

APPENDIX A

DETAILS OF INFRASTRUCTURE ON FAIRMONT CREEK



A-1 INTRODUCTION

This appendix is meant to be a compilation of relevant details for the various infrastructure along Fairmont Creek, particularly along the developed reaches. This compilation includes culverts, bridges, berms, weirs and ponds shown in Table A-1 and on Figure A-1.

BGC has estimated the capacity of culverts and bridges for comparisons to event peak discharges and for simulation in the numerical model. The capacities reported in this appendix are order of magnitude estimates and should not be considered as exact values.

Table A-1 Infrastructure on Fairmont Creek from upstream to downstream.

Infrastructure	Approximate Capacity ¹	Notes
Weirs and basins	17,000 m ³	Three weirs and two basins built in 2018
FHSR intake sheds' berm		Berm and armouring
Campground access road culvert	5 to 6 m ³ /s	
Resort footbridge		
Golf course bridge 1	60 to 70 m ³ /s	
Golf course berms	13,800 m ³	Built in 2015
Golf course bridge 2	15 to 20 m ³ /s	At the golf course pond inlet
Golf course pond	8,000 m ³	
Golf course bridge 3	15 to 20 m ³ /s	At the golf course pond outlet
Golf cart path culvert	1 to 2 m ³ /s	
Mountainside Villas culvert	1 to 3 m ³ /s	
Golf cart path bridge	10 to 15 m ³ /s	
Columbia River Road culverts	3 to 7 m ³ /s	
Fairmont Creek Road culverts	3 to 6 m ³ /s	

Note:

1. Storage capacity for weirs, basins and berms is based on the design or construction records for the structures. Culvert capacities were estimated using nomographs provided in MoTI (2019). Bridge capacities were estimated with open channel flow equations and do not account for water and bridge interactions.

