life safety risk, when compared to risk thresholds in other jurisdictions, shows that 23 parcels are above the 1:10,000 PDI threshold and the group risk is above the reference line. The main deliverable of the hazard and risk assessment is a map showing hazard zones that are equivalent to typical risk levels.

The hazard mapping and risk assessment demonstrate the need for additional mitigation on the fan to further reduce risk. BGC developed three large-scale conceptual mitigation options that include a debris-flow barrier and basin upstream of Fairmont Hot Springs Resort, a parallel basin on the golf course, and improved channel conveyance downstream of the golf course pond. BGC recommends input and discussion with other stakeholders on the mitigation options and that the chosen option is refined further in detailed design.

TABLE OF REVISIONS

Date	Revision	Remarks
July 4, 2025	Interim draft	Hazard and risk assessment draft for comments
October 8, 2025	Draft	Final draft for comments
October 24, 2025	Final	Issued to client

CREDITS AND ACKNOWLEDGEMENTS

BGC would like to acknowledge the following contributors to this report from the BGC team:

- Natalea Cohen, Junior Intern
- Hilary Schirra, P.Eng., Hydrotechnical Engineer.

In addition, BGC acknowledges the contributions and collaboration of RDEK staff to the project work presented in this report:

- Kara Zandbergen, Project Supervisor, Flood Mitigation and Water Resources, RDEK.

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ACRONYMS AND ABBREVIATIONS

CEPF	Community Emergency Preparedness Fund
CN	Curve numbers
EGBC	Engineers and Geoscientists BC
F-M	Frequency-magnitude
FHSR	Fairmont Hot Springs Resort
GCM	General Circulation Model
LDOF	Landslide dam outbreak flood
NHC	Northwest Hydraulic Consultants Ltd.
PCIC	Pacific Climate Impact Consortium
PDI	Probability of death of an individual
SSP	Shared socio-economic pathway
Urban	Urban Systems Ltd.
WMB	Water Management Board

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1.0 INTRODUCTION

The unincorporated community of Fairmont Hot Springs, BC is situated on the coalesced alluvial fans of Cold Spring and Fairmont creeks (Figure 1-1 and Drawing 01). Both creeks are subject to debris-flood and debris-flow processes. A significant debris-flow event occurred on Fairmont Creek in 2012 which led to a hazard and risk assessment with mitigation recommendations completed by Clarke Geoscience Ltd. and Golder Associates (Clarke & Golder, January 11, 2013). Since this initial assessment, RDEK has implemented mitigative measures in phases including re-establishing the channel and bank protection works along the Marble Canyon reach, widening and armouring the reach downstream of Marble Canyon to the golf course pond, construction of debris containment structures upstream of the community and resort, and installing a weather station in the Fairmont Creek watershed. However, the existing mitigation may not be suitable for reducing risk from debris-flow events.

The RDEK was awarded funding from the Province of BC's Community Emergency Preparedness Fund (CEPF) to update the hazard and risk assessments and pursue conceptual mitigation on Fairmont Creek. This work was approved by Kara Zandbergen on July 12, 2024 and is being conducted under the professional services agreement signed by RDEK and BGC on August 15, 2024.

The purpose of this project is to update the hazard and risk assessment with new and more detailed analysis methods, and to provide mitigation concepts to reduce risk to the Fairmont Hot Springs community. RDEK plans to use this assessment to make decisions around potential mitigation strategies and funding applications in the future.

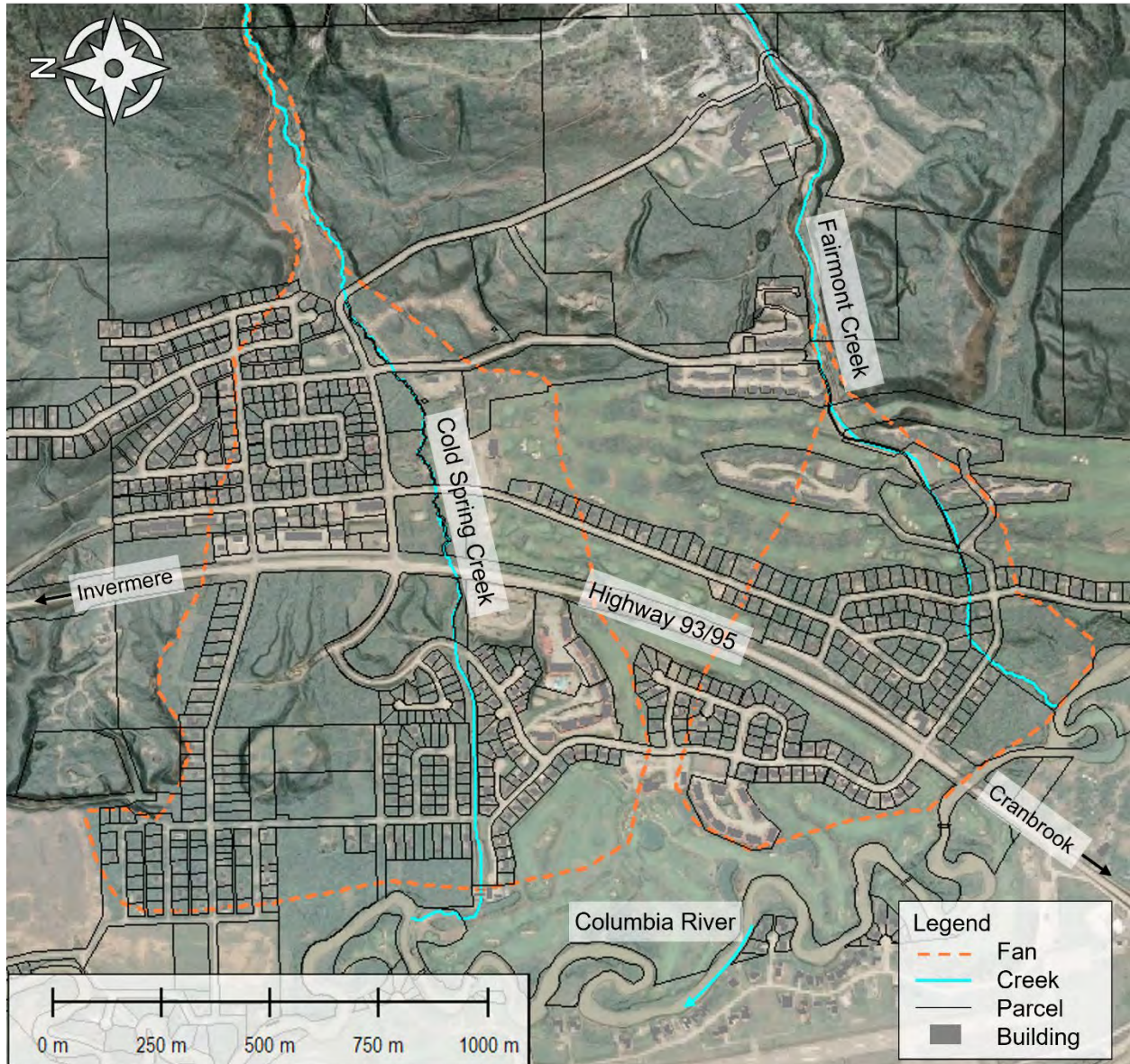


Figure 1-1 Overview of Cold Spring and Fairmont fans. The background imagery is a combination of 2018 lidar hillshade and 2023 imagery.

1.1 Scope

The scope for this project includes the following tasks:

- Desktop study that includes air photo review and review of previous work
- Field assessment with a channel investigation to collect data for hazard and risk assessment
- Hazard assessment including frequency-magnitude (F-M) development, numerical modelling, and hazard mapping
- Risk assessment for life safety (individual) and societal (group) risk
- Development of conceptual mitigation that reduces risk to the community

- Reporting that summarizes the hazard and risk assessment, and conceptual mitigation with appropriate drawings.

1.2 Background

The Fairmont Creek fan contains the namesake hot spring and much of the Fairmont Hot Springs Resort (FHSR) infrastructure as well as several golf courses and residential homes. The springs were used by Indigenous people prior to the colonial development in the 1920s (Quinn, 2023). Fairmont Creek geohazards have been studied since the 1980s in response to ongoing development on the fan. The first well documented debris-flow event occurred in 2012 and since then various studies and mitigation efforts have ensued. This section summarizes previous studies and events on Fairmont Creek that BGC is aware of.

1.2.1 Previous Work

The following documents were reviewed as part of this project:

Boyer (1989)

As the FHSR proposed to subdivide property on the Cold Spring and Fairmont Creek fans, the BC Water Management Branch (WMB) required a restrictive covenant on the property. The Boyer report provides observations and a preliminary assessment of the debris torrent² hazard stemming from both Cold Spring and Fairmont creeks. The WMB personnel observed recent debris flow activity and debris levees and lobes in the Fairmont Creek channel upstream of the present-day resort as well as oversized lone boulders on the fan surface. They also noted the presence of sediment sources in the watershed and suggested that according to the watersheds' Melton ruggedness, both Cold Spring and Fairmont creeks could be prone to debris flow processes. The report also notes that two golf course ponds on Fairmont Creek were filled with sediment in a recent debris torrent event prior to the field visit on November 15, 1988, but do not note the event date.

Reid Crowther & Partners Ltd. (1994)

To support ongoing development on FHSR properties, Reid Crowther & Partners Ltd. conducted a hazard identification study for all of the FHSR properties. They identified debris flow, flooding, erosion and gully, silt liquefaction slides and poor foundation condition hazards. Debris flow hazard was identified at Fairmont Creek and debris deflection dam conceptual mitigation measures were recommended. This report did not assess the frequency or magnitude of the hazards and recommended further study if mitigation measures were to be implemented.

Clarke and Golder (2013)

After the 2012 debris flow, Clarke and Golder (January 11, 2013) provided post-event analysis, conducted a hazard and risk assessment, and recommended mitigative measures for Fairmont Creek to the RDEK. The post-event analysis provided estimates of sediment volume and peak

² Debris torrent is an older term that is now considered synonymous with the term "debris flow".

discharge for the 2012 event, as well as observations of the extents and damage, which are discussed in Section 1.2.2 and referenced throughout this report. The hazard and risk assessment provided qualitative hazard and risk mapping of the fan. The recommended mitigation measures provided multiple options along the creek and supported some of the emergency works immediately after the event. More details of the mitigation are discussed in Section 5.0.

Urban Systems Ltd. (2015)

From 2014 to 2015, Urban Systems Ltd. (Urban) provided design, tendering and construction supervision services to RDEK for mitigation from the outlet of Marble Canyon to the golf course pond. The 2015 record drawings show channel conveyance improvements, bank armouring and berms along the channel banks that also extend partially onto the golf course to potentially contain debris that may avulse from the channel (Urban, September 16, 2015). These mitigative measures are shown in Figure 1-2 and discussed in more detail in Appendix A.

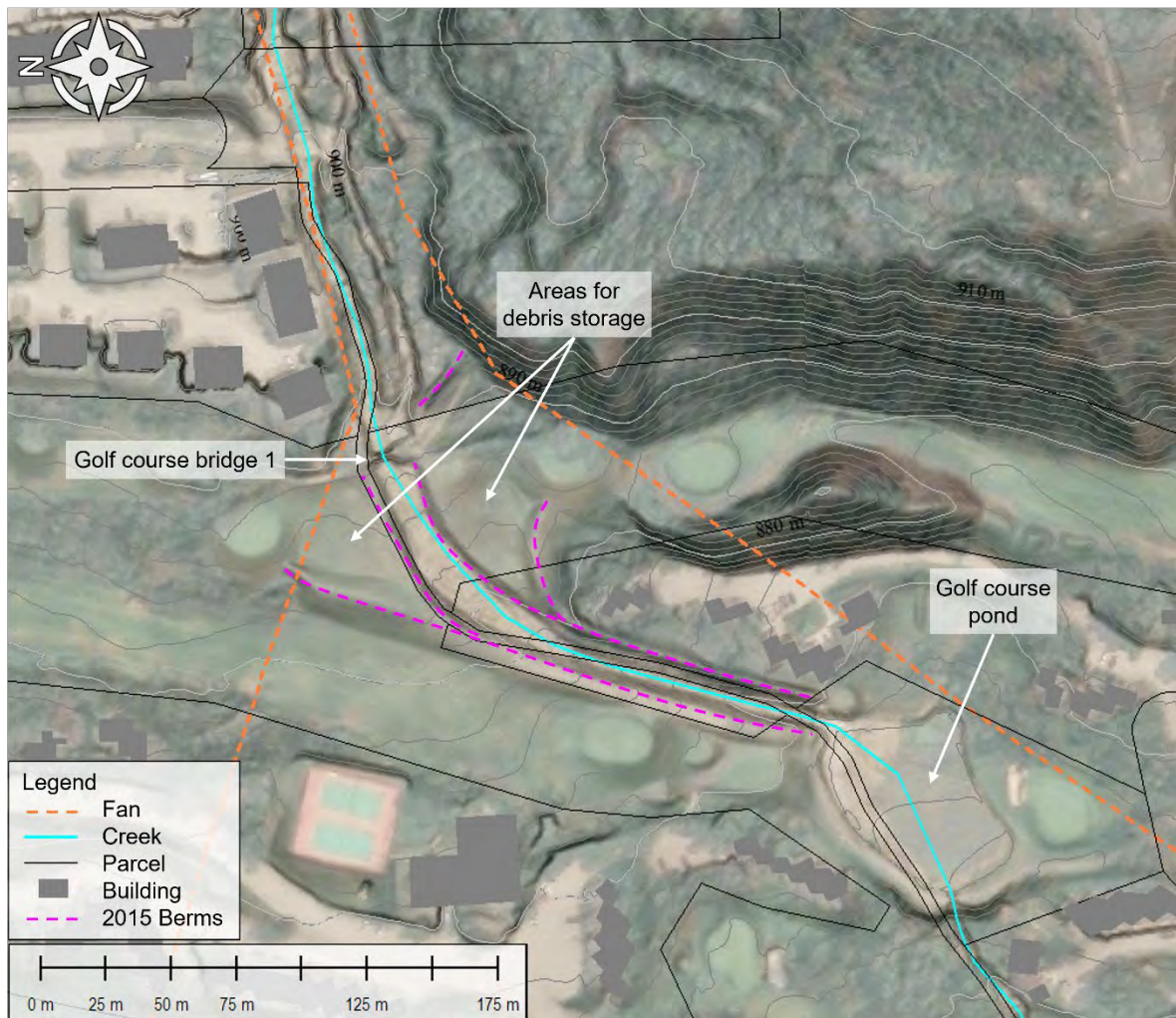


Figure 1-2 Extent of mitigation designed by Urban (2015). Contour interval is 2 m.

Northwest Hydraulic Consultants Ltd. (April 13, 2017; August 3, 2018)

Northwest Hydraulic Consultants Ltd. (NHC) designed mitigation for Fairmont Creek upstream of the fan apex and upstream of FHSR infrastructure. The mitigation was referred to as Phases 2 and 3 after the 2012 debris flow event. NHC conducted an options assessment as part of conceptual mitigation design in 2016, which selected three sediment traps as the preferred option to store debris. The constructed mitigation is comprised of three widened and deepened basins along the channel with three rock weirs (Figure 1-3). The system was designed to store approximately 17,000 m³ of debris. During this phase, a berm and channel armoring was also designed and constructed to reduce hazard to the FHSR intake sheds.

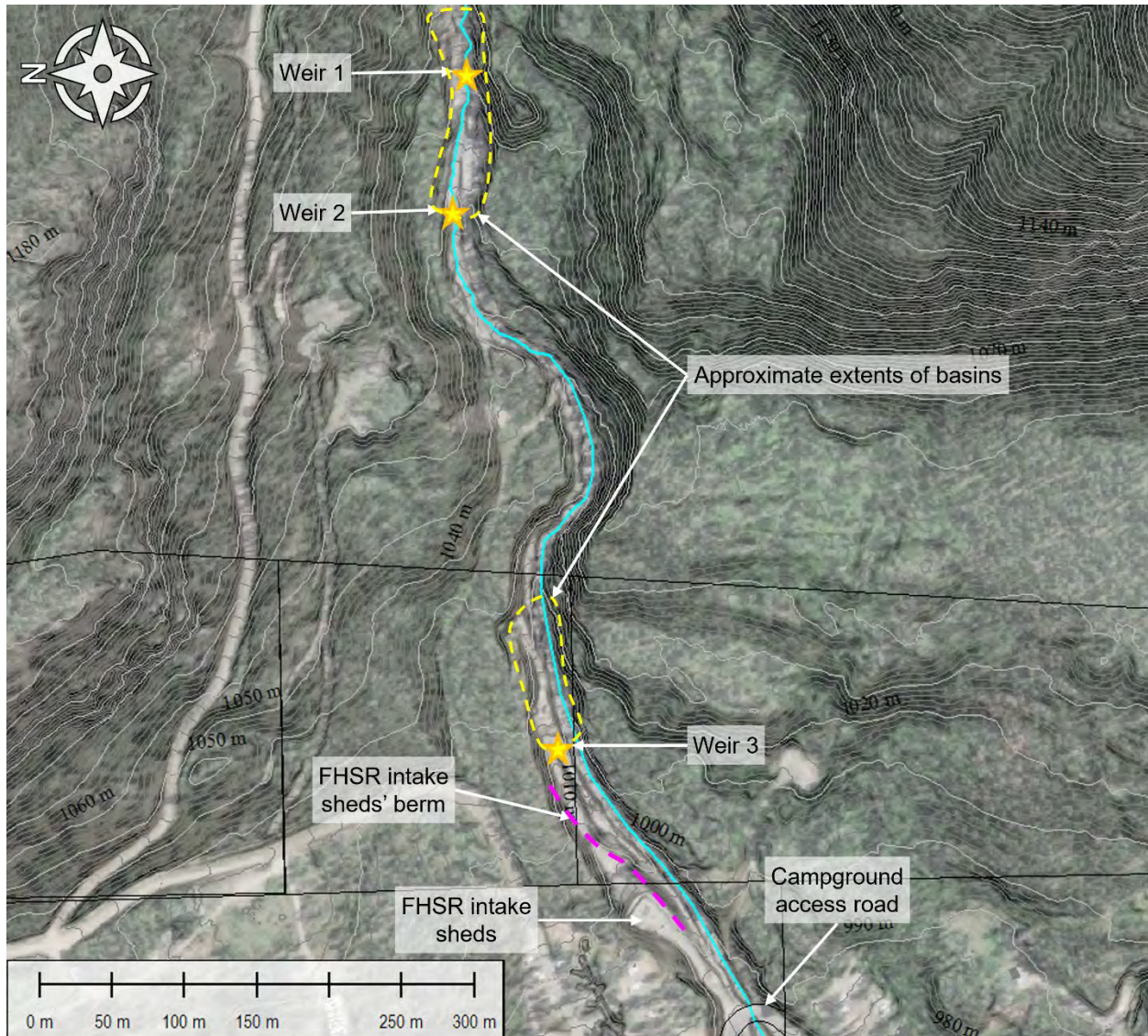


Figure 1-3 Locations of weirs, basins, and berm designed by NHC. Contour interval is 2 m.