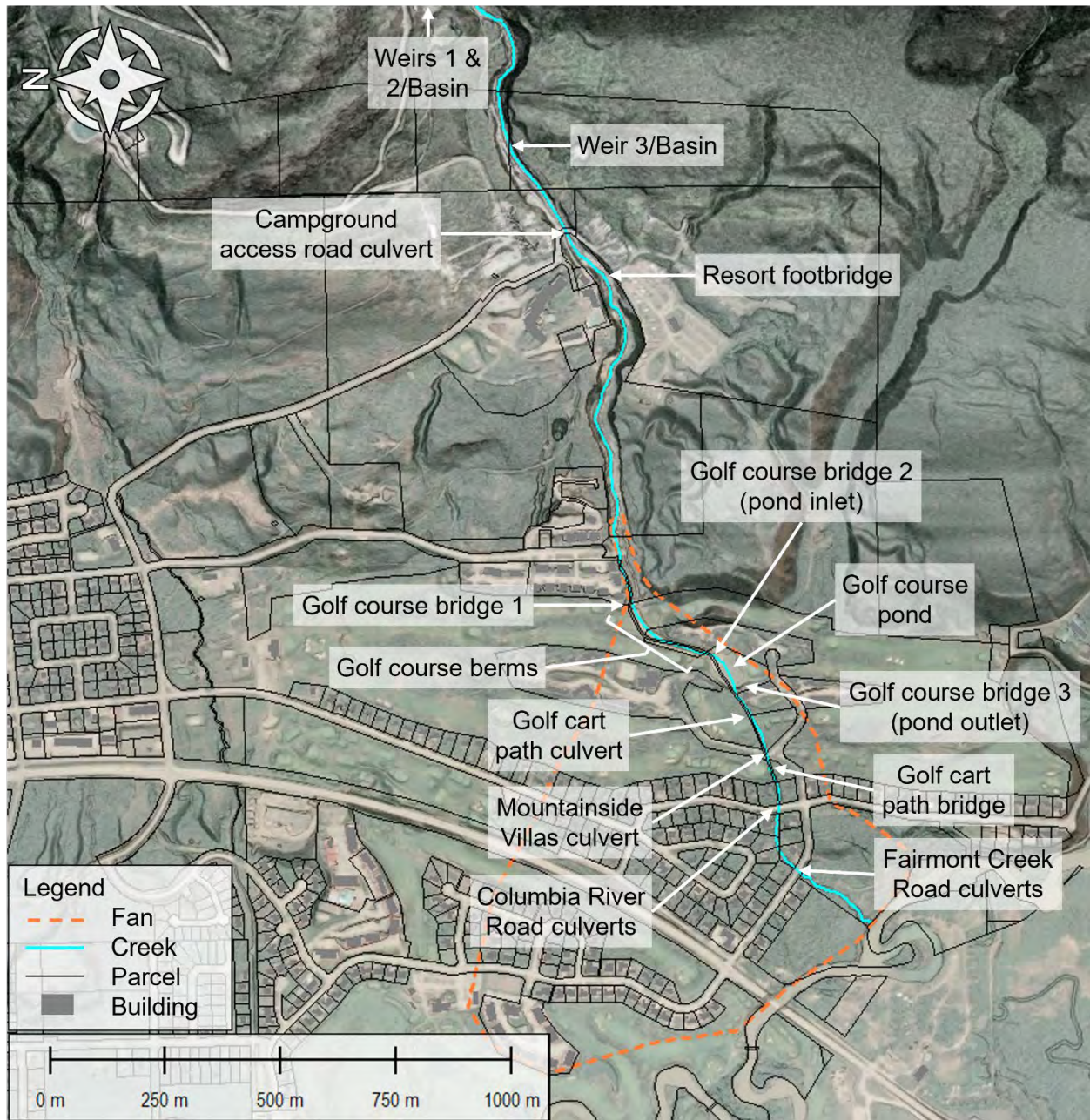


Figure A-1 Locations of infrastructure along the developed reaches of Fairmont Creek. Weirs 1 and 2, and the upper basin are beyond the extent of the figure but shown in Figure A-2 below.

A-1.1 Weirs and Basins

As part of Phases 2 and 3 of mitigation construction following the 2012 debris-flow event, NHC designed and supervised construction of three riprap weirs in two basins (Weirs 1 and 2 create one basin). Figure A-2 shows the layout of the mitigation upstream of FHSR's main development. Figure 1-4 in the main report shows photos of the weirs.