Since completion of construction in 2018, the basins have filled with sediment and required cleanout on numerous occasions (outlined in Table 1-1 below). Therefore, the current

configuration of the weirs and basins may not exactly match the design drawings. BGC has not reviewed the construction completion documentation. Figure 1-4 shows photos from BGC's field visit in August 2024.



Figure 1-4 Photos of the weirs and berm taken during BGC's August 2024 field visit. The photo of the berm shows the general condition and structure of the berm but does not show the entire extent.

[NHC \(June 24, 2020\)](#)

NHC completed a post-event analysis of debris floods in May 2020 that occurred on Fairmont and Cold Spring creeks. The report outlines post-event observations and recommendations on clean-up prior to lifting evacuation orders for residents. NHC suggested a revised return period for the 2012 event based on the continued collection of data. The analysis estimated the volume of the event to be 20,000 m³ and the peak discharge to be 4 to 7 m³/s. NHC (June 24, 2020) also provided observations of the event extents and damage and made recommendations to improve flood management for future events on Fairmont Creek.

1.2.2 Previous Events

Since 2012, RDEK has been tracking events and debris removal volumes on Fairmont Creek. Table 1-1 summarizes events that required debris removal. Key information and observations on the 2012 and 2020 events are provided below.

Table 1-1 Debris removal volumes from Fairmont Creek since 2012, as recorded by RDEK.

Date	Debris Volume (m ³)	RDEK Notes
July 15, 2012	65,000	Volume estimated by Clarke and Golder (January 11, 2013). Debris flow event triggered by local storm.
June 20, 2013	6,000	Widespread weather event.
August 12, 2019	3,000	
May 31, 2020	20,000	Volume estimated by NHC (June 24, 2020), not including debris entrainment on the fan. Debris flood event triggered by rain event following snowmelt.
May 24, 2021	6,000	
May 1, 2023	2,000	
August 4, 2024	4,000	Convective storm.

2012 Debris Flow

Clarke and Golder (January 11, 2013) estimated the sediment volume of the 2012 debris flow to be 65,000 m³ with a peak discharge of 165 m³/s. The debris flow deposited material in the main channel from the hot spring intake sheds to the golf course pond, including burying the intake sheds. The debris flow blocked the culvert under the road leading to the FHSR campground and damaged the footbridge connecting the campground to the main resort. Downstream of Marble Canyon the event avulsed from the main channel in several locations inundating residential buildings, roads and the Mountainside Golf Course with debris. The debris flow required approximately 350 people to be evacuated. Water source intakes along the creek for the resort and golf course irrigation were destroyed. No single landslide was identified as the source for the debris flow, although small landslides and bank failures were observed in the watershed. The event is likely to have been triggered by a localized storm after a wet spring, although regional climate stations have differing rainfall amounts during this event. Rainfall intensities have been estimated from radar to be up to 8mm/hr.

2020 Debris Flood

NHC (June 24, 2020) estimated the volume of the 2020 debris flood³ to be 20,000 m³ with a peak discharge on the distal fan downstream of the golf course pond of 4 to 7 m³/s. The event filled all three weirs that were constructed in 2018 and buried the upstream weir in up to 3 m of

³ NHC (June 24, 2020) reports 20,000 m³ as being the volume of material mobilized upstream of the weirs while more debris was mobilized between and downstream of the weirs contributing to the total deposited in the weirs and golf course pond of 32,000 m³.

debris. Downstream of the weirs, the flow eroded banks and knick-points due to the lack of sediment in the flow after depositing in the weirs. Key locations of erosion included the downstream end of 2018 armouring work on the right bank where the channel moved towards the FHSR intake sheds, the downstream slope of the campground access road where flow overtopped the culvert, and the path at the bottom of Marble Canyon, parallel to the channel. Approximately 8,000 m³ of debris was deposited on the golf course and in the golf course pond downstream of Marble Canyon. No substantial sediment transport occurred downstream of the golf course pond, although flow overwhelmed the channel capacity at several locations, particularly around undersized culverts. At the Fairmont Creek station, the maximum 24-hour and 1-hour rainfall was 32.8 mm and 10.2 mm, respectively. This was in addition to snowmelt runoff driven by two days of warm weather prior to the event.

1.2.3 Data

This report relies on the following data sources:

- 2018 lidar provided by RDEK and collected by McElhanney Ltd. on September 12, 2018
- BC parcel dataset with assessment data joined from GeoBC received in October 2023.

2.0 STUDY AREA CHARACTERISTICS

This section provides an overview of the geology, watershed and fan characteristics, hazard process type, hydroclimatic conditions and climate change impacts. Fairmont Creek is in the Southern Interior Mountains ecoprovince and the Southern Rocky Mountain Trench ecoregion which is characterized by its location in the Rocky Mountain Trench and along the Columbia River (Demarchi, 2011). The southern Rocky Mountain Trench is a wide, flat-bottomed valley marking the boundary between the Omineca (i.e., Purcell and Selkirk Mountains) and Foreland (i.e., Rocky Mountains) belts. Fairmont Creek is on the western edge of the Foreland belt within the Stanford Range.

2.1 Geology

2.1.1 Bedrock Geology

The bedrock geology in the watershed consists of meta-sedimentary rocks of the Horsethief, Beaverfoot and Sullivan formations (Höy et al., 1994). The rocks vary from limestones and dolomites to phyllites but can generally be categorized as highly weatherable carbonaceous or calcareous rocks. Due to the high weathering potential of these rock types, there is an abundance of sediment available for transport in the form of talus slopes in the upper watershed and bedrock colluvium in the mid to lower watershed (Figure 2-1).



Figure 2-1 View of upper Fairmont Creek watershed highlighting unvegetated talus slopes (dashed yellow areas). Imagery from Google Earth.

2.1.2 Surficial Geology and Geomorphology

High level surficial geology mapping of this area is available and indicates till covering mountainous slopes in the watershed (Ryder & Rollerson, 1977). BGC interprets from the geomorphology visible in the lidar hillshade that bedrock in the mid to lower watershed is covered by till and colluvium generated from large deep-seated landslides and earthflows (Drawing 01). The depth to bedrock varies throughout the mid to lower watershed. These features indicate that Fairmont Creek has an abundant supply of sediment available for transport.

As the creek leaves the confined mountainous reaches, it has incised through carbonate spring deposits and kame terrace⁴ materials before flowing onto the fan. Due to the existence of the spring, which the community is named after, the surficial geology above the fan is unique compared to other creeks in the area. After deglaciation, approximately 10,500 years ago, Fairmont Creek began downcutting through the kame terrace. During this downcutting, the spring was also depositing carbonates in sheets across the kame terrace and creek. These overlapping processes created the laminated deposits that are now seen in the vertical sidewalls of Marble Canyon (Figure 2-2). This depositional process is described in Rainey (2009) and shown in Figure 2-3.

⁴ A kame terrace is a glacial deposit feature composed of sands and gravels. Kame terraces are deposited along the sides of melting glaciers.



Figure 2-2 Vertical carbonate spring deposits on the right (north) sidewall of Marble Canyon with the FHSR spring water outlet. Photo taken by BGC on August 27, 2024.

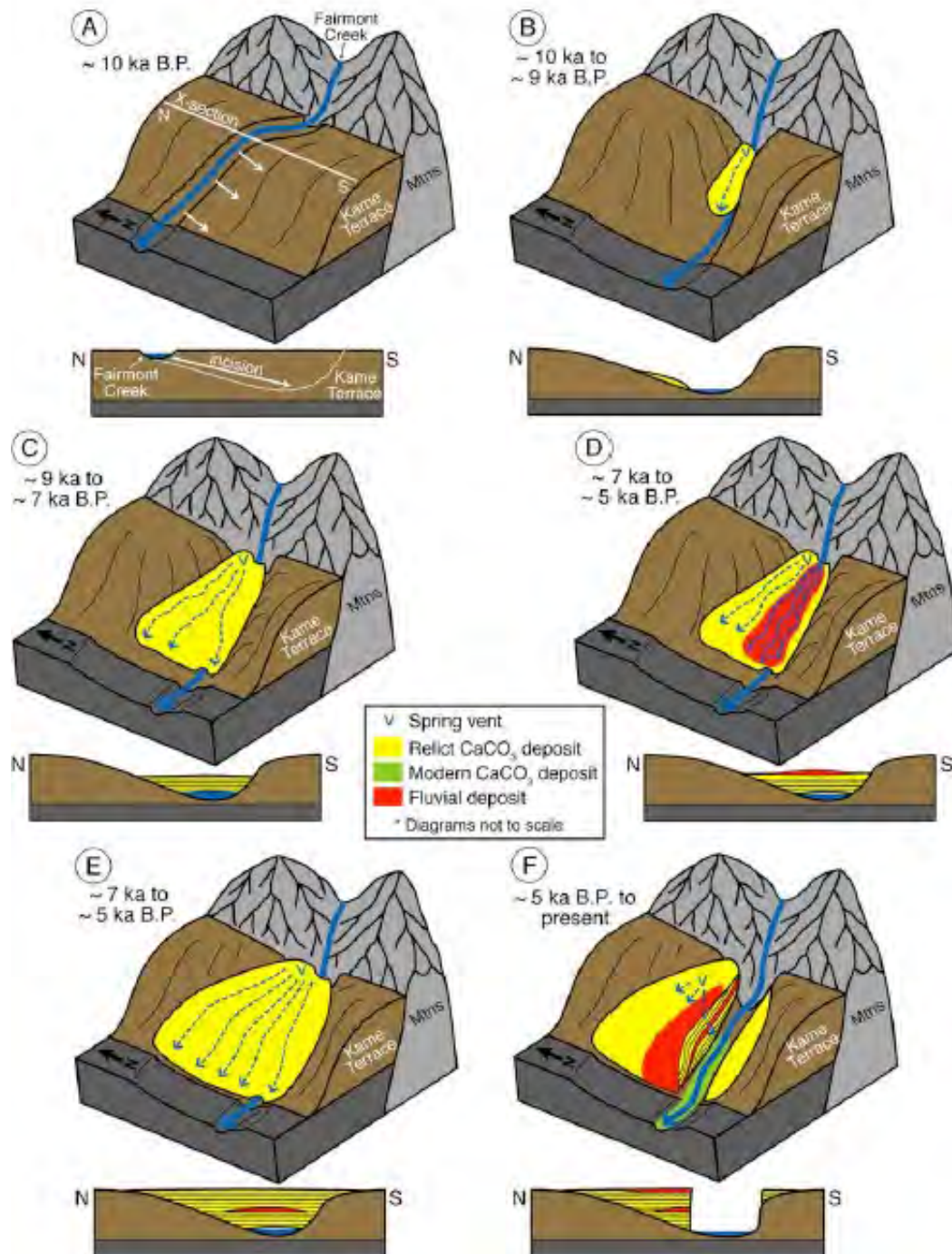


Figure 2-3 Development of the Fairmont Hot Springs carbonate deposit. Reproduced with permission from Rainey (2009). A) Post-deglaciation incision of kame terrace by Fairmont Creek. B) Fairmont Hot Springs become active and precipitate calcite. C) Deposition of lower carbonate sequence. D) Deposition of middle clastic sequence. E) Deposition of upper carbonate sequence. F) Deposit incision, development of Fairmont Creek valley and establishment of current carbonate depositional patterns that are controlled by channelled, rather than sheeted spring flow.

2.2 Watershed and Fan Characteristics

The Fairmont Creek watershed features two main tributaries that join approximately 2 km upstream of the fan apex (Drawing 01). The south tributary appears to be more active since the 2012 debris-flow event in aerial imagery (Section 3.5.1). The upper third of the watershed is more sparsely vegetated with steep bedrock faces and open talus slopes, before becoming forested in the lower two-thirds. The Fairmont Creek watershed and fan are naturally a mix of Douglas fir, spruce and pine (Forest Analysis and Inventory Branch, 2021). There is no record of significant timber harvesting activity or wildfire events⁵ (BC Wildfire Service 2025; Forest Analysis and Inventory Branch, 2025).

As the creek leaves the confined mountainous reaches, it passes through three weirs that were constructed in 2018 to contain sediment during debris floods (Figure 1-4; NHC, August 3, 2018). Downstream of the weirs, Fairmont Creek passes the FHSR intake sheds and flows through an incised reach through Marble Canyon. The FHSR intake sheds are adjacent to a berm and bank armouring that was also installed in 2018 (Figure 1-4). The berm, at its highest, is approximately 4.5 m above the current channel. This reach of the channel has most likely aggraded since the FHSR intake sheds were installed⁶, as the sheds are approximately 4 m below the elevation of the channel. The downstream end of the bank armouring was partially eroded during the 2020 event and threatened access to the FHSR intake sheds (NHC, June 24, 2020).

Marble Canyon is up to 25 m deep and 30 m wide (Figure 2-4). The active channel is 5 to 10 m wide with a recreational trail parallel to the channel through the canyon. FHSR outlets their spring water to Fairmont Creek 300 m upstream from the fan apex (Figure 2-4). Some pools have been formed under the outlet providing freely accessible hot springs to the public. From this outlet point downstream to the golf course pond, there are observable deposits of carbonates on the channel bed.

⁵ The BC provincial wildfire database records begin in 1917 (over 100 years of record).

⁶ From the aerial imagery record (Section 3.5.1), the FHSR intake sheds cannot exactly be observed in the imagery due to the resolution, but that area was first observed to be disturbed in the 1960 air photo.



Figure 2-4 Key locations along Fairmont Creek. The background imagery is a combination of 2018 lidar hillshade and 2023 imagery.

From the Marble Canyon outlet, the creek turns to flow south through the Mountainside Golf Course as it enters the fan. From the fan apex to the golf course pond, the creek is approximately 6 to 13 m wide since the 2015 mitigation work. The golf course pond is approximately 400 m downstream of the fan apex and has a surface area of 3,000 m². This pond has acted like a sediment retention basin in previous events in 2012 and 2020. In the 2020 debris flood, the golf course pond was estimated to have contained 8,000 m³ of debris (NHC, June 24, 2020), which is close to Clarke and Golder (2013)'s capacity estimate of 7,000 m³.

Downstream of the golf course pond, the creek flows west and southwest to the Columbia River over a distance of 650 m. This reach of the creek is approximately 3 to 5 m wide, 1 to 1.5 m deep, with a gradient of 6%, and passes through residential development.

Table 2-1 summarizes physical characteristics of the watershed and fan.

Table 2-1 Watershed and fan characteristics of Fairmont Creek.

Characteristic	Value
Watershed area (km ²)	11
Fan area (km ²)	0.6
Maximum watershed elevation (m)	2,570
Minimum watershed elevation (m)	890
Watershed relief (m)	1,680
Watershed length (km)	7.4
Melton ratio ¹ (km/km)	0.48
Average channel gradient of mainstem upstream of fan apex (%)	29
Average channel gradient on fan (%)	9
Average fan gradient (%)	10

Note:

1. Melton ratio is an indicator of the relative susceptibility of a watershed to debris flows, debris floods or floods. Melton ratio is the ratio of elevation range (i.e., relief) to the square root of the watershed area.

2.2.1 Existing Development

The Fairmont Creek fan is largely developed with resort infrastructure, a golf course and residential buildings. At the upstream end of Marble Canyon, the main resort development includes a hotel, restaurant, campground and hot spring pools. The campground is on both sides of the creek while the rest of the development is on the right (north) bank. Below Marble Canyon, the Mountainside Golf Course and pockets of condominiums and townhomes cover the upper third of the fan. The lower two thirds of the fan is largely developed as single-family residential lots with Highway 93/95 and the Riverside Golf Course on the distal portion of the fan.

The current creek alignment passes through and under several culverts and bridges. The culvert and bridge locations are shown on Figure 2-5. The structures' details are summarized in Appendix A.

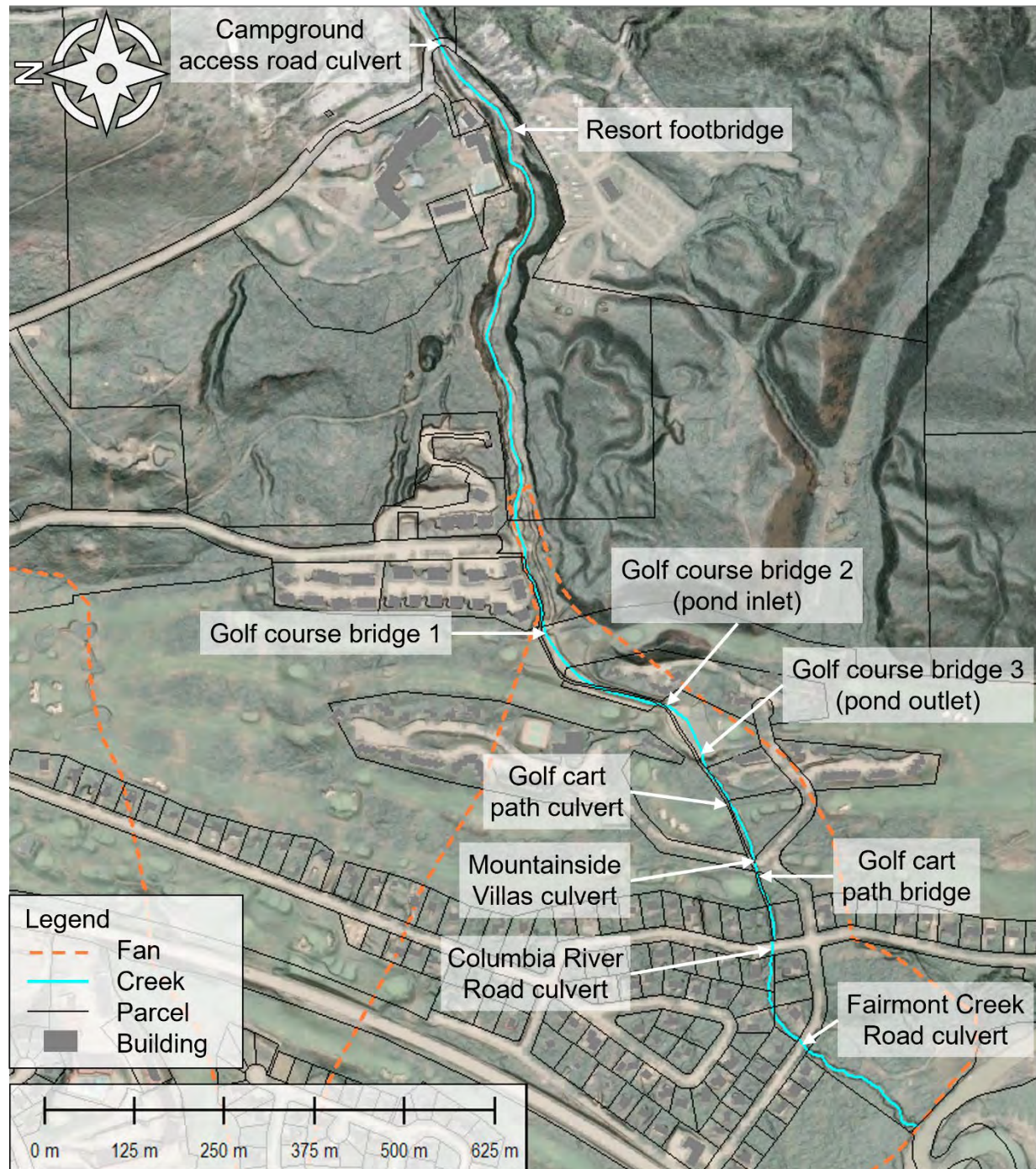


Figure 2-5 The locations of bridge and culvert infrastructure on Fairmont Creek.