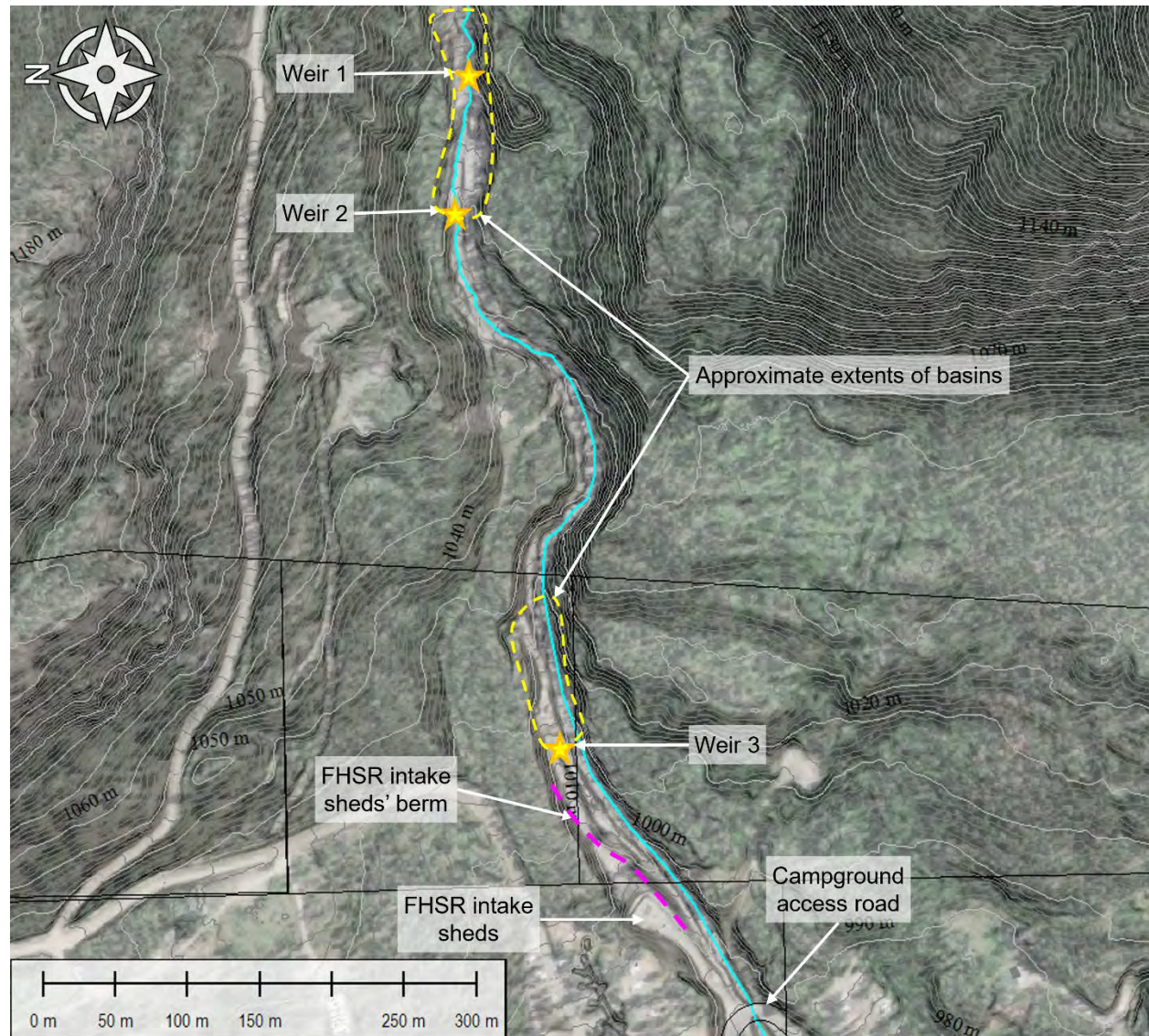


Figure A-2 Locations of weirs, basins, and berm designed by NHC. Contour interval is 2 m.

Since completion of construction in 2018, the basins have filled with sediment and required cleanout on numerous occasions (outlined in Table 1-1 in the main report). Therefore, the current configuration of the weirs and basins may not exactly match the design drawings. BGC has not reviewed the construction completion documentation.

NHC estimated that weirs 1 and 2 contained 15,000 m³ of debris and weir 3 contained 10,000 m³ of debris during the 2020 debris flood (NHC, June 24, 2020). This is higher than the estimated capacity of 17,000 m³ as NHC's estimates conservatively did not account for depositional angles and only accounted for horizontal debris deposition up to the invert elevation of each weir (NHC, June 24, 2020).

A-1.2 FHSR Intake Sheds' Berm

As part of Phases 2 and 3 of mitigation construction following the 2012 debris-flow event, NHC designed and supervised construction of a berm and bank armouring meant to reduce risk to the FHSR intake sheds. Figure A-2 shows the layout of the mitigation upstream of FHSR's main development, including the alignment of the berm and Figure 1-4 in the main report shows a photo of the berm.

The berm is approximately 120 m long and abuts into the natural right bank downstream of weir 3. At it's tallest, the berm is 4.5 m above the current channel and is riprapped to approximately 2 m above the current channel. The FHSR intake sheds are approximately 4 m below the current channel elevation as shown in Figure A-3.

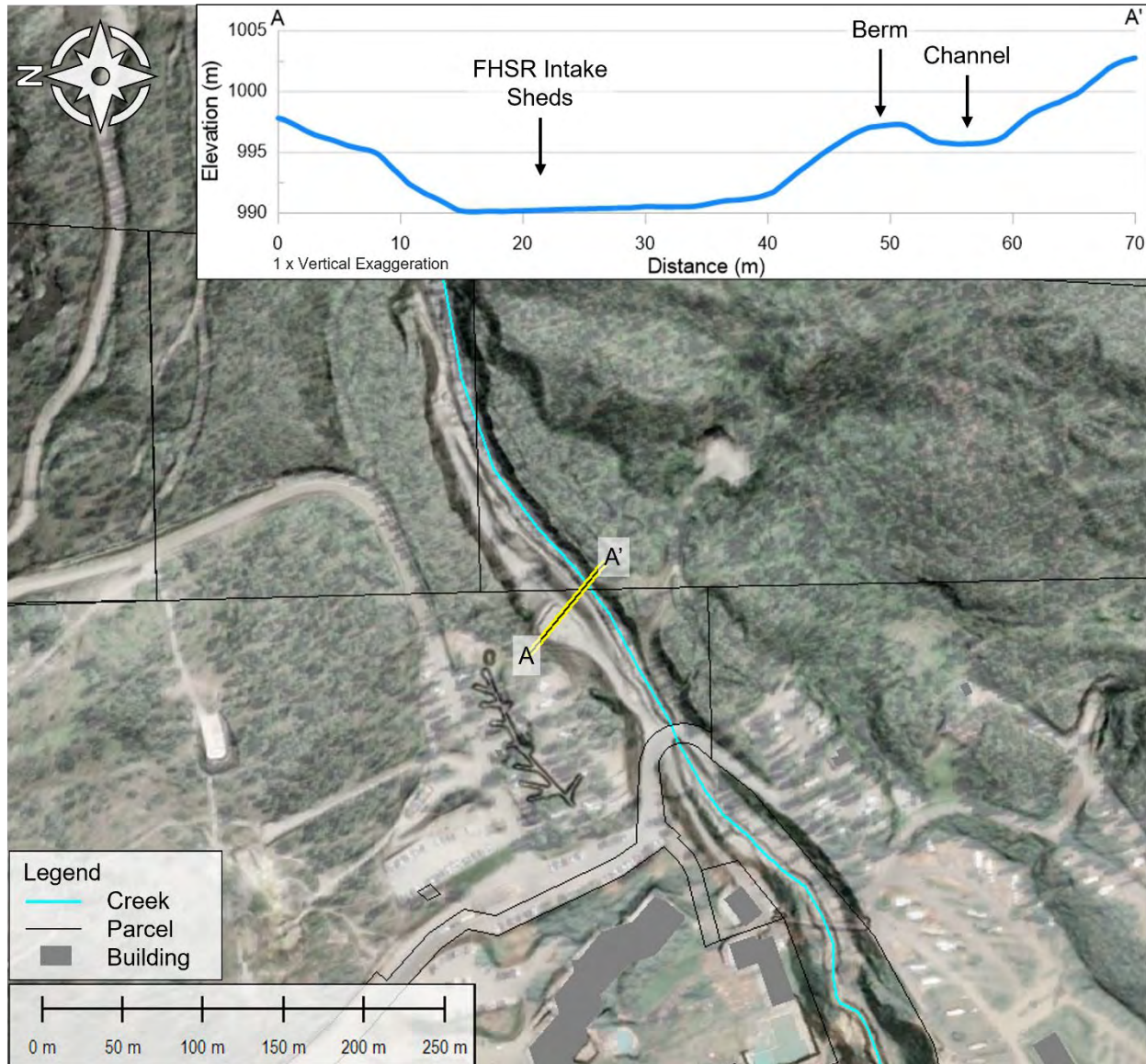


Figure A-3 Cross section showing difference in elevation between FHSR intake sheds and current channel. Cross section is based on 2018 lidar data and the berm has been reconstructed since.