2.3 Hazard Process Type

BGC assessed the potential steep creek process types and hazards on Fairmont Creek based on the Melton ratio and historical and field evidence. In comparison with a large dataset of steep creeks in BC and Alberta, Fairmont Creek plots in the zone of debris flows to debris floods (Figure 2-6), which is consistent with field evidence.

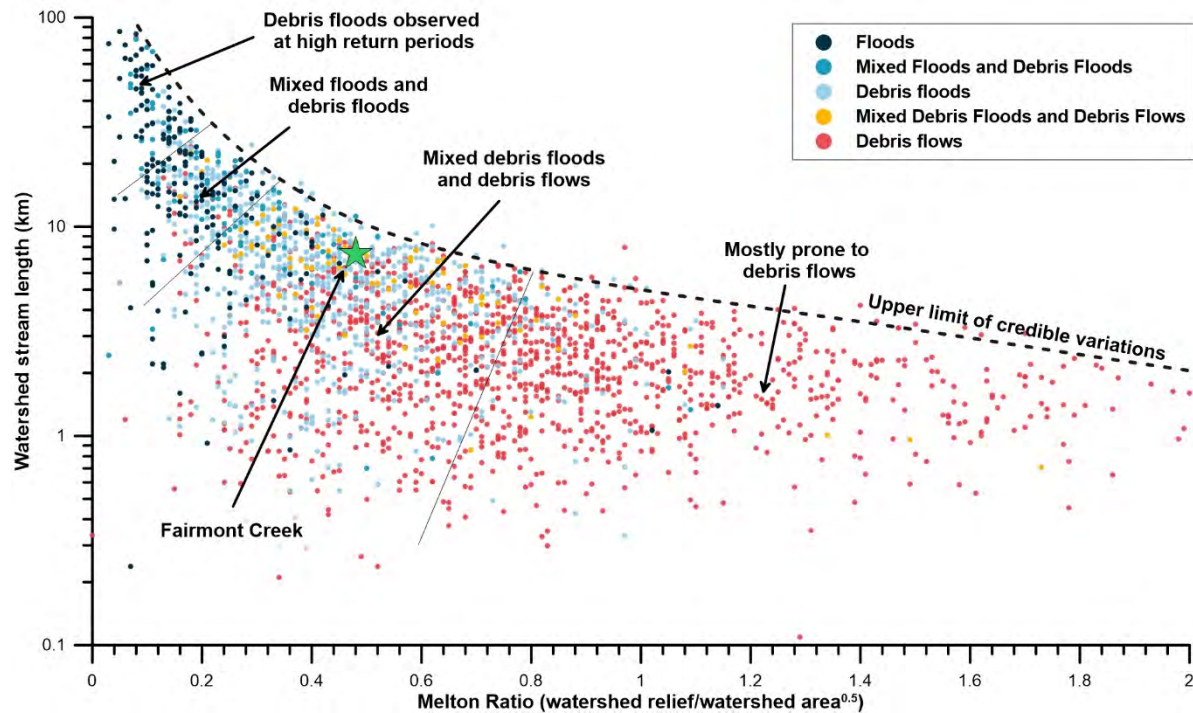


Figure 2-6 Tendency of creeks to produce floods, debris floods and debris flows as a function of Melton ratio and stream length (data from Holm et al., 2016; Lau, 2017).

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) (Church & Jakob, 2020). This differentiation is not included in the above plot as such nuances are unknown for the data included above; however, it is included in this detailed assessment.

BGC interprets that Fairmont Creek is susceptible to debris flows and all three types of debris floods, although not all processes are credible at all return periods. Details of processes at various return periods are discussed in Section 3.2.

2.4 Hydroclimatic Conditions

The Southern Rocky Mountain Trench ecoregion is the driest part of the Southern Interior Mountains ecoprovince being in a rain shadow from both Pacific systems coming over the Columbia Mountains and systems from Alberta and Montana coming over the Rocky Mountains (Demarchi, 2011). The Fairmont Hot Springs climate is characterized by hot, dryer summers where precipitation falls mainly during convective storms, and cold winters with most precipitation falling historically as snow from November to March (Figure 2-7). This leads to streamflows that exhibit a glacial-nival regime (e.g., snowmelt and glacier melt dominated) with peak flows dominated by freshet and wet springs, followed by a gradual decrease in flows during the late summer and fall and lowest flows over the winter (Schnorbus, Werner, & Bennett, 2014).

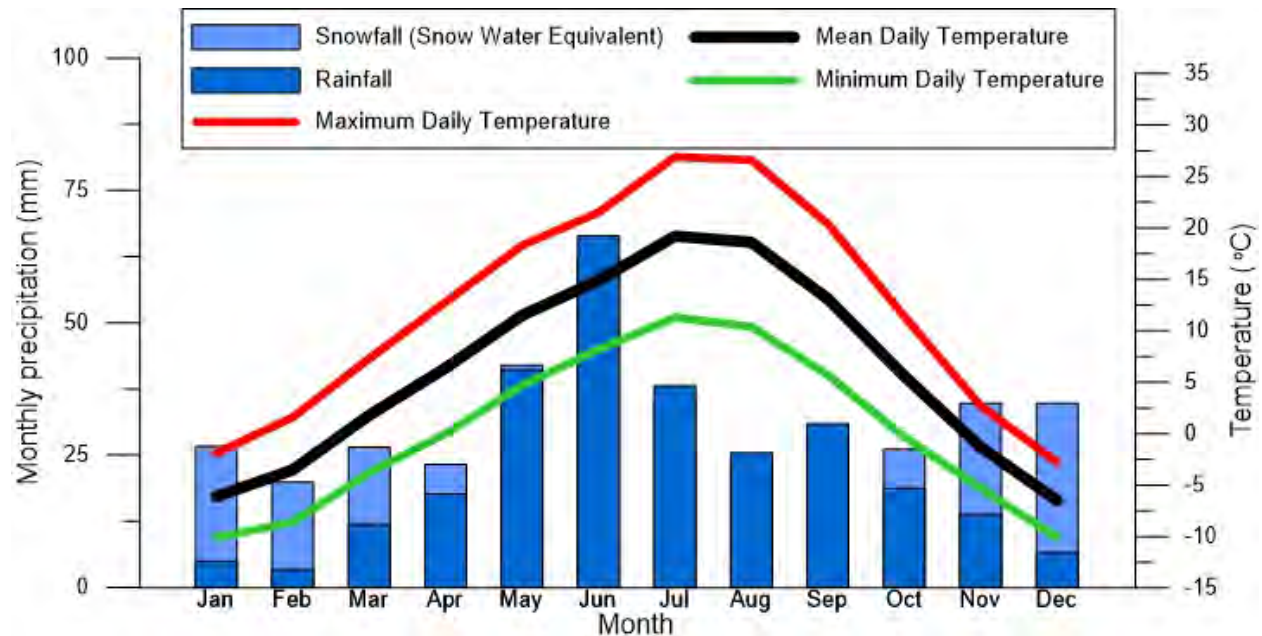


Figure 2-7 Climate normals for Cranbrook (Station IDs 1152102, 1152105, 1152106) for the period 1991 to 2020.

2.5 Climate Change Impacts

Climate change is a significant systemic shift in the long-term statistics of climate variables over several decades or longer due to natural or human induced forces. Climate change can impact the frequency, magnitude and duration of extreme events such as snow and ice storms, heavy rains, heat waves, thunder, lightning, and windstorms, which can impact steep creek hazards.

Climate projections are available from the ClimateNA dataset as published by Wang et al. (2016). This gridded dataset includes historical data and climate projections based on multiple General Circulation Models (GCMs). The shared socio-economic pathway (SSP) 5 was assumed for climate characterization. This assumption implies a radiative forcing of +8.5 Watts/m² by 2100 under a fossil-fueled development scenario with negligible emission reduction. This is considered a conservative scenario (Gillett, 2024), but changes to precipitation under the likely SSP2 scenario are similar and therefore BGC chose the SSP5 scenario for the analysis.

Climate projections show an increase in mean temperature and precipitation, and a net decrease in the mean snowfall by the 2071 to 2100 timeframe (Figure 2-8; Wang et al., 2016). The minimum temperature is projected to increase by approximately 2°C in the winter by the end of the century. Winter precipitation is projected to increase by up to 46%. This precipitation is anticipated to fall increasingly as rain as opposed to snow depending on the elevation. The proportion of winter precipitation falling as snow is projected to decrease by 50% in valley bottoms by the end of the century (Columbia Basin Trust, 2017).

The maximum temperature is projected to increase by approximately 5°C in the summer (Figure 2-8; Wang et al., 2016). The summer precipitation is projected to decrease by 13%.

These results are consistent with other studies published for the Columbia River watershed (Schnorbus et al., 2014).

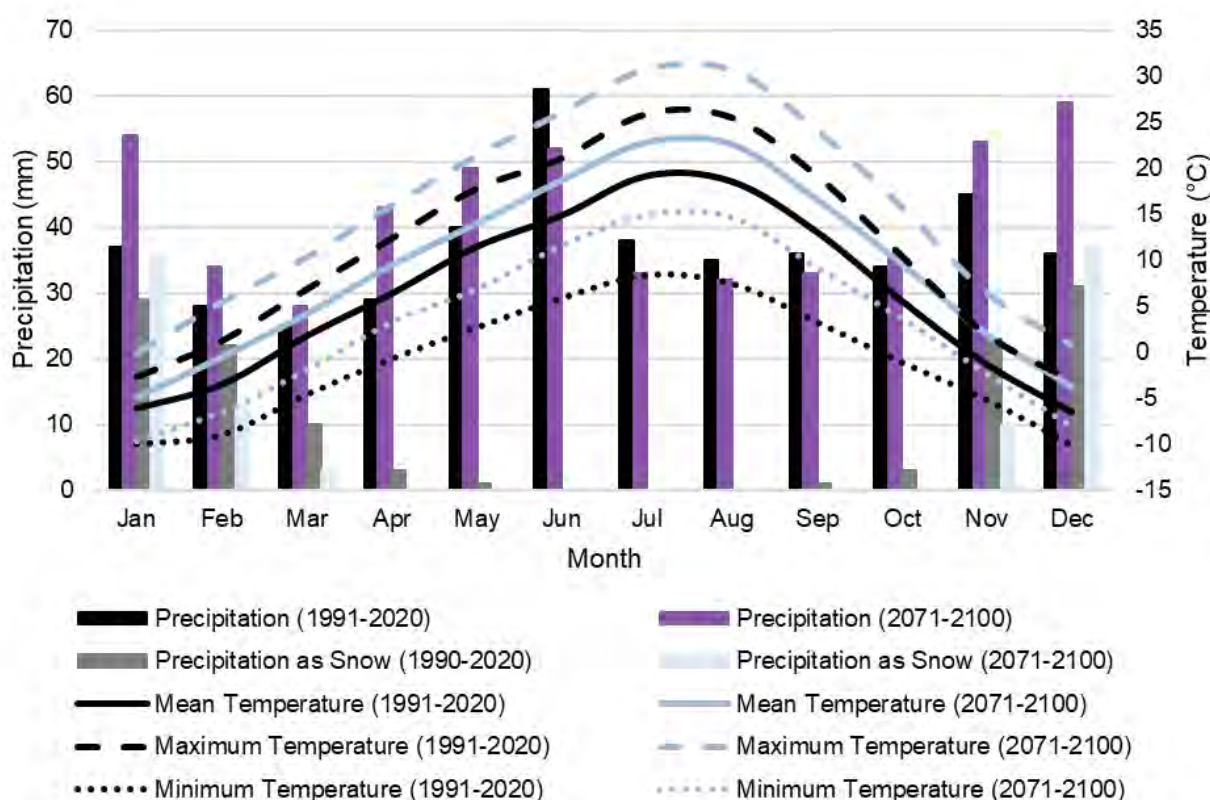


Figure 2-8 Comparison of historical (1991 to 2020) and projected (SSP5-8.5, 2071 to 2100) temperature and precipitation for Fairmont Hot Springs (Wang et al., 2016).

The impact of climate change on Fairmont Creek is expected to be primarily from changes to snow hydrology and to a lesser extent from changes to seasonal rainfall. Changes in peak flows will vary spatially and seasonally based on snow and precipitation changes and topography-based temperature gradients. An increase in peak flows for larger rivers within the Columbia River Basin is projected towards the end of the century for nearly all return periods. In other words, the probability that flows will be exceeded in any given year is expected to increase. The 100-year peak flow is projected to increase by 15% to 40% by the 2080s (Queen et al., 2021). 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 an earlier timing of the peak flow is expected (Schnorbus et al., 2014; Farjad, Gupta & Marceau, 2016).

Simulated daily mean streamflow was projected to 2100 by the Pacific Climate Impact Consortium (PCIC) at the *Kootenay River at Fort Steele* (08NG065) hydrometric station located just downstream of its confluence with the St. Mary River as well as the *Columbia River at Nicholson* (08NA002) hydrometric station, located 80 km south and 130 km north of Fairmont Hot Springs, respectively. Peak flows (ensemble median of the six GCMs) are projected to

increase by a maximum of 20% for the 200-year flood on the Kootenay River and Columbia River by the end of the century from corresponding historical results.

BGC considered climate change impacts on the frequency and magnitude of steep creek hazard processes on Fairmont Creek. The impact on debris flood processes is quantified through the increase in precipitation expected and therefore increased peak flows (Section 3.4.1). The impact on debris flow processes is highly complex and subject to much uncertainty as the increased precipitation that is predicted does not necessarily directly lead to larger or more frequent debris flows as triggering mechanisms are often more nuanced (Stoffel et al., 2024). One area of climate change impact to debris flows that has become more prevalent is post-wildfire debris-flow processes. BGC has incorporated a post-wildfire debris-flow analysis, along with relevant climate change variables, into the debris-flow assessment (Section 3.5.4).

3.0 HAZARD ASSESSMENT

This section summarizes the methods and results of the hazard assessment including field work, frequency-magnitude (F-M) development, numerical modelling and hazard mapping. Figure 3-1 shows the workflow followed.

3.1 Field Work

On August 26 to 28, 2024, Beatrice Collier-Pandya, P.Eng., and Natalea Cohen from BGC conducted a field visit to Fairmont Hot Springs and Fairmont Creek. Hamish Weatherly, P.Geo. from BGC also visited the field on August 26 and 27, 2024. During the field visit, BGC hiked the south channel to approximately 4.5 km upstream of the fan apex and the north channel to 2.5 km upstream of the fan apex to collect observations and cross-section measurements along the channel. Along the developed reaches of the creek near the resort and on the fan, BGC collected measurements and dimensions of infrastructure and mitigation. No test pitting was conducted during the field visit due to access limitations. Limited dendrochronological samples were collected as the fan has been extensively developed, and few older trees still exist on the fan.

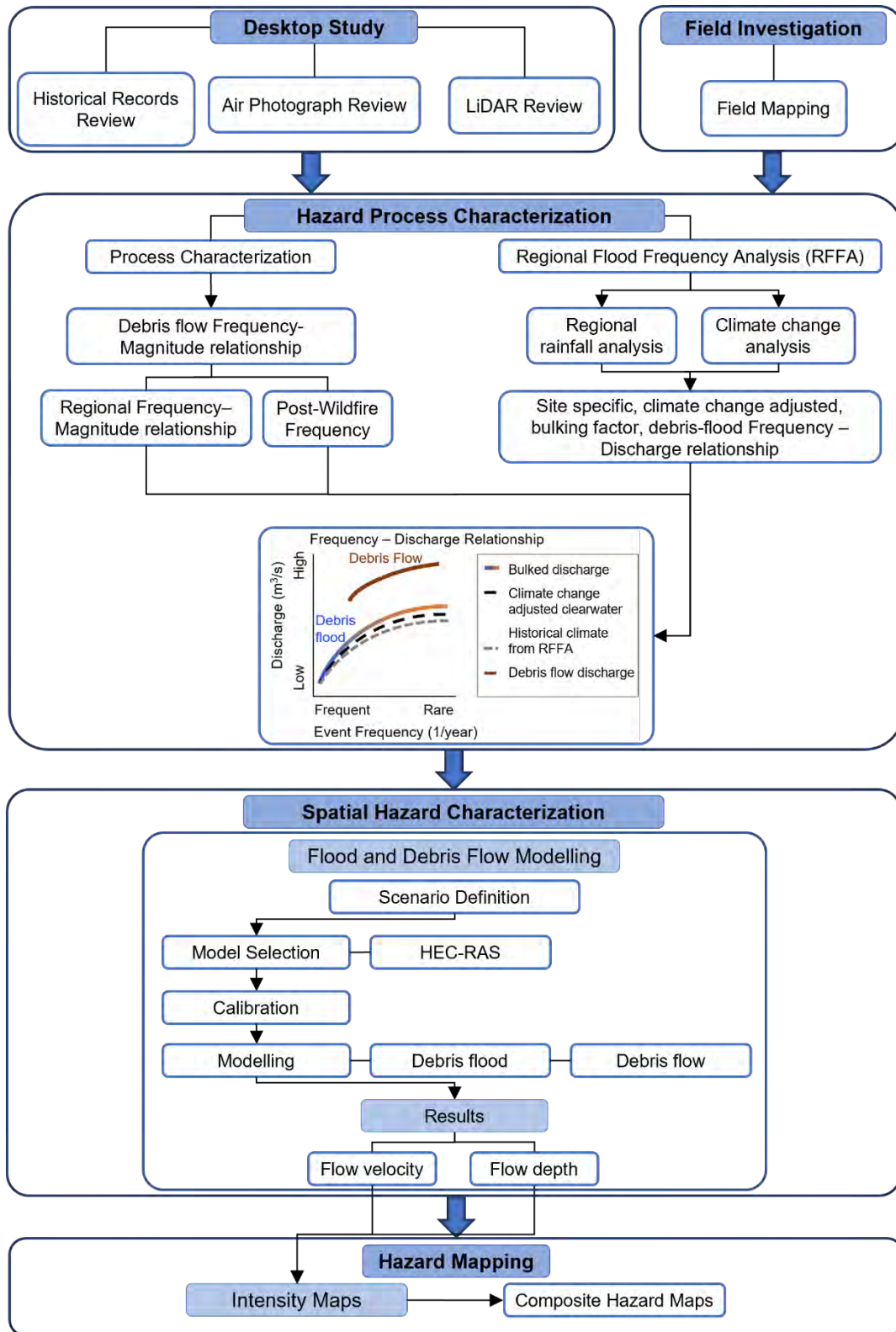


Figure 3-1 The workflow followed by BGC for the Fairmont Creek hazard assessment.

3.2 Hazard Process Characterization

Figure 2-6 indicates that Fairmont Creek is prone to debris floods and debris flows. This result is consistent with the following evidence:

- The creek produced a debris flow in 2012 and several debris floods in the last decade
- The average channel gradient above the fan apex is 29%, which allows sustained debris flow transport
- Large, subangular boulders are found at surface around the fan that are likely to have been transported by past debris flows (Figure 3-2)
- BGC interprets the watershed to be supply-unlimited, i.e., event sizes are limited by the transport capacity of the creek rather than sediment availability (Figure 3-3)
- BGC observed debris-flow geomorphology in the watershed while in the field, e.g., historical deposits, levees, debris lobes, and high-water marks well above typical creek levels (Figure 3-4).



Figure 3-2 Boulders found on the mid-fan that are interpreted to be from historical debris flows. Photos taken by BGC on August 28, 2024.



Figure 3-3 Extensive sediment supply in the watershed. A) From erodible materials in the banks and B) weak, weathering bedrock and talus slopes. Photos taken by BGC on August 27, 2024.



Figure 3-4 Debris flow geomorphology observed in the watershed on both main tributaries. Photos taken by BGC on August 26 and 27, 2024.

Table 3-1 shows the dominant process type at each return period for Fairmont Creek interpreted by BGC according to event records from RDEK, watershed geomorphology, and field observations. Using the 2012 event as a proxy for debris flow events in this watershed, debris flows in this watershed appear to be triggered in the late spring or early summer during heavy rainfall events combined with some degree of snowmelt providing antecedent soil moisture. Debris is readily available in or adjacent to the channel and is entrained, rather than a large landslide becoming channelized. During BGC's previous debris-flow threshold work, higher intensity rainfall than during the 2012 event has occurred without triggering a debris flow, indicating that this is not the only factor involved in triggering a debris flow.

Table 3-1 Steep creek process types for Fairmont Creek at various return periods.

Return Period (Years)	Process Type
10 to 30	Type 1 debris flood
30 to 100	Type 2 debris flood
100 to 300	Debris flow
300 to 1000	Debris flow
1000 to 3000	Debris flow

3.3 Frequency-Magnitude Relationships

An F-M relationship answers the question “how often (frequency) and how big (magnitude) can steep creek hazard events become?”. The ultimate objective of an F-M analysis is to develop a relationship that relates the frequency of the hazard to its magnitude. For this assessment, frequency is expressed using return periods⁷, and sediment volume and peak discharge are used as a measure of magnitude. The following sections describe the methods employed by BGC to develop an F-M relationship for debris floods and debris flows from Fairmont Creek.

This analysis considers return periods up to 3000 years for hazard events and modelling. This return period was chosen based on the Engineers and Geoscientist BC (EGBC) Landslide Guidelines (EGBC, 2023), which consider the application of the assessment and the elements at risk.

3.4 Debris-Flood Frequency-Magnitude Relationships

3.4.1 Clearwater Flood Peak Discharges

Fairmont Creek is a relatively small, steep tributary to the Columbia River, with a watershed area of 11 km². To estimate the peak flows associated with lower return period clearwater floods, a hydrologic model was created using HEC-HMS, v.4.12 (USACE, 2024a). Flows were modelled using the SCS curve number (CN) method (USACE, 2025). The curve number was selected using judgement based on a combination of field observations, and the Global Curve Number Dataset (Jafaar et al., 2019). The rainfalls associated with the events were estimated using the 24-hour rainfall depths associated with the equivalent return period storm from the BC Met Portal (RTI International, 2022). These rainstorms were assumed to fall with an SCS Storm Type 2 distribution, per Millar (2017). This distribution selection was validated using historical rainfall patterns recorded at the Cranbrook A climate station. The HEC-HMS input parameters are shown in Table 3-2.

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

Table 3-2 Input parameters for HEC-HMS model to simulate peak flows.

Parameter	Value
Area (km ²)	11
Length (m)	5,300
Slope (m/m)	0.25
Composite Curve Number (CN)	72

To account for climate change, the peak discharges from the HEC-HMS model had an adjustment factor applied. As discussed in Section 2.5, flood peak discharges for rivers near Fairmont Creek are projected to increase by up to 20% by 2100. Although Fairmont Creek floods cannot be directly compared to floods on the Kootenay and Columbia rivers, there is generally less data and research on specific impacts to smaller streams. Therefore, historical peak flows are increased by 20% to account for climate change on Fairmont Creek (Table 3-3).

Table 3-3 Historical and climate change adjusted clearwater flood peak discharges on Fairmont Creek.

Return Period (Years)	Peak Discharge (m ³ /s)	
	Historical	Climate Change-Adjusted
10 to 30	8	10
30 to 100	14	17

3.4.2 Bulking Factors

The main distinguishing characteristic between clearwater floods and debris floods is their higher sediment concentration. Therefore, to estimate debris flood peak discharges a bulking factor was applied for each return period. Bulking factors were estimated according to Jakob et al. (2022). The bulking factor and peak discharge for each debris-flood return period are shown in Table 3-4.

Table 3-4 Bulking factor and debris-flood peak discharges on Fairmont Creek.

Return Period (Years)	Bulking Factor	Debris-Flood Peak Discharge (m ³ /s)
10 to 30	1.1	11
30 to 100	1.3	22

3.4.3 Sediment-Rainfall Relationship

Although sediment volumes are not as crucial for numerical modelling of debris floods, event volumes are beneficial for mitigation option assessment. BGC estimated debris-flood event volumes based on empirical relationships developed by Rickenmann and Koschni (2010) and refined by Jakob et al. (2022). The relationships relate sediment volumes to rainfall volumes for fluvial transport, debris-flood and debris-flow events. These relationships yield the sediment

volumes shown in Table 3-5. As BGC interprets the debris floods at the 30 to 100-year return period to be Type 2 (i.e., diluted debris flows), the combined relationship for fluvial transport and debris flow events was deemed appropriate.

Table 3-5 Estimated debris-flood volumes for Fairmont Creek.

Return Period (Years)	Debris-Flood Volume (m ³)	Notes
10 to 30	9,000	Fluvial transport and debris flood events relationship – Type 1 debris flood
30 to 100	28,000	Fluvial transport and debris flow events relationship – Type 2 debris flood

3.5 Debris Flow Frequency-Magnitude Relationships

3.5.1 Aerial Imagery Interpretation

Air photos dated between 1949 and 2000 and satellite images from 2017 to 2023 were examined for evidence of past sediment transport events, and significant observations are noted in Table 3-6. A complete list of the imagery reviewed is included in Appendix B. Figure 3-5 shows air photos with significant development between them.

Events were identified from the appearance of bright areas and disturbed vegetation relative to previous imagery. 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 images or successive events that overlap may not be captured. Imagery interpretation was supplemented by historical records of past events.

Table 3-6 Substantial aerial imagery observations.

Image Year	Observations
1949	Fairmont Creek follows a straighter path across the fan from the outlet of Marble Canyon to the Columbia River. The fan is crossed by a road with a similar alignment to the current day Hot Springs Road. There are some buildings near the present-day resort development with a road alignment that does not appear to be used in the present. No fresh events observed in the watershed.
1964	A small avulsion path is visible approximately 350 m upstream from the confluence with the Columbia River and the main channel is more visible than in previous air photo. Highway 93/95 has been built, and construction has begun on the Mountainside Golf Course. There has been continued development and road building around the present-day resort. Air photos only cover lower portion of the watershed, and no substantial changes are observed.
1975	The current day golf course pond is now in place and the creek appears to be following the current day alignment. Fairmont Hot Springs Resort Ski Area developed and start of residential development adjacent to golf course. There is continued development at the present-day resort. No substantial changes observed in the watershed.
1988	Start of construction of Riverside Golf Course. There is continued residential development on the fan, particularly on the lower fan and the Mountainside Vacation Villas adjacent to the creek. The campground south of the present-day resort has been developed. The channel through the watershed appears brighter to the downstream end of Marble Canyon but no deposition of material outside of the channel is observed on the fan.
2000	Continued residential development. No substantial changes observed in the watershed.
2017	This orthoimage covers the watershed. The channel through the watershed appears brighter and wider down to the present-day resort.
2023	This orthoimage covers the fan. The channel appears brighter and wider from the resort down to the golf course pond.

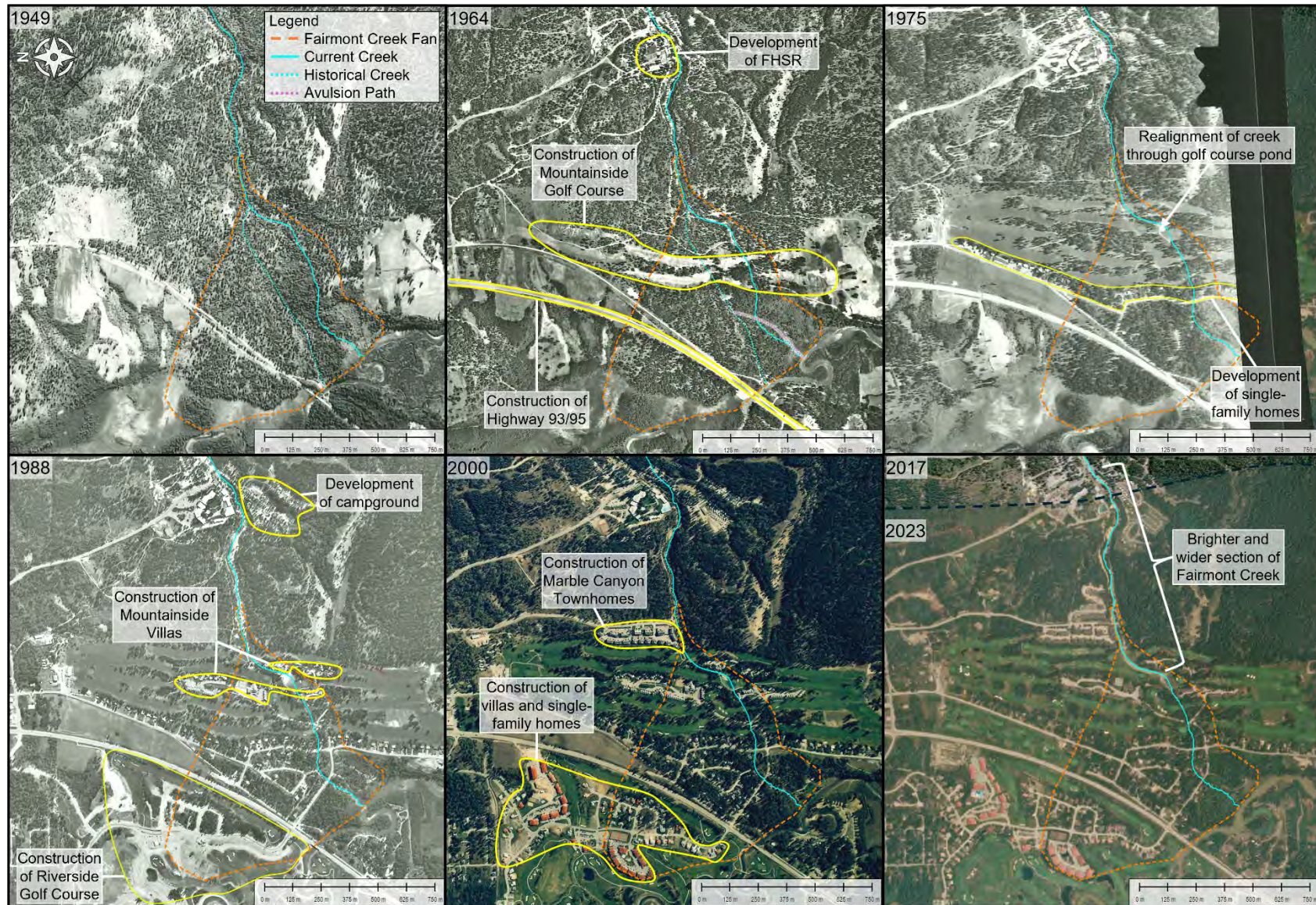


Figure 3-5 Comparison between 1949, 1964, 1975, 1988, 2000, and 2017/2023 aerial imagery showing changes on the fan through time.

BGC was not able to interpret deposition areas of any past events but did identify an avulsion from the main channel in the 1964 air photo. The main channel is also more visible in the photo as well, indicating the likely occurrence of a hydrogeomorphic event on Fairmont Creek between 1960 and 1964. The channel in the watershed and the fan in the most recent satellite imagery (i.e., 2017 and 2023) show a much more active channel that is wider and more visible. This is attributable to the 2012 debris-flow event. No other events were identified in the aerial imagery record.

3.5.2 Other Frequency Methods

Other frequency methods that are often used for debris-flow hazard assessment such as dendrochronology, test pit logging and radiocarbon dating were limited in this assessment. Due to the substantial development on the Fairmont Creek fan, there are few older trees on the fan for coring. BGC collected several dendrochronological samples along the channel in the watershed, but they did not provide any further evidence of other events.

Test pitting on the fan to observe past events was conducted after the 2012 event by Clarke and Golder (January 11, 2013). No test pitting was able to be completed as part of this assessment due to access constraints.

Clarke and Golder (January 11, 2013) identified debris flow deposits in several test pits but were unable to date the deposits. Debris flow and alluvial deposits are interfingering with carbonate deposits, which agrees with Rainey (2009)'s model that shows deposits from Fairmont Creek interbedded with carbonates since deglaciation (Figure 2-3). This data is not explicitly used in this assessment but has been qualitatively compared to volume estimates and numerical modelling results. Figure 3-6 shows an example of one test pit, the photo is from Clarke and Golder (2013), while the interpretation is by BGC based on the test pit logs from the report.

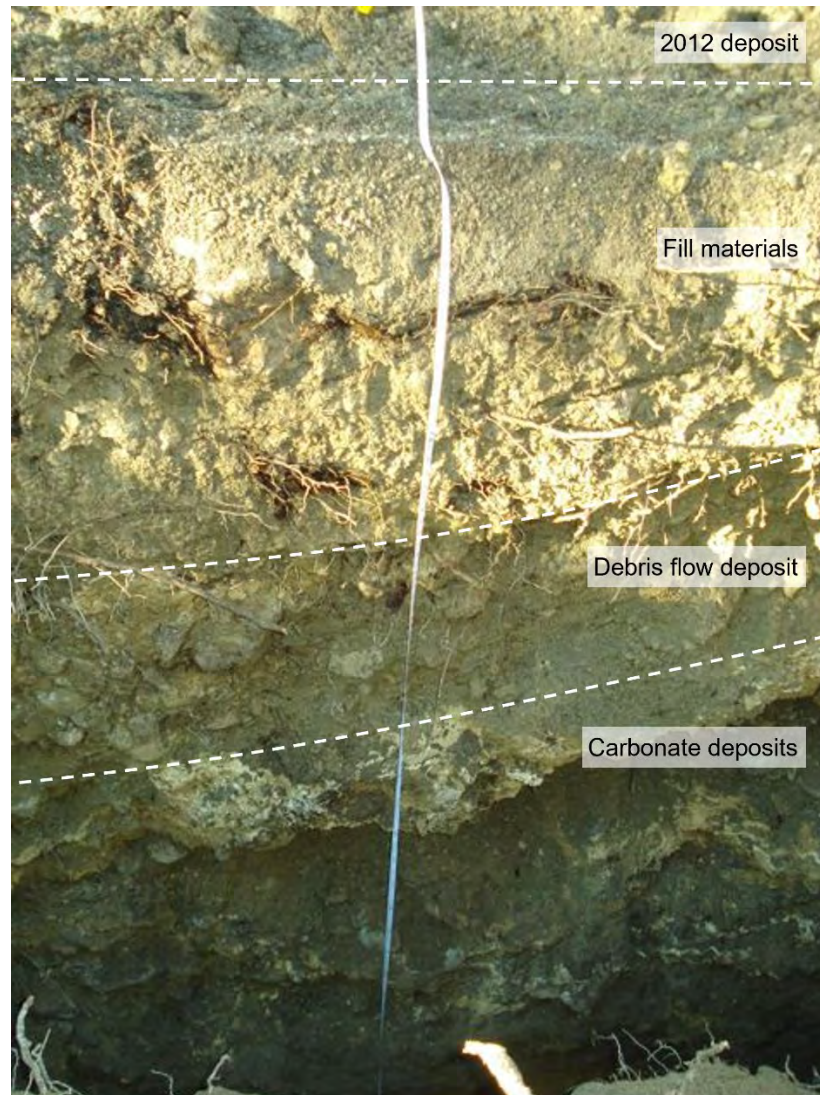


Figure 3-6 Photo of Clarke and Golder (2013)'s TP-03. Notes and delineations are by BGC based on Clarke and Golder (2013)'s test pit log.

3.5.3 Regional Frequency-Magnitude Relationship

BGC applied a regional F-M model developed by Jakob et al. (2020) for debris-flow and debris-flood creeks in southwestern BC and the Bow Valley near Canmore, AB. The model was developed by normalizing F-M relationships by their fan area for individual creeks that have been studied in detail and creating a relationship that can be applied to creeks where there is limited site-specific data available.

BGC used an F-M model developed with the Bow Valley debris-flow prone creeks for application to Fairmont Creek. Creek selection was based on:

- Similar geology and climate
- Similar process type (debris flow)
- Similar fan and watershed geomorphology.

As Fairmont Creek has unique fan geomorphology due to the extensive carbonate deposits that has limited the fan area compared to other creeks in the area, BGC chose to adjust the model by normalizing by watershed area rather than fan area. Equation 3-1 shows the resulting regional, watershed-normalized F-M relationship used for this study.

$$V_{NAW} = 3130 \ln(T) - 8550 \quad [\text{Eq. 3-1}]$$

where V_{NAW} is the normalized sediment volume associated with the watershed area and T is the return period in years.

The results of the relationship for Fairmont Creek, denormalized, are shown in Table 3-7.

Table 3-7 Regional frequency-magnitude relationship debris-flow volumes for Fairmont Creek.

Return Period (Years)	Debris-Flow Volume (m ³)
100 to 300	83,000
300 to 1000	122,000
1000 to 3000	161,000

3.5.4 Post-Wildfire Debris Flows

Wildfires in watersheds can change the geohazard regime depending on the burn severity and extent. Wildfire changes both the vegetation and soil properties. Post-wildfire, changes to soil infiltration and removal of vegetation increases run-off which leads to higher peak discharges (Gartner et al., 2024). These factors lead to an increased likelihood of post-wildfire related geohazards in the years after wildfire. Most runoff-generated post-wildfire debris floods and debris flows typically occur within the first two to three years following a fire (Cannon & Gartner, 2005; DeGraff et al., 2015; Graber et al., 2023). As wildfire has been part of the natural historical regime in these watersheds until the recent past, post-wildfire debris flows have most likely occurred on Fairmont Creek and can be considered to be incorporated in the regional F-M relationship. BGC uses an explicit post-wildfire debris flow model to compare to other F-M methods.

BGC estimated post-wildfire debris-flow volumes using an empirical model (Gartner, Cannon, & Santi, 2014). This involved:

- Calculating the likelihood of a wildfire occurring in the Fairmont Creek watershed
- Estimating the volume of a post-wildfire debris flow.

The details of the analysis are presented in Appendix C. Table 3-8 shows the resulting volumes for a range of watershed burn areas and frequencies.

Table 3-8 Estimated post-wildfire debris-flow volumes for a range of watershed burn areas.

Return Period (Years)	Post-Wildfire Debris-Flow Volumes According to Watershed Burn Area		
	20%	40%	60%
30 to 100	30,000	39,000	45,000
100 to 300	49,000	62,000	72,000
300 to 1000	78,000	100,000	116,000

3.5.5 Volume-Peak Discharge Relationships

Having estimated sediment volumes, peak discharges were estimated with an empirical relationship developed for BC muddy debris flows (Bovis & Jakob, 1999). This relationship was chosen by comparing estimates from various empirical relationships to the 2012 event peak discharge estimate and field cross section estimates.