During the 2020 event, NHC (June 24, 2020) reported that bank erosion on the downstream end of the berm and armouring threatened to allow migration of the creek towards the intake sheds which could have inundated the lower area with water and debris (Photos 3.25 and 3.26 in NHC [June 24, 2020]).

A-1.3 Campground Access Road Culvert

An access road crosses Fairmont Creek from the main FHSR development to the portion of the campground on the south side of the creek. Fairmont Creek passes through an 1800 mm diameter, corrugated steel pipe that is abutted by rounded boulders (Figure A-4). BGC estimates the capacity of the culvert to be 5 to 7 m³/s.



Figure A-4 Upstream and downstream views of campground access road culvert. Photos taken by BGC on August 27, 2024.

Prior to 2012, there was a 900 mm culvert in place that was washed out during the debris flow.

A-1.4 Resort Footbridge

A pedestrian footbridge crosses Fairmont Creek from the main FHSR development to the portion of the campground on the south side of the creek, approximately 150 m downstream of the campground access road. The bridge spans the channel and is about 9 m above the channel. BGC estimates the capacity of the footbridge to be sufficient to pass the 1000 to 3000-year debris flow. Prior to the 2012 event, the channel was spanned by a wooden bridge that had multiple piers. The 2012 event damaged some of those piers and the bridge was replaced with the spanning bridge currently in place.

A-1.5 Golf Course Bridge 1

A golf cart and pedestrian bridge crosses Fairmont Creek at the downstream end of Marble Canyon (Figure A-5). The bridge is wooden with lock block abutments, is 10 m wide across the channel and 2 m above the channel bed. BGC estimates the capacity to be 60 to 70 m³/s. This bridge was damaged and/or washed out during the 2012 event.



Figure A-5 Golf course bridge 1 at the downstream end of Marble Canyon. Photo taken looking upstream by BGC on August 28, 2024.

A-1.6 Golf Course Berms

As part of Phase 1 of mitigation construction following the 2012 debris-flow event, Urban Systems Ltd. (September 16, 2015) designed and supervised construction of berms and bank armouring along the Fairmont Creek reach from the golf course bridge 1 to the golf course pond. Figure A-6 shows the extent of the work.