Cross sectional measurements were collected in the field between debris flow levees, which in some cases may have been from the 2012 event or between vegetation trimlines⁸ from more recent events. Flow velocities were then estimated using Prochaska et al. (2008). Figure 3-7 shows where BGC measured cross sections, and Table 3-9 presents the discharge estimates.

⁸ High flow events on a creek, such as debris floods or debris flows, can leave high flow marks with mud or by stripping vegetation.

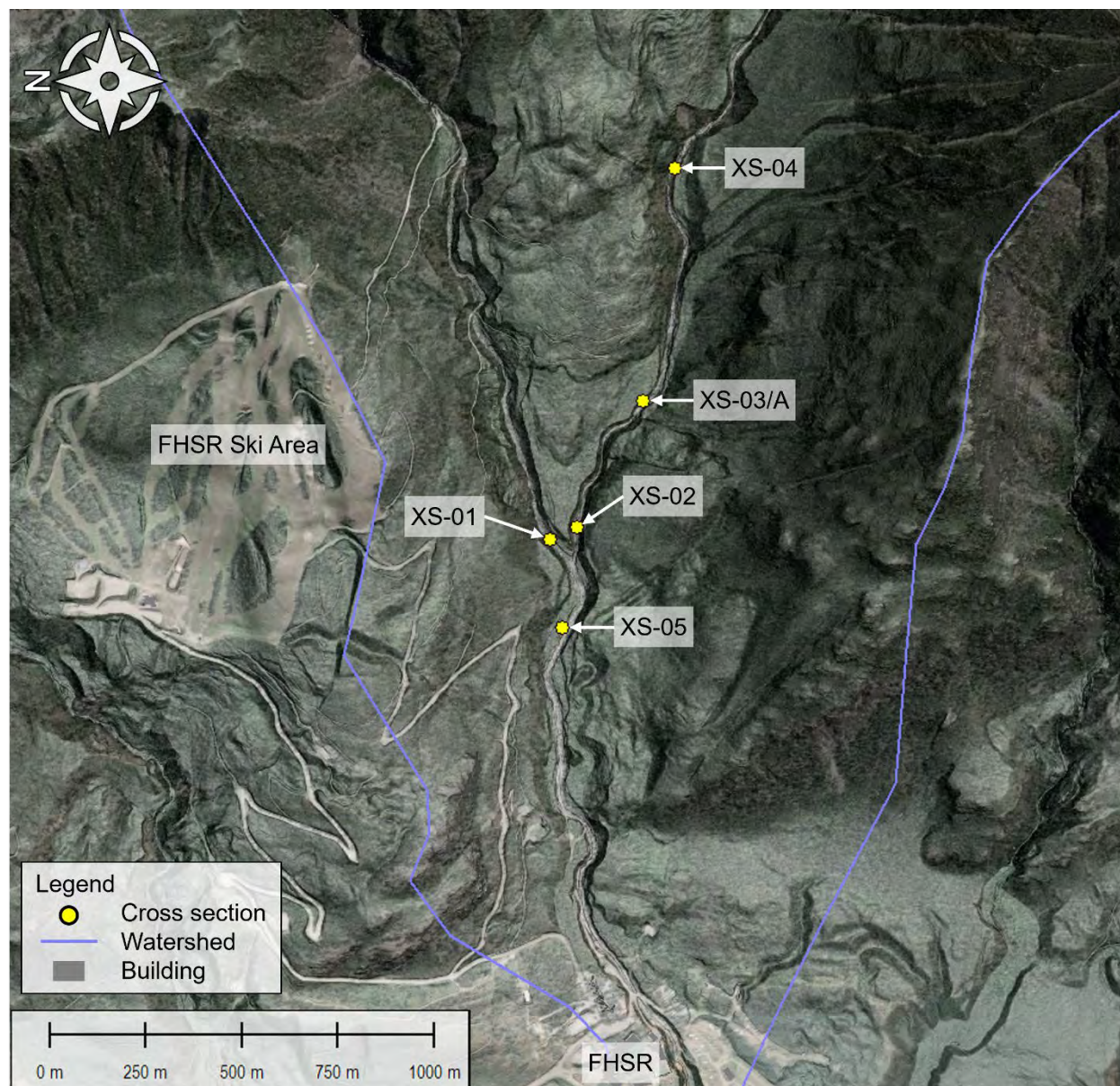


Figure 3-7 Locations of cross sections for peak discharge estimates.

Table 3-9 Estimates of past event debris-flow peak discharges at cross sections in the watershed.

Cross Section	Peak Discharge (m ³ /s)	Notes
XS-01	30	Recent ¹ event trimline on north tributary.
XS-02	80	Recent event trimline on south tributary.
XS-03	80	Recent event trimline on south tributary.
XS-03A	150	Interpreted 2012 event at same cross section, on south tributary.
XS-04	100	Bedrock controlled section and recent trimline on south tributary.
XS-05	180	Large section between terraces measured from lidar DEM to compare to 2012 event peak discharge estimate.

Note:

1. In this context, recent is defined as little growth of new vegetation and most likely on the order of two to five years.

These estimates for recent events demonstrate that higher peak discharges are observed in the watershed than near the FHSR or on the fan. This is attributable to debris flows transitioning to debris floods as they dilute with downstream transport, and their sediment concentration decreases (i.e., Type 2 debris flood). Cross sections 03A and 05 are interpreted to be from the 2012 event and the estimated peak discharges are comparable to what was estimated by Clarke and Golder (January 11, 2013) for the event (i.e., 165 m³/s).

3.6 Summary of Frequency-Magnitude Relationships

BGC assessed the F-M relationship for debris floods and debris flows on Fairmont Creek with several models for volumes. Figure 3-8 shows the frequency-volume model results together along with the 2012 and 2020 events.

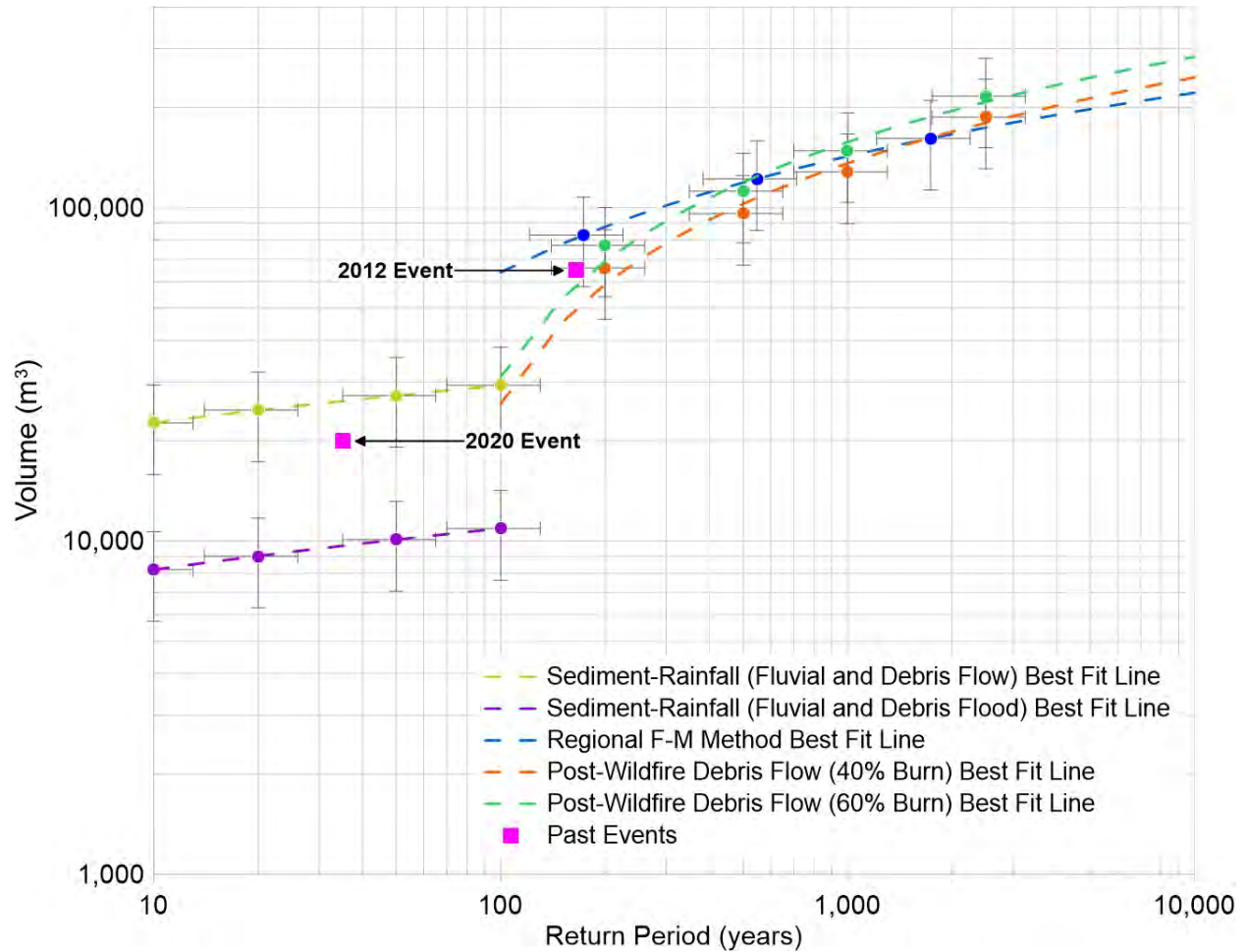


Figure 3-8 Frequency-volume model results for Fairmont Creek.

Table 3-10 shows the peak discharges and volumes estimated for debris floods and debris flows on Fairmont Creek. These values are used as inputs into the numerical modelling and in the mitigation options analysis. These values should be considered best estimates within upper and lower bounds, rather than precise values. Bounds are shown on Figure 3-8 for the various frequency-volume models.

Table 3-10 Debris-flood and debris-flow peak discharge and volume estimates for Fairmont Creek.

Return Period (Years)	Peak Discharge (m ³ /s)	Volume (m ³)	Process Type
10 to 30	11	9,000	Debris flood (Type 1)
30 to 100	20	28,000	Debris flood (Type 2)
100 to 300	240	72,000	Debris flow
300 to 1000	410	122,000	Debris flow
1000 to 3000	540	161,000	Debris flow

These estimates can be compared to recent events. The 2020 event was estimated to have a return period of 35 years and a volume of 20,000 m³ by NHC (June 24, 2020), which compares closely to BGC's 30 to 100-year event estimate. The peak discharge for the 2020 event was estimated on the distal end of the fan rather than upstream of Marble Canyon, therefore it is not comparable to the peak discharge estimated by BGC for numerical modelling initiation.

BGC compared the results of multiple debris-flow F-M models as no one model can produce precise results for Fairmont Creek. The regional F-M and post-wildfire debris-flow models have similar results which lends confidence to the estimated volumes. The 2012 event also falls at the lower return period end for debris flows.

These estimates can also be compared to the previous hazard assessment work that has been conducted on Fairmont Creek by Clarke and Golder (2013) and NHC (June 24, 2020). Clarke and Golder (2013)'s F-M analysis was generally qualitative and estimated the return period for a hazardous debris flow to be 25 years but estimated that return period event would most likely stay within the mainstem channel and terminate upon reaching the fan apex. Clarke and Golder (2013) assigned the 2012 debris flow event a 475-year return period.

During NHC's subsequent design work and post-event analysis, the 2012 event was used as the design event for mitigation design (NHC, April 13, 2017; August 3, 2018). After the 2020 debris flood event, NHC updated the estimated return period for the 2012 event as 165 years and assigned the 2020 event a return period of 35 years (NHC, June 24, 2020).

3.7 Numerical Debris-Flood and Debris-Flow Modelling

BGC modelled the return period events described in Section 3.6 to assess the intensity and spatial extents of hazards from debris floods and debris flows from Fairmont Creek. BGC used HEC-RAS (version 6.6), a public domain hydraulic modelling program developed and supported by the United States Army Corps of Engineers (USACE, 2024b). HEC-RAS includes modeling capabilities for Newtonian (e.g., clearwater flood) and non-Newtonian (e.g., debris flows) fluids. Appendix D describes the modelling methods and limitations. Modelling results are provided on Drawing 02 and discussed in Table 3-11.

As described in Appendix D, the modelling topography is based on September 2018 lidar. Berms downstream of Marble Canyon to the golf course pond were constructed prior to lidar collection and are therefore incorporated in the topography. The topography was altered to

include the berm adjacent to the FHSR intake shed, which was constructed after the lidar was collected. The three weirs were not incorporated into the modelling topography as their changing geometry makes an accurate depiction challenging. Additionally, although the weirs store debris, recent events have also shown that flow downstream of the basins entrain material. HEC-RAS is unable to model debris entrainment, therefore BGC judges that these two processes, deposition and entrainment, approximately balance each other with the model results likely being nominally conservative.

Table 3-11 Summary of key numerical modelling results.

Return Period (Years)	Key Observations
10 to 30	- Flow generally stays within the channel until the downstream end of the golf course pond. Flow may back up and overtop the campground access road culvert, which may send shallow flows towards the campground (i.e., <0.1 m). - At the downstream end of the golf course pond, flow overtops on either side of the outlet and is over the capacity of the channel all the way down to the Columbia River. At Fairmont Creek Road, most flow over the capacity of the channel flows diffusely southwest to meet the Columbia River. - Flows outside the channel between the golf course pond and the Columbia River reach up to 2 m/s and 0.5 m depth. There is localized ponding up to 1 m deep.
30 to 100	- The campground access road culvert will likely overtop which may send shallow flows towards the campground (i.e., <0.1 m). - Flow may begin to avulse around the golf course bridge near the Marble Canyon outlet with low depths and velocities (i.e., <1 m and <1 m/s). - Similar to the 10 to 30-year flow, the flow is over capacity for the golf course pond outlet and the channel from the golf course pond to the Columbia River. - Flows outside the channel between the golf course pond and the Columbia River reach up to 2.5 m/s and 0.5 m depth. There is localized ponding up to 1 m deep.

Return Period (Years)	Key Observations
100 to 300	• Flow overtops the berm protecting the hot spring intake sheds, with up to 2 m of flow around the sheds. • Flow overtops the campground access road culvert and may send shallow flows towards the campground (i.e., <0.1 m). • Through Marble Canyon, the flow fills the entire width of the canyon and is up to 4 m deep and flows at up to 8 m/s in constricted reaches. • The debris flow enters the Marble Canyon Townhome complex with depths up to 1 m and velocities up to 1 m/s. • Flow avulses from the main channel at the outside curve, near the upstream golf course bridge. This avulsion crosses multiple golf course fairways, flows through the Mountainside Villa complex and through single-family residential parcels on the east side of Highway 93/95. Flow depths are up to 1 m, with velocities from 1 m/s further from the channel to 4 m/s closer to the channel. • The flow also avulses along the bermed, confined reach of the channel upstream of the golf course pond and at the outlet of the golf course pond. These avulsions merge and flow across multiple golf course fairways, through the southern portion of the Mountainside Villa complex, and through single-family residential parcels between the golf course and the Columbia River. Flow depths are up to 1 m, with velocities from 1 m/s further from the channel to 4 m/s closer to the channel. • Avulsed flow may find preferential paths across the fan where velocities and flow depths will be locally increased (i.e., up to 2.5 m and 6 m/s). • Although modelling does not show avulsions into the Mountainside Villas on the east side of the channel, BGC interprets that flows could impact this area as the berm is close to being overtopped in the models. Flow magnitudes could be similar to the upstream avulsion at the golf course bridge (i.e., depths up to 1 m, velocities from 1 to 4 m/s).
300 to 1000	• Flow for this return period follows similar avulsions paths to the 100 to 300-year return period event and only changes are noted here. • Flow depth around the hot spring intake sheds increases to 3 m. • Through Marble Canyon, the flow is up to 5 m deep and flows at up to 9 m/s in constricted reaches. • The debris flow enters the Marble Canyon Townhome complex with depths up to 1.5 m and velocities up to 1.5 m/s. • Flow avulses to the west along the whole channel reach from the Marble Canyon outlet to the golf course pond. • The most upstream avulsion path flows across Highway 93/95 to Riverview Road. Flow depths are up to 1 m, with velocities from 2 m/s further from the channel to 5 m/s closer to the channel. • The downstream avulsion inundates a similar area as the previous return period. Flow depths are up to 1.5 m, with velocities from 2 m/s further from the channel to 5 m/s closer to the channel. • Avulsed flow may find preferential paths across the fan where velocities and flow depths will be locally increased (i.e., up to 2.5 m and 8 m/s). • Although modelling does not show a full avulsion into the Mountainside Villas on the east side of the channel, BGC interprets that flows could impact this area as the berm is close to being overtopped in the models. Flow magnitudes could be similar to the upstream avulsion at the golf course bridge (i.e., depths up to 1 m, velocities from 2 to 5 m/s).

Return Period (Years)	Key Observations
1000 to 3000	- Flow for this return period follows similar avulsions paths to the 300 to 1000-year return period event and only changes are noted here. - Flow depth around the hot spring intake sheds increases to 4 m. - Through Marble Canyon, the flow is up to 5 m deep and flows at up to 9 m/s in constricted reaches. - The debris flow enters the Marble Canyon Townhome complex with depths up to 1.5 m and velocities up to 2 m/s. - Flow avulses over the right bank of the channel from the Marble Canyon Townhomes to the golf course pond. - The upstream avulsion path flows over a wider area, inundating more of the golf course, the Mountainside Villa complex and single-family residential parcels. The avulsion also flows down the highway and reaches the Sunchaser Vacation Villa complex on the distal end of the fan. Flow depths are up to 1.5 m, with velocities from 2 m/s further from the channel to 5 m/s closer to the channel. - The downstream avulsion inundates a similar area as the previous return period. Flow depths are up to 2 m, with velocities from 2 m/s further from the channel to 5 m/s closer to the channel. - Avulsed flow may find preferential paths across the fan where velocities and flow depths will be locally increased (i.e., up to 2.5 m and 8 m/s). - Although modelling only shows a small amount of flow inundating the Mountainside Villas on the east side of the channel, BGC interprets that flows could impact this area as the berm is close to being overtopped in the models. Flow magnitudes could be similar to the upstream avulsion at the golf course bridge (i.e., depths up to 1.5 m, velocities from 2 to 5 m/s).

Generally, the debris flood modelling results show that the channel is adequately sized to convey flows until the golf course pond. The models show some flooding and overtopping around the campground access road culvert which may direct some flows into the campground but those are expected to be less than 0.1 m deep. Flows through Marble Canyon may overtop the current channel in some locations. Downstream of the golf course pond, the pond outlet and channel down to the Columbia River do not have sufficient capacity to convey the debris floods modelled. This would result in flooding and potential sediment deposition on the golf course, through parts of the Mountainside Villa complex and single-family residential parcels downstream of the golf course to the Columbia River. Debris floods are also commonly associated with bank erosion and although BGC did not model bank erosion, erosion can be expected along the main channel as well as any preferential paths flow may take when leaving the channel.

Debris flow modelling shows:

- The hot spring intake sheds are impacted at all of the return periods modelled
- The campground access road culvert is blocked at every return period and may direct shallow flows towards the campground (i.e., <0.1 m)
- Debris flows fill the bottom width of Marble Canyon (i.e., the walking path is inundated)
- Flows avulse from the channel preferentially over the right bank from the Marble Canyon Townhomes complex to the golf course pond at differing magnitudes for the various return periods

- The avulsion flows reach the distal end of the fan impacting roads, Highway 93/95 and single-family residential parcels downstream of the golf course
- Intensities large enough to damage buildings and cause life loss can occur which are discussed in more detail in Section 4.0.

3.8 Auxiliary Hazards

BGC only assessed the hazards to the Fairmont Hot Springs community stemming from the Fairmont Creek watershed. This assessment mainly focuses on debris floods and debris flows but landslides in the watershed are mapped on Drawing 01 as they contribute sediment to the channel. BGC considered the potential of landslide dam outbreak floods (LDOFs) in the watershed but due to the steep and narrow channel it is unlikely that a landslide within the considered return period would dam a large enough volume of water to create an outbreak flood larger than the debris flows considered. The geology in the watershed could produce a large, catastrophic landslide that could cause an LDOF at a higher return period than considered for this assessment, such as the landslide identified in the Cold Spring Creek watershed (BGC, September 25, 2020).

BGC has not modelled or quantified the bank erosion hazard along Fairmont Creek as it is assumed to not drive life loss risk on the fan although BGC is aware that there has been localized erosion in previous events.

BGC has not assessed or quantified the flooding hazard from the Columbia River or steep creek hazards from adjacent Meredith Creek. Landslide mapping was confined to the Fairmont Creek watershed, lack of hazard mapping beyond the watershed or fan boundaries does not preclude the existence of a landslide.

4.0 RISK ASSESSMENT

Risk is a measure of the combined probability and severity of an adverse outcome and is estimated by the product of hazard probability (or likelihood) and consequences. By combining hazard and consequence, risk can often demonstrate an appropriate return period for design and can show the benefit for managing the hazard.

This risk assessment was completed at a “building and parcel” level of detail and was based on geohazard scenarios defined in the numerical modelling section (Section 3.7), which represent the spectrum of events that could credibly result in life-loss. The risk assessment estimated the likelihood that geohazard scenarios will occur, impact building occupants on the Fairmont Creek fan, and potentially cause loss of life or economic losses.

4.1 Risk Estimation

For this assessment, BGC estimated life-loss risk for individuals and groups within buildings and estimated economic risk. The general risk equation and terms that are used in this assessment are shown and explained in Figure 4-1.

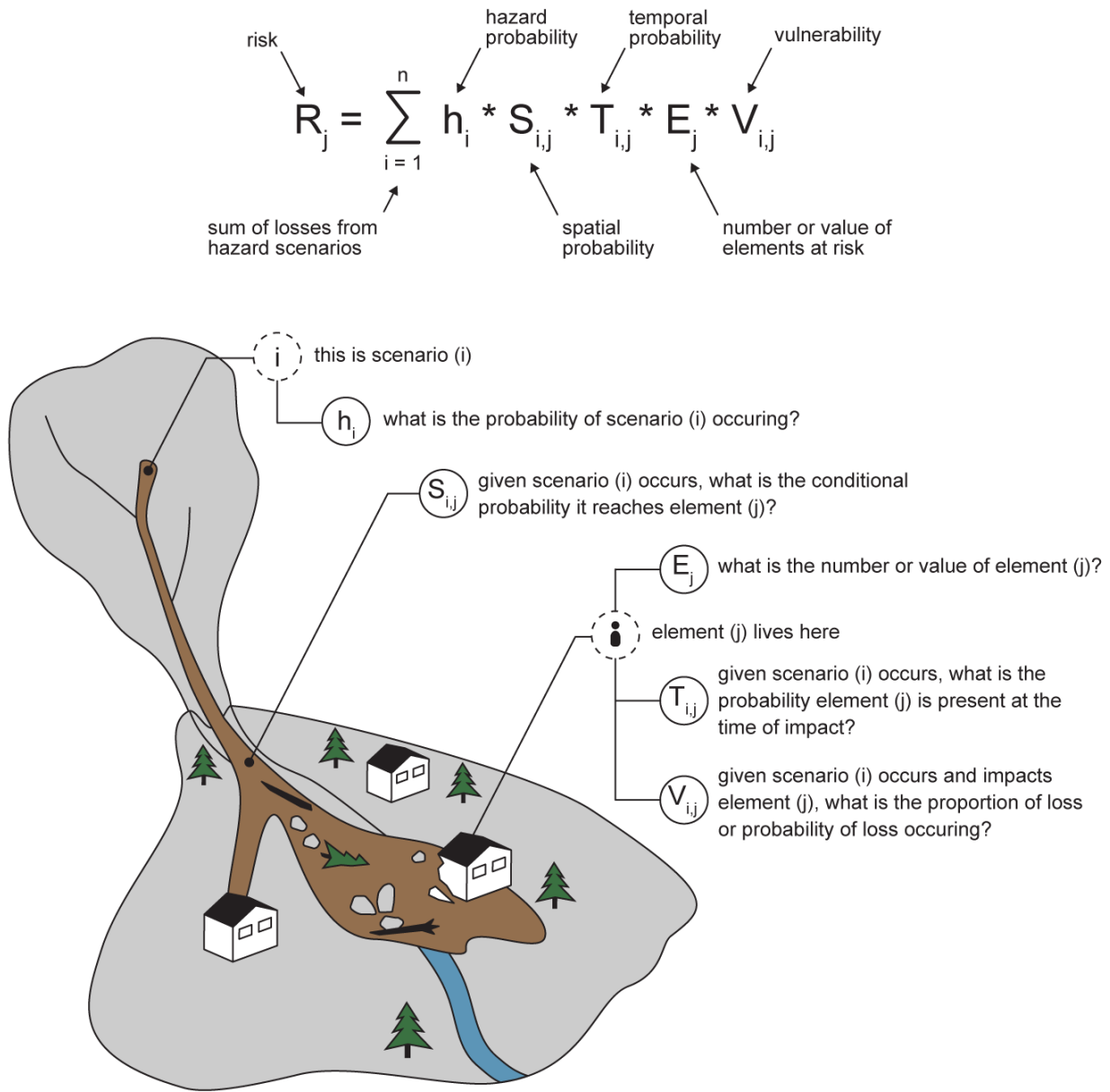


Figure 4-1 Schematic demonstrating the calculation of risk. Sketch by S. Zubrycky.

Individual risk, also known as the annual Probability of Death of an Individual, (PDI), evaluates the chance that a specific person will be killed by the hazard. This metric focuses on the person judged to be most at risk, corresponding to a person spending the greatest proportion of time at home, such as a young child, stay-at-home person, or an elderly person. For this assessment, individual risk (PDI_j) is calculated as follows:

$$PDI_j = \sum_{i=1}^n h_i S_{i,j} T_{i,j} V_{i,j} \quad [\text{Eq. 4-1}]$$

Group risk, also known as societal risk, evaluates the number of people that could be killed during a geohazard event, considering all people located within the impacted area.

Group risk is derived from f-N pairs where the annual probability of a given geohazard scenario, f_i , corresponds with an estimated number of fatalities, N_i defined as follows:

$$f_i = h_i \quad [\text{Eq. 4-2}]$$

$$N_i = \sum_{j=1}^m S_{i,j} T_{i,j} V_{i,j} E_j \quad [\text{Eq. 4-3}]$$

Economic risk estimates the damage cost of an event and can be calculated to varying levels of details. For this assessment, BGC estimated the damage cost to buildings impacted by events (C_j) by the following equation:

$$C_j = \sum_{i=1}^n h_i S_{i,j} T_{i,j} V_{i,j} E_j \quad [\text{Eq. 4-4}]$$

Costs associated with debris cleanup and emergency response were also included for each scenario.

The following sections provide more detailed descriptions of methods to estimate each variable in Equations 4-1 to 4-4.

4.1.1 Hazard Probability, h_i

The hazard probability defines the annual probability that an event will occur on Fairmont Creek with a certain magnitude. It addresses the question, “What is the probability that, in any given year, a certain event will occur?”. The event probabilities for each modeled scenario are shown in Table 4-1.

Table 4-1 Annual hazard event probabilities for debris floods and debris flows on Fairmont Creek.

Return Period (Years)	Annual Probability (h_i)	Process
10 to 30	0.067	Debris flood
30 to 100	0.023	Debris flood
100 to 300	0.0067	Debris flow
300 to 1000	0.0023	Debris flow
1000 to 3000	0.00067	Debris flow

4.1.2 Spatial Impact Probability, $S_{i,j}$

Spatial impact probability considers the hazard extents in relation to the location of elements at risk. It addresses the question, “given that an event occurs with a certain magnitude, what is the probability a certain location is impacted?”. Numerical modelling results (Section 3.7) were used

to assess spatial probability. If a building within a parcel was impacted by the modelled flow, the parcel was assigned a value of 1, and if no buildings were impacted within a parcel, the parcel was assigned a 0.

This approach implies a certainty in the model results; however, the spatial impact probabilities likely overestimate risk at parcels shown to be impacted and underestimate risk at non-impacted parcels. This is addressed through an interpreted hazard map that partially accounts for model uncertainties.

4.1.3 Temporal Impact Probability, $T_{i,j}$

Temporal impact probability considered the proportion of time the element at risk is at the impacted location. For people, this would be the proportion of time occupants spend within buildings, and addresses the question, “what is the chance a person is inside a building when an event occurs?”. For buildings, in the economic risk assessment, the temporal probability is assumed to be 1 as a building is always there.

BGC assumed that temporal probability varies between parcels depending on the parcel's primary use. For example, the amount of time occupants spend within a home is likely higher than the amount of time occupants spend in school or at work. Therefore, temporal impact probability was assigned to parcels based on their primary use defined by BC Assessment (GeoBC, 2023), and according to the assumptions listed in Table 4-2.

Table 4-2 Temporal impact probability assumptions.

Primary Use Type	Occupation Rate Assumption	Temporal Impact Probability
Residential	Occupied about 50% of the time on average. A more conservative value of 90% is used for estimation of individual risk, corresponding to a person spending the greatest proportion of time at home, such as a young child, stay-at-home person, or an elderly person.	0.5 (group risk) 0.9 (individual risk)
Commercial	Occupied during business hours, assumed to be 40 hours per week on average.	0.25
Civic, Institutional and Recreational ¹	This assessment only applies to people in buildings.	0

Note:

1. On Fairmont Fan, these parcels are generally golf course parcels. One exception is the Fairmont Hot Springs Fire Department which is treated like a commercial parcel instead.

4.1.4 Vulnerability, $V_{i,j}$

Vulnerability is defined as the probability of a fatality given a building is impacted in the hazard scenario. For life loss it addresses the question, “what is the chance of fatality for persons within buildings, given the building is impacted?”. Vulnerability can also be applied as a damage state to buildings for the economic risk assessment.

Figure 4-2 shows the relationship used to estimate the vulnerability of persons within buildings to impacts from rapid, flow-type landslides developed by LeSueur et al. (Submitted). These criteria are based on impact pressure, which is calculated using model results as:

$$Pressure = (\frac{1}{2}k\rho g d + \alpha\rho v^2)/1000 \quad [\text{Eq. 4-5}]$$

where k is the static pressure coefficient, ρ is flow bulk density (kg/m^3), g is acceleration due to gravity (m/s^2), d is flow depth (m), α is the dynamic impact coefficient, and v is flow velocity (m/s).

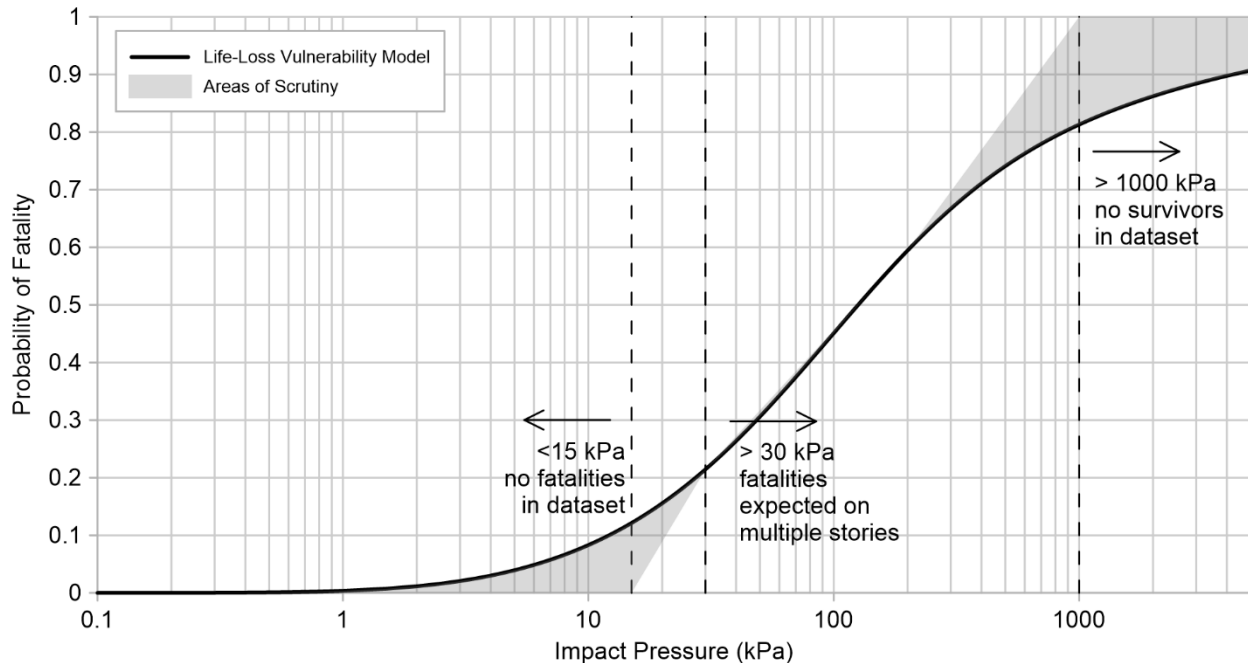


Figure 4-2 Life-loss vulnerability relationship for risk analysis of people in buildings impacted by rapid, flow-type landslides (LeSueur et al., Submitted).

Similarly, a damage curve was developed for the economic risk assessment using building damage states developed by LeSueur et al. (Submitted) and assigning a damage proportion to each state.

Vulnerability is assigned to each parcel based on the maximum pressure that impacts a building in the parcel in the model results.

4.1.5 Exposure, E_j

Exposure is the number of people or value of elements that could be impacted at each parcel. For group risk, BGC made population assumptions based on the primary use type of each parcel. These assumptions are shown in Table 4-3. For economic risk, the improvement value for parcels was taken from BC Assessment data (GeoBC, 2023).

Table 4-3 Population assumptions based on parcel primary use.

Primary Use Type	Occupancy
Residential ¹	2.3
Commercial ²	3.5
Civic, Institutional and Recreational ³	0

Notes:

1. Building occupancy for residential use was determined from the 2021 national census data (Statistics Canada, 2023).
2. Building occupancy for commercial use was estimated from average employee counts for businesses across BC of similar description.
3. This assessment only applies to people in buildings.

BGC did not differentiate between floors of buildings and therefore all people were assumed to be on the first floor of buildings. For multi-family dwellings such as condominiums or townhomes, the population was estimated by multiplying by the number of units. BGC checked this assumption against the total population for the Fairmont Hot Springs community in the 2021 census data.

BGC understands that due to the tourism opportunities provided in the Fairmont Hot Springs community there is a highly transient population. BGC has conservatively assumed that all residential units are occupied full-time but has also assessed a lower bound value that accounts for part-time occupancy.

4.1.6 Other Damage Costs

BGC also estimated debris clean-up costs for each event based on average clean-up costs from previous events from RDEK. The economic risk assessment does not account for business or tourism interruptions and losses, or road and land damage costs (e.g., damage to golf courses).

4.2 Risk Results

The following sections provide the results of the individual and group life-loss risk, and economic risk assessments.

4.2.1 Individual Risk

Individual risk was estimated for the most at-risk person in a building at each parcel for the currently developed areas of the fan. Figure 4-3 summarizes the results. 76 parcels are impacted by the events modeled in the hazard assessment. These results are integrated into the hazard map developed in Section 5.0.

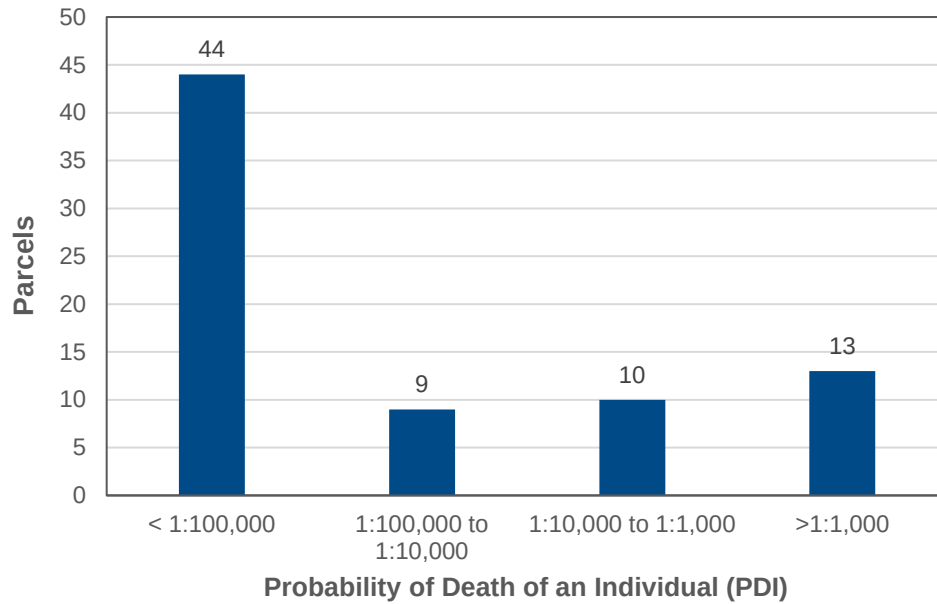


Figure 4-3 Individual risk assessment results.

Although RDEK does not have risk threshold policies developed, the results of the risk assessment for Fairmont Creek can be compared to other jurisdictions in BC and Alberta that have policy around acceptable risk to provide context. In several jurisdictions, risk is aimed to be brought below a 1:10,000 PDI for existing development and below 1:100,000 PDI for new development (Town of Canmore, 2016; District of North Vancouver, 2018; District of Squamish, 2018; Cowichan Valley Regional District, 2019). Comparing to those criteria, the Fairmont Creek fan has 23 parcels that are above the 1:10,000 PDI threshold.

4.2.2 Group Risk

The group risk estimated for the Fairmont Creek fan is presented in Figure 4-4 and is compared to the group risk curve estimated for Cold Spring Creek in the previous risk assessment prior to mitigation construction (BGC, March 12, 2021).