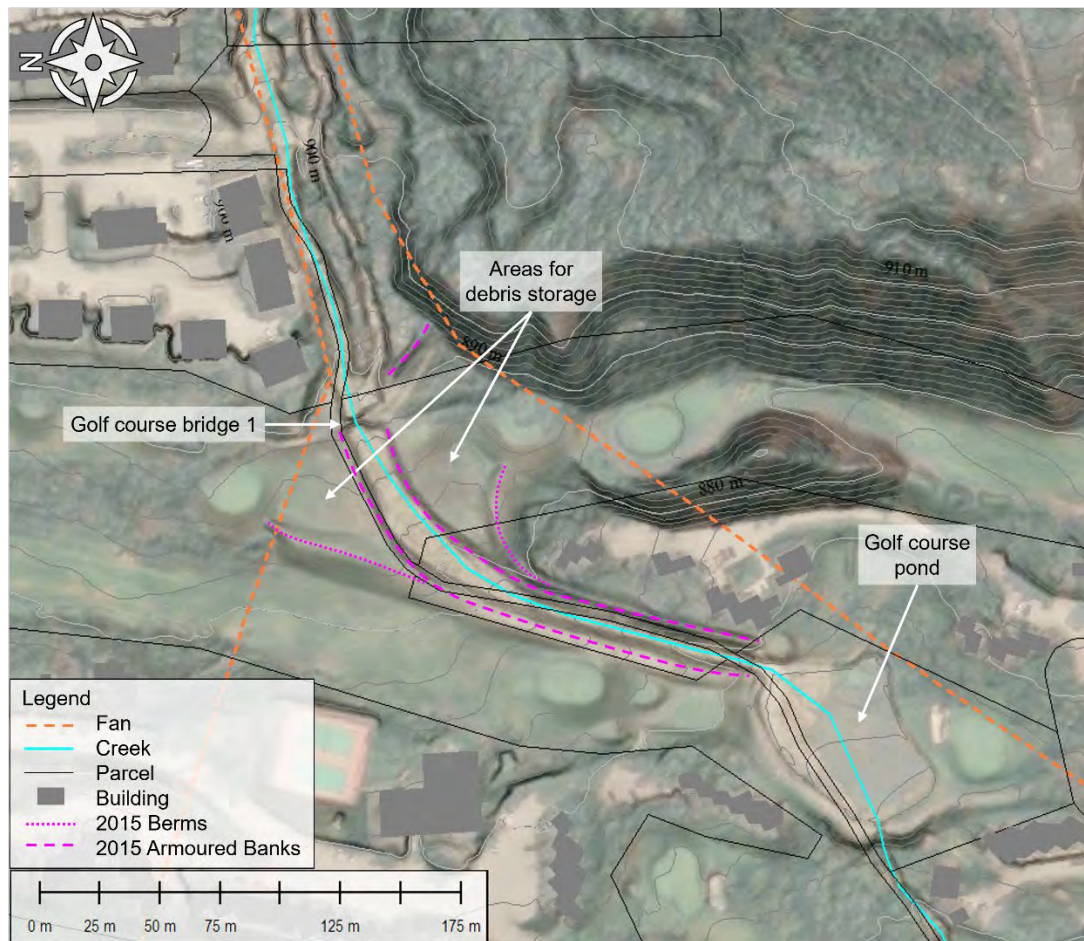


Figure A-6 Extent of mitigation designed by Urban (September 16, 2015). Contour interval is 2 m.

Generally, the berms beyond the banks of the creek are up to 1 m higher than the surrounding ground, have gentle slopes to blend with the golf course fairways and are unarmoured. The banks were built up and armoured to achieve better conveyance (Figure A-7). Urban Systems Ltd. (September 16, 2015) suggested the berms and bank armouring as constructed can store up to 13,800 m³ assuming a uniform 1 m deposition across the areas behind the berms.



Figure A-7 Downstream view of Fairmont Creek between Marble Canyon and the golf course pond with built up and armoured banks. BGC photograph of August 28, 2024.

A-1.7 Golf Course Bridge 2

At the inlet of Fairmont Creek to the golf course pond there is a pedestrian bridge (Figure A-8). The wooden bridge is on concrete pads, approximately 4 m wide across the creek and 2 m above the channel bottom. BGC estimates the capacity to be 15 to 20 m³/s. This bridge was washed out during the 2012 event.



Figure A-8 Upstream view of Golf course bridge 2 at the inlet to the golf course pond. BGC photograph of August 28, 2024.

A-1.8 Golf Course Pond

The golf course pond exists as an aesthetic feature on the golf course but has functioned as a sediment retention basin during the 2012 and 2020 events. The pond has an approximate surface area of 3000 m² and NHC (June 24, 2020) estimated that 8000 m³ of material was stored in the pond during the 2020 event.

A-1.9 Golf Course Bridge 3

At the outlet of the golf course pond there is a pedestrian bridge (Figure A-9). The wooden bridge is on a concrete channel that acts as a weir, approximately 3 m wide across the creek and 2 m above the channel bottom. BGC estimates the capacity to be 15 to 20 m³/s. This bridge was washed out during the 2012 event.



Figure A-9 Upstream and downstream views of the golf course pond outlet bridge and weir structure. BGC photographs of August 28, 2024.

A-1.10 Golf Cart Path Culvert

Between the golf course pond and the Mountain Villas access road, there is a golf cart path that crosses Fairmont Creek with a culvert (Figure A-10). The culvert is an 1100 mm diameter, steel corrugated pipe with grouted, stone pitching wingwalls. BGC estimates the capacity to be 1 to 2 m³/s. This culvert was flooded during the 2012 and 2020 events.



Figure A-10 Upstream and downstream views of the golf cart path culvert. Photos taken by BGC on August 28, 2024.

A-1.11 Mountainside Villas Culvert

At the Mountainside Villas access road, Fairmont Creek passes through a culvert (Figure A-11). The culvert is an 1100 mm diameter, steel corrugated pipe with riprap and cast-in-place concrete wingwalls. BGC estimates the capacity to be 1 to 3 m³/s.



Figure A-11 Upstream view of the Mountainside Villas culvert. Photo taken by BGC on August 28, 2024.

A-1.12 Golf Cart Path Bridge

As the creek runs adjacent to the most downstream golf fairway, it crosses under a golf cart path bridge (Figure A-12). The wooden bridge is on lock block abutments, 3 m wide across the channel and 1.5 m above the channel. BGC estimates the capacity to be 10 to 15 m³/s.



Figure A-12 Downstream end of the golf cart path bridge. Photo taken by BGC on August 28, 2024.

A-1.13 Columbia River Road Culverts

At Columbia River Road, Fairmont Creek passes through twinned culverts (Figure A-13). The culverts are 1200- and 1000-mm diameter, steel corrugated pipes with riprap wingwalls. BGC estimates their combined capacity to be 3 to 7 m³/s.



Figure A-13 Twinned culverts at Columbia River Road crossing. Photos taken by BGC on August 28, 2024.

A-1.14 Fairmont Creek Road Culverts

At Fairmont Creek Road, Fairmont Creek passes through twinned culverts (Figure A-14). The culverts are both 1100 mm diameter, steel corrugated pipes with riprap wingwalls. BGC estimates their combined capacity to be 3 to 6 m³/s.



Figure A-14 Upstream end of the twinned culverts at Fairmont Creek Road. Photo taken by BGC on August 28, 2024.

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APPENDIX B

AERIAL IMAGERY INTERPRETATION



B-1 AERIAL IMAGERY INTERPRETATION

Air photos dated between 1949 and 2000 and satellite images from 2017 and 2023 were examined for evidence of past sediment transport events. Events were identified from the appearance of bright areas and disturbed vegetation relative to previous air photos that is indicative of material loss or deposition. Smaller events that did not deposit sediment in areas large enough to be discernible in the air photos are not captured in this analysis. Similarly, events that occurred during large gaps between images or successive events that overlap may also not be identified by this approach.

B-2 IMAGERY REVIEWED AND OBSERVATIONS

Image Year	Air Photo Roll	Air Photo Frame	Observations
1949	BC878	32, 93	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.
1960	BC2748	71, 76	Fairmont Resort Road has been built across the Cold Spring Creek fan to Fairmont Creek. There is continued development around the present-day resort. There is a new road across the Fairmont Creek fan. No substantial changes observed in the watershed.
1964	BC4229	71, 155, 158	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.
1967	BC4433	77, 92	There is continued development of the Mountainside Golf Course. No substantial changes observed in the watershed.
1975	BC7818	17, 19	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.
1981	BC81112	104	Continued residential development on fan. No substantial changes observed in the watershed.
1988	BCC852	41, 40	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.
1995	BCB95058	31	Continued construction of Riverside Golf Course. Fairview Drive has been developed, and Marble Canyon Townhomes development has started. No substantial changes observed in the watershed.
2000	BCC00069	15, 38	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.

APPENDIX C

POST-WILDFIRE DEBRIS FLOWS



C-1 POST-WILDFIRE DEBRIS-FLOW ASSESSMENT

This section outlines the methodology to assess post-wildfire debris-flow likelihood and magnitude for Fairmont Creek.

BGC