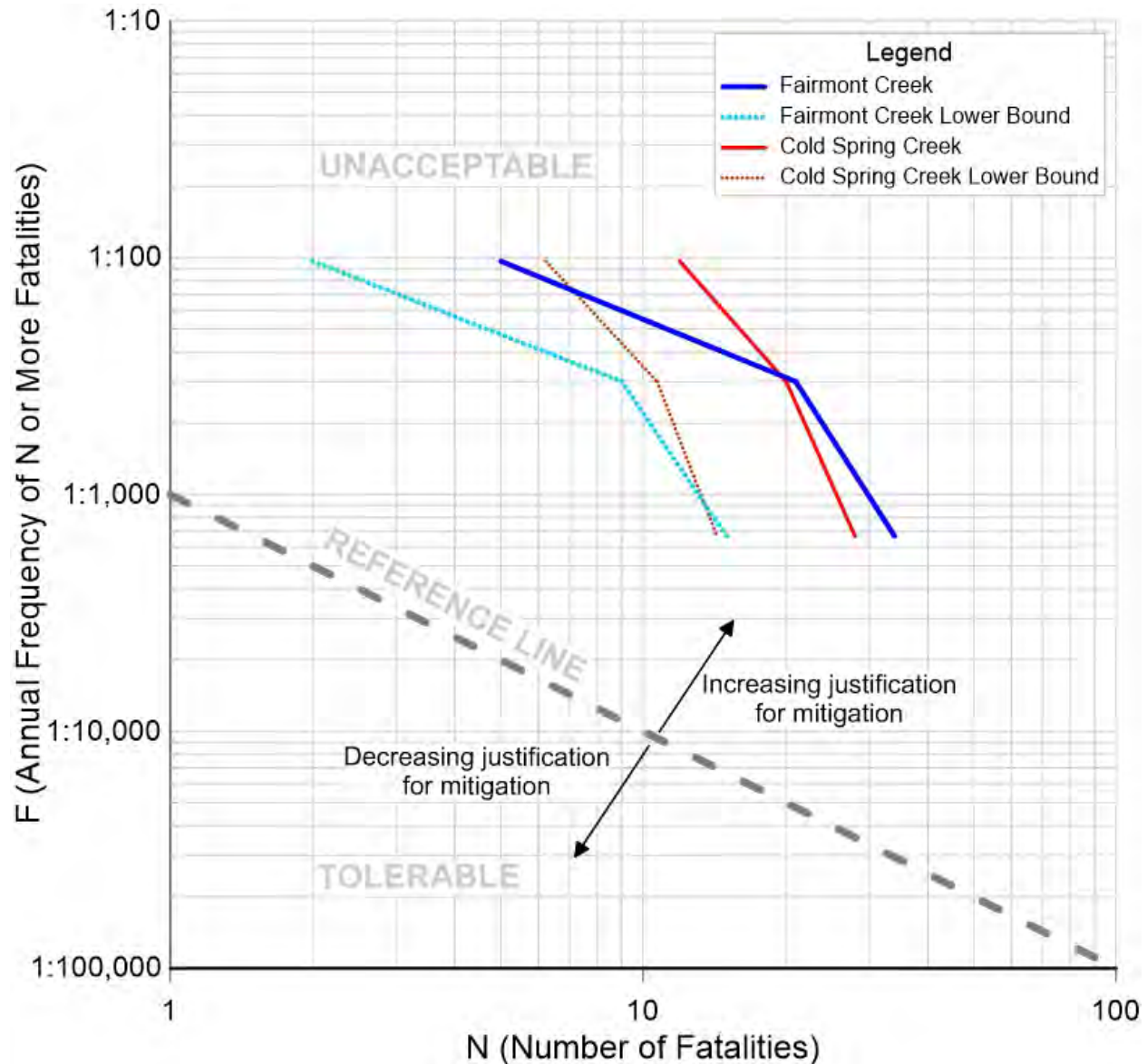


Figure 4-4 Group risk on the Fairmont Creek fan.

The group risk curve presented assumes that all units are occupied full-time and is therefore, most likely, a conservative estimate. BGC also assessed a part-time occupancy scenario to present a range of values.

The group risk at Fairmont Creek is similar to that at Cold Spring Creek prior to mitigation construction. Although there are some differences between the assessments as methods have changed and improved, these are not expected to make substantial changes to the overall group risk curve. The similarity between the two curves can be attributed to two opposing factors: there are some residential buildings on the Cold Spring Creek fan quite close to the fan apex that have high risk, while flows on Fairmont Creek begin to attenuate in Marble Canyon before reaching residential buildings. Additionally, there is a higher population density on the Fairmont Creek fan contributing to increased estimated fatalities.

4.2.3 Economic Risk

The economic risk results are presented in Table 4-4. The values are presented as estimates for an event cost and annualized costs. The annualized cost is useful to demonstrate which event is contributing the most to damage costs, which in this case is the 100 to 300-year debris flow event.

Table 4-4 Economic risk results for building damage and clean-up costs.

Return Period (Years)	Damage Cost	Clean-up Cost	Total	Annualized Total (\$/year)
10 to 30	0.6M	0.4M	1.0M	63,000
30 to 100	1.0M	1.1M	2.1M	49,000
100 to 300	14.0M	2.9M	16.9M	112,000
300 to 1000	21.8M	5.0M	26.8M	63,000
1000 to 3000	30.4M	6.6M	37.0M	24,000
Total	-	-	-	311,000

The economic risk presented is not comprehensive but provides relative values that can be used when assessing the efficacy of mitigation options in the conceptual mitigation section.

5.0 HAZARD MAPPING

Hazard maps are important risk-management tools for land use planning, emergency management, and public awareness. As part of this assessment, BGC updated the hazard map previously produced by Clarke and Golder (2013) for the Fairmont Creek fan based on the updated topography, hazard scenarios, and numerical modelling.

5.1 Methods

BGC delineated hazard zones based on lidar topography, geomorphic interpretation, and a calculated risk index derived from numerical modelling of the hazard scenarios. The risk index is calculated using the risk equation (Eq. 4-5) and numerical model results assuming any location in the model domain is fully occupied (temporal probability of 1) with a typical detached wood-frame building. The resultant map is a tool to guide hazard zonation with risk-based land-use criteria in mind. The proposed hazard zones for Fairmont Creek (Table 5-1) align with risk tolerance criteria adopted by other jurisdictions in BC (Section 4.2.1).

Table 5-1 Hazard zones.

Hazard Zone	Risk Index ¹ (PDI)	Other Jurisdictions' Risk Tolerance Criteria ²	Comparable Annual Risk of Fatality (PDI)
Very High	>1:1,000	Existing and proposed development unacceptable without mitigation works.	40 th year of life in USA from all causes (1:500)
High	1:10,000 to 1:1,000	Existing and proposed development unacceptable without mitigation works	Covid-19 in 2020 (1:1,000) Car accident (1:10,000)
Moderate	1:100,000 to 1:10,000	Existing development tolerable Proposed development unacceptable unless <25% increase to gross floor area or mitigation works implemented.	Gun violence in USA (1:25,000) General anesthesia per instance (1:100,000)
Low	<1:100,000	Existing and proposed development acceptable	Drowning in bathtub (1:1,000,000)

Notes:

1. Risk level assumes fully occupied, detached, wood-frame building and does not account for site-specific building characteristics or mitigation.
2. Other jurisdictions such as Town of Canmore (2016), District of North Vancouver (2018), District of Squamish (2018), and Cowichan Valley Regional District (2019).

5.2 Results

Drawing 03 depicts hazard zones associated with debris flows on Fairmont Creek for unmitigated (baseline) conditions. The map is intended to support hazard communication and future land use planning by property owners and RDEK by delineating areas of relatively higher or lower potential risk. The proposed hazard zones (Drawing 03, Table 5-1) align with risk tolerance criteria used in other jurisdictions, and can inform the selection of building locations,

permitted uses, and requirements for development. Examples of risk controls that may be applied by property owners or RDEK include:

- Siting buildings on areas with low hazard
- Implementing flood construction levels through raising buildings on fill above ground level and/or adding raised concrete perimeter foundations
- Designing building structures to withstand impact loading
- Designing the locations of building openings (windows, doors) on sides of structure not directly exposed to hazards
- Designing a building layout so the areas most frequently occupied are on upper floors or downstream side of the building.

Selection of appropriate risk controls, if required, will depend on specific site characteristics. BGC recommends that a Qualified Professional is engaged in the design and implementation of the above risk controls and, where required, to review a proposed development or building permit.

6.0 CONCEPTUAL MITIGATION

The risk assessment and hazard mapping shows that there are locations of the fan with unacceptable risk when compared to risk thresholds in other jurisdictions in BC. Therefore, BGC has developed conceptual mitigation options for consideration on Fairmont Creek.

As discussed in Section 1.2.1 and detailed in Appendix A, there are several mitigation components that have been constructed on Fairmont Creek since the 2012 event. These mitigation components were designed to store debris at various locations on the channel but may not have considered debris flow characteristics in their design such as preferential flow paths, entrainment, or depositions angles.

6.1 Design Considerations

To compare and evaluate different mitigation options, the following factors were considered:

- **Geohazard process:** design for debris flood and debris flow impacts, including deposition, scour, and bank erosion, while also operating under normal fluvial conditions
- **Risk reduction:** reduce life safety-risk as low as reasonably practical given project constraints (i.e., cost, space); reduce damages to buildings, recreation areas, and infrastructure (i.e., roads, hot spring intake sheds); and reduce recreation and infrastructure service interruption and road access
- **Risk transfer:** avoids risk transfer
- **Location:** accessible to RDEK for construction and maintenance
- **Private land:** minimizes impacts to private land during construction and operations
- **Performance and uncertainty:** technically feasible with low performance uncertainty
- **Maintenance:** minimizes maintenance requirements and costs
- **Capital cost:** minimizes capital cost
- **Phasing:** can be constructed and functional in a phased approach to align with funding limits
- **Public impacts:** minimizes impacts to public, such as trail access, sight-lines, recreation space, and disruption during construction.

6.2 Design Event

Traditionally, mitigation is designed for a particular event where space and budget constraints are less pressing and that design event may be chosen by evaluating the event that contributes the most to risk when considering life-safety risk reduction. But often for communities such as Fairmont Hot Springs, there are practical space and budget constraints on what mitigation can be constructed. Therefore, BGC proposes that the design event be the 100 to 300-year debris flow event as it contributes the most to life-safety risk on the fan (Section 4.2), but ultimately the design will be budget- and space-based.

6.3 Conceptual Design Options

The conceptual design options are split into two categories for consideration: large-scale mitigation options and local mitigation options. The large-scale mitigation options aim to reduce

risk to the entire fan, although multiple options may be required, whereas the local mitigation options provide protection for particular locations on the creek or fan. Figure 6-1 shows the locations of the various options, which were developed in consultation with the RDEK.

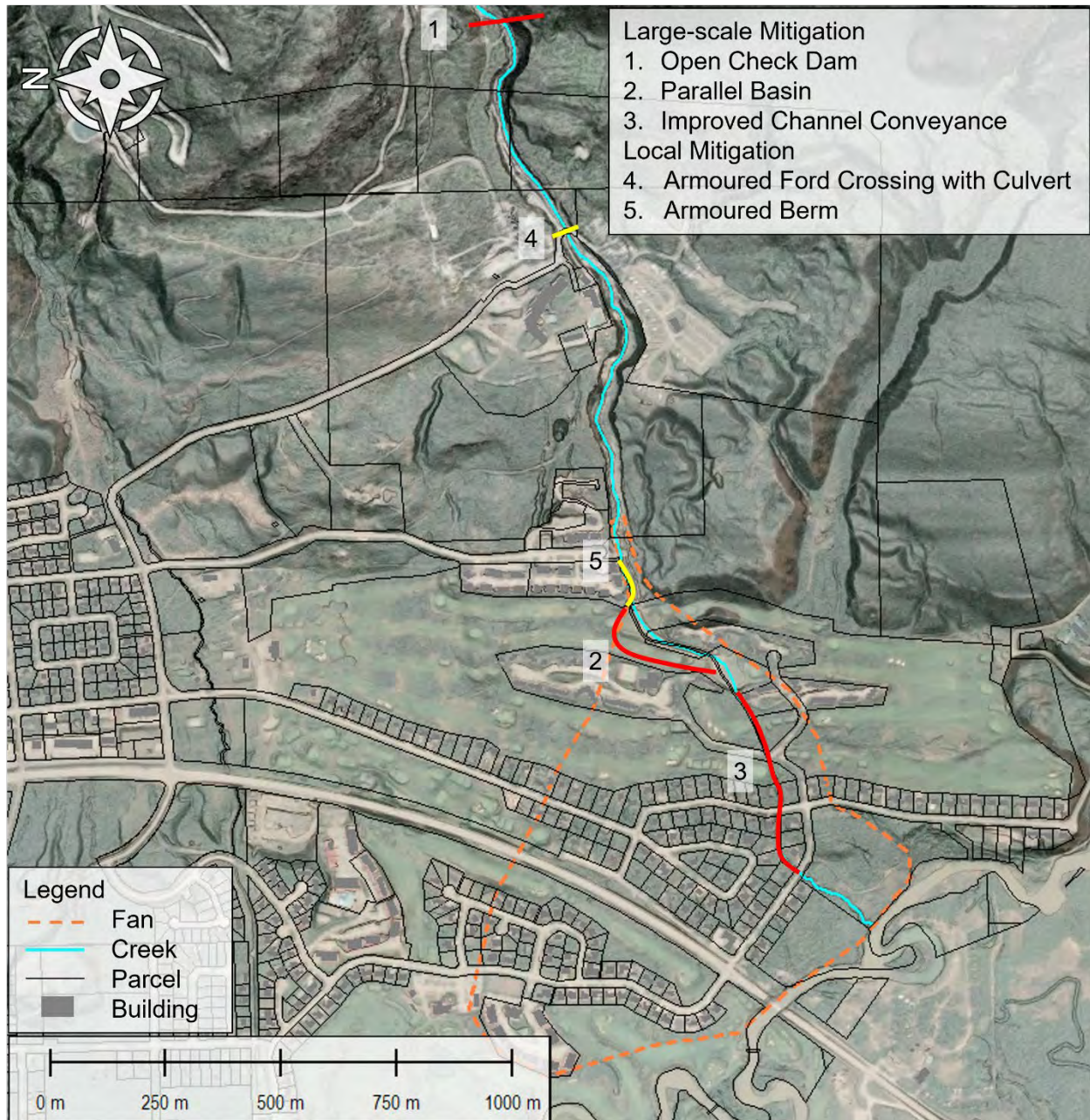


Figure 6-1 Locations of conceptual mitigation options.

This section summarizes the conceptual design of each option which includes a preliminary layout, approximate dimensions, and an order of magnitude cost estimate. BGC estimated costs based on overall costs of similar projects and did not estimate costs item by item. Any chosen options will require further site investigation and detailed design.

Large-Scale Mitigation Options

6.3.1 Option 1 – Debris Barrier and Basin (Upstream)

A large debris flow barrier is the most upstream mitigation option considered. The function of this option is to store debris and reduce the size of debris flows reaching the fan. A barrier could be aligned in several different locations depending on geotechnical investigation, design optimization, access requirements and property acquisition. Figure 6-2 shows one potential alignment that allows for the existing three weirs to continue functioning and is positioned approximately 200 m upstream of the FHSR intake sheds. BGC understands that excavation work near the FHSR intake sheds affects the hot spring temperatures and turbidity, and a location further upstream is preferred to prevent negatively affecting the hot springs.

The barrier would have an open slot to allow daily flow and smaller events to pass through to reduce the need for the basin to be cleaned out on a regular basis. The slot size would be optimized in detailed design and could also feature steel grillage to capture larger boulders and woody debris. The shown alignment would require an approximately 95 m wide barrier at this location and BGC assumed a 20 m high crest and 15 m spillway height. To optimize and increase the storage potential of the barrier, a basin would be excavated upstream of the barrier. Assuming a 4 degree deposition angle⁹ in the basin, BGC estimates that this barrier could store approximately 60,000 m³ of debris.

This option would also require downstream erosion protection to reduce entrainment. Although this option is meant to be self-cleaning for smaller events, there can be some performance uncertainty around slot width and steel grillage sizing.

BGC estimates the order of magnitude cost of this option to be approximately \$20M to \$30M based on the engineering and construction costs of the Cold Spring Creek barrier plus 50%.

⁹ For the conceptual design of all mitigation options, the debris deposition angle, in degrees, is assumed to be half of the channel grade at the location of each option location.

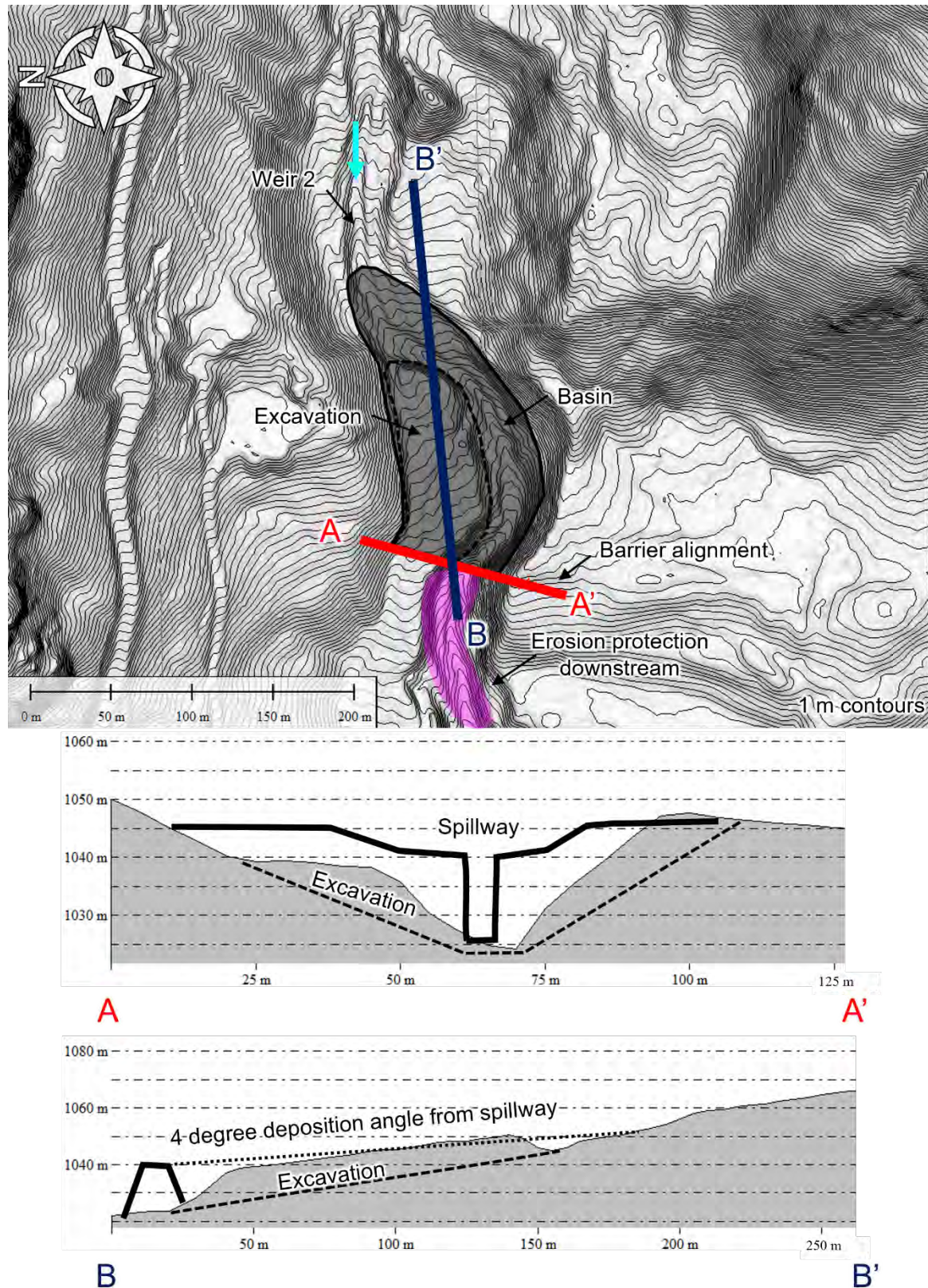


Figure 6-2 Conceptual layout of a debris-flow barrier and basin upstream of the Fairmont Creek fan. Sketches are not to scale.

6.3.2 Option 2 – Parallel Basin (Golf Course)

A basin parallel to the channel could be constructed on the golf course, downstream of Marble Canyon. This option is a similar concept to the berms installed on the golf course in 2015 with refinements to improve robustness and increase the storage capacity. The function of the parallel basin would be to capture avulsions during debris-flow events where the channel is overwhelmed. The conceptual layout is shown on Figure 6-3. The location is ideal as it takes advantage of where flow would most likely avulse due to the current channel geometry as is shown in the numerical model results (Section 3.7). BGC understands that the preference would be to reduce the impact to the golf course as much as possible. The conceptual layout aims to align around the edges of the greens and fairways and only crosses one fairway. The detailed design could benefit from consultation with a golf course architect to blend the mitigation in where possible or create features on the course.

The option consists of an in-channel weir, armoured inlet and weir outlet for the basin, training berm along the channel, and a perimeter berm around the basin. BGC has conceptualized a 360 m long perimeter berm that is 2 to 3 m above the current ground surface. The basin would also require some excavation to optimize the storage capacity. Assuming a 3 degree depositional angle in the basin, this option is estimated to have a storage capacity of approximately 30,000 m³.

The largest uncertainty with this design is the inlet and in-channel weir's ability to control the size of event that is directed into the basin.

BGC estimates the order of magnitude cost of this option to be \$3M to \$5M.

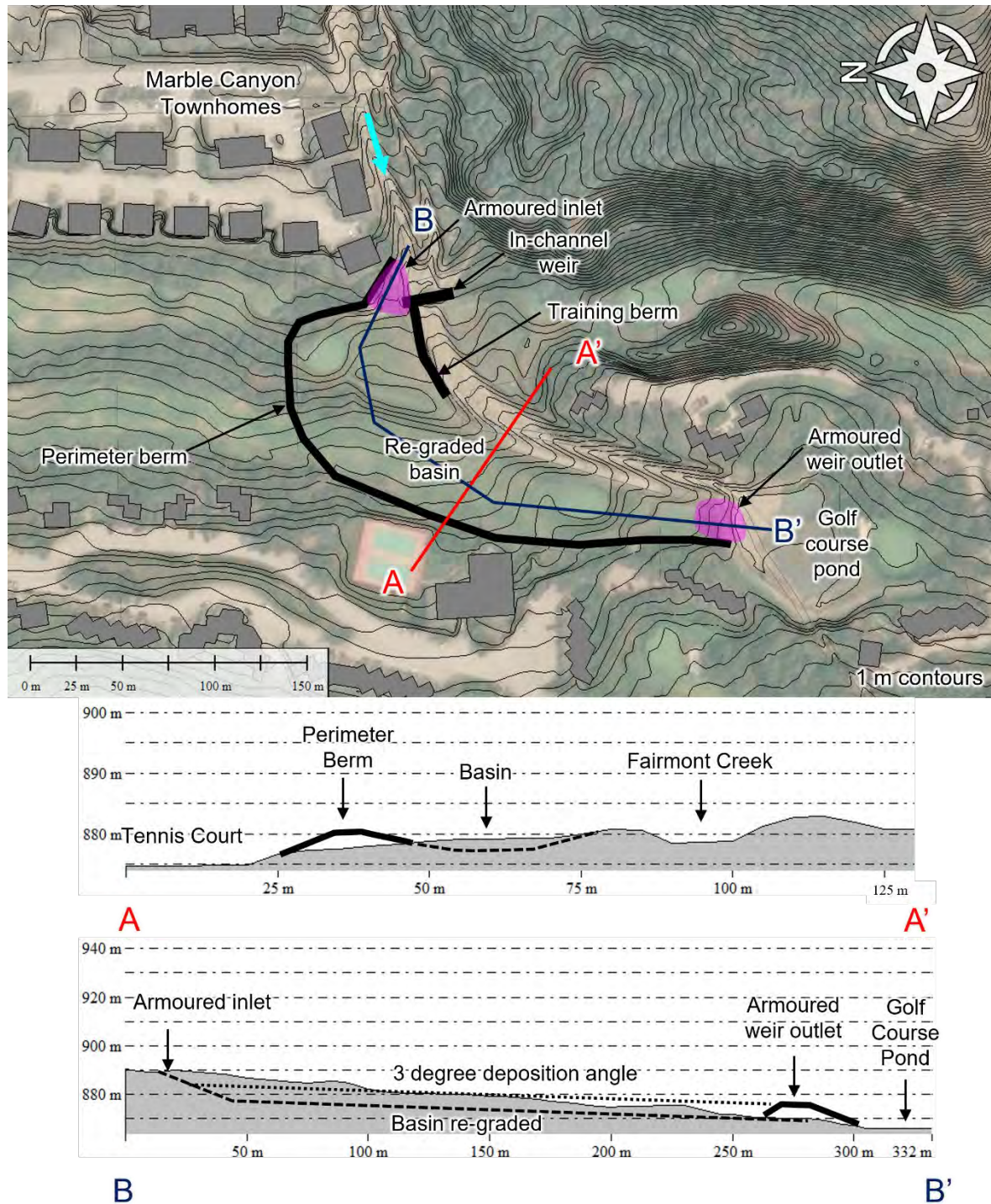


Figure 6-3 Conceptual layout of a parallel basin on the Fairmont Creek fan. Sketches are not to scale.

6.3.3 Option 3 – Improved Channel Conveyance (Golf Course Pond to Fairmont Creek Road)

The final large-scale mitigation option is to improve channel conveyance between the golf course pond and Fairmont Creek Road (Figure 6-4). Improved channel conveyance could be achieved by increasing the size of the channel, installing berms along the banks and armouring the channel. Additionally, the golf course pond outlet capacity would require an increase in capacity and there are several culverts that would require upgrading as well to match the design channel capacity. The design capacity for this option would be constrained by the space that is able to be procured for the channel through private property but is unlikely to be able to convey debris flows or improve life safety risk. The function of this option is to reduce frequent nuisance flooding.

Improving the channel conveyance in any one location has the potential to transfer risk downstream, therefore channel improvements would be required for the whole reach of the creek. The main uncertainty with this option would be the channel performance if the golf course pond or sections of the channel were to be infilled with debris.

This option would require channel improvements to approximately 450 m of channel and the upgrade of three road crossings to higher conveyance structures such as bridges or box culverts. BGC estimates the order of magnitude cost for this option to be \$5M to \$15M. The large range in the cost is due to the uncertainty of what space would be afforded for this option and what type of channel improvements would be made (e.g., berms, grouted riprap armouring).



Figure 6-4 Conceptual layout of improved channel conveyance (dashed black line) on the Fairmont Creek fan. Sketches are not to scale.

Local Mitigation Options

6.3.4 Option 4 – Armoured Ford Crossing with Culvert (Campground Access Road)

This local option is to improve the robustness of the campground access road crossing by improving the armouring around the current crossing. The culvert crossing is located at a low point along the road where flow can over-top and re-enter the channel during flows that exceed the culvert capacity. Improving the armouring on the upstream and downstream sides of the crossing with grouted riprap would reduce the risk of erosion severing the road (Figure 6-5).

The conceptual layout of this design requires an area of approximately 400 m² to be armoured. Grouted riprap armouring is likely the most effective armouring material to resist debris flows. BGC estimates the order of magnitude cost for this option to be \$0.5M to \$1M.



Figure 6-5 Conceptual layout of armouring around campground access road culvert crossing. Background image is an aerial photo taken after the 2020 event looking west (NHC, 2020). Sketches are not to scale.

6.3.5 Option 5 – Armoured Berm (Marble Canyon Townhomes)

The local mitigation option at the Marble Canyon Townhomes is for the installation of an armoured berm to reduce the risk of avulsion into the townhome complex and to increase channel capacity. The upstream end of the berm would tie into the high bank at the outlet of Marble Canyon, and the downstream end would tie in at the golf course bridge or could be merged into the parallel basin perimeter berm on the golf course if that option (Option 1) was selected (Figure 6-6).

The conceptual layout for the berm is approximately 130 m long, and the height is estimated at 2 m above ground surface depending on the selected design event and what mitigation may be installed upstream. The berm would require armouring and keying-in to the channel thalweg or lower to reduce the likelihood of erosion or undermining. Excavation in the channel would also increase channel capacity. BGC estimates the order of magnitude cost of this option to be \$1M to \$2M.

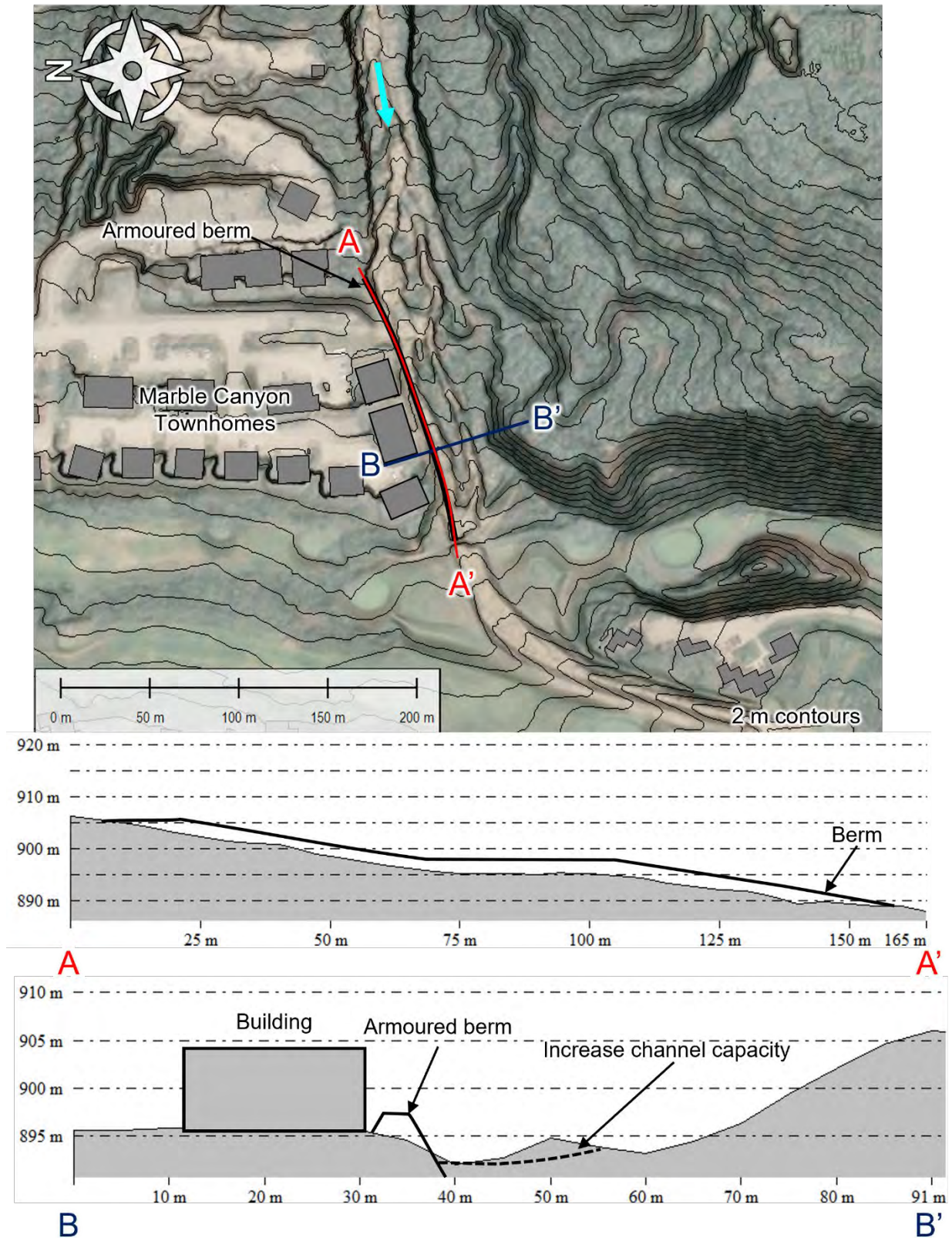


Figure 6-6 Conceptual layout of armoured berm adjacent to Marble Canyon Townhomes. Sketches are not to scale.

6.4 Option Ratings and Comparison

To compare the options considered, BGC developed a simplified three-point rating system for the design considerations discussed in Section 6.1. The ratings are shown in Table 6-1. This comparison is meant to serve as a preliminary framework for mitigation option discussion. As some options are eliminated from consideration and more detailed design work is conducted, these ratings could be refined, and certain design considerations could be weighted higher than others. The local mitigation options are not included in the comparison table as they provide localized risk reduction that does not compare well to the larger-scale mitigation options.

With the current rating and comparison structure, the upstream debris barrier and basin option scores the highest of the three large-scale options but considering different weights on the design considerations could change the comparison.

Table 6-1 Summary of large-scale mitigation option ratings and comparison.

Option	Option 1 - Debris Barrier and Basin (Upstream)	Option 2 - Parallel Basin (Golf Course)	Option 3 - Improved Channel Conveyance (Golf Course Pond to Fairmont Creek Road)
Approximate Storage Volume Order of Magnitude Cost	60,000 m ³ \$20M to \$30M	30,000 m ³ \$3M to \$5M	- \$5M to \$15M
Design Consideration	Ratings (0 = does not meet criteria, 1 = poor, 2 = good, 3 = optimal)		
Risk Reduction	2	2	1
Risk Transfer	3	3	1
Location	2	1	1
Private Land	3	0	0
Performance Uncertainty	1	2	2
Maintenance	3	2	2
Capital Cost	1	2	1
Phasing	0	1	1
Public Impacts	2	0	0
Total Score	63%	48%	33%

7.0 UNCERTAINTIES AND LIMITATIONS

This section outlines the key uncertainties and limitations of BGC's assessment.

7.1 Hazard Assessment

As the hazard assessment considers the present conditions and recorded events, it is considered a snapshot in time. Future changes such as significant alterations to the channel geometry, or a geohazard event may warrant reassessment of the hazard on Fairmont Creek.

7.1.1 Frequency-Magnitude Relationship

While standard scientific methods were used to develop frequency-magnitude relationships for Fairmont Creek, there is some uncertainty inherent in using empirical models developed with data from other sites. To address these uncertainties, BGC compared model and relationship outputs to site specific data where available and also calibrated models with region specific data when possible. On the higher end of the frequency-magnitude relationships (i.e., higher return period events that occur less frequently), there is less site-specific data available, such as radiocarbon dates from test pits, to calibrate and compare to, therefore there is more uncertainty in those estimates. Comparing results from multiple models lends some confidence to the values estimated.

7.1.2 Numerical Modelling

Steep creek processes are natural processes with complex behaviour that is challenging to model. BGC used industry standard methods to best estimate the extent and intensity of events on Fairmont Creek. It is not possible to capture every possible scenario therefore model results should be considered representative scenarios rather than precise events. Detailed uncertainties and limitations are outlined in the numerical modelling methods appendix (Appendix D).

7.2 Risk Assessment

There is inherent uncertainty in the risk assessment due to the number of variables that need to be estimated. BGC uses parameters that are consistent across assessments of similar sites and uses the newest data where available to inform the assessment. This risk assessment relies on BC Assessment data from 2023 (GeoBC, 2023). The data were spot checked for consistency with assumed present day uses.

7.3 Hazard Mapping

As noted in Section 5.1, the hazard map assumes any location in the mapping area is fully occupied (temporal probability of 1) with a typical detached wood-frame building. As such, the risk index levels presented on the hazard map (Drawing 03) may differ from the individual risk results presented in Figure 4-3 due to the current occupancy and site-specific mitigations. In summary, the risk index map represents a baseline with standardized assumptions; it is not

intended to identify individual properties with unacceptable risk, rather it displays hazard zones that could be used in policy and decision making.

The hazard map is based on the 2018 lidar topography and BGC's current understanding of the steep creek hazard on Fairmont Creek. Similar to the hazard assessment, any future changes to the channel geometry or the occurrence of a significant geohazard event may warrant reassessment of the hazard zones on Fairmont Creek.

7.4 Conceptual Mitigation

The mitigation options laid out in this report are at a conceptual level for discussion only and no design work has been done. The order of magnitude costs are presented in ranges to capture the uncertainty but these estimates could be exceeded depending on materials and methods chosen for each option. The option rankings and comparison presented have been developed by BGC with input from RDEK but have not benefited from other stakeholder input at this time.

8.0 CONCLUSION AND RECOMMENDATIONS

BGC has completed an updated hazard and risk assessment on Fairmont Creek for debris floods and debris flows up to the 3000-year return period that impact the Fairmont Creek fan. Modelling of the chosen hazard scenarios demonstrate that debris floods are conveyed in the channel until downstream of the golf course pond where the channel capacity is limited. Debris flows avulse from the channel at the bend downstream of Marble Canyon and downstream of the golf course pond.

The risk assessment estimated life safety and economic damage risk on the Fairmont Creek fan. The individual and group life safety risk, when compared to risk thresholds in other jurisdictions, demonstrates that some parcels are above the 1:10,000 PDI threshold and the group risk is above the reference line.

BGC presented three large-scale mitigation options and two localized mitigation options for consideration to improve the life safety and economic risk on the fan. The three large-scale options are a debris-flow barrier and basin upstream of FHSR, a parallel basin on the golf course, and improved channel conveyance downstream of the golf course pond. These options were rated and compared using the design considerations developed by BGC. With equal weighting of all design considerations, the upstream debris barrier and basin option scores the highest.

Finally, BGC recommends the following next steps:

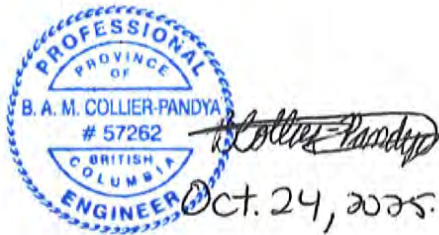
- The mitigation option rankings and comparison should be discussed further with other stakeholder involvement before selecting a mitigation option
- The conceptual design of the selected option should be refined during a detailed design phase that should include a site investigation task to gather subsurface information
- The hazard mapping and risk assessment should be re-assessed after the construction of any additional mitigation.

9.0 CLOSURE

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

Yours sincerely,

BGC Engineering Inc.
per:



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BCP/HW/sf/th

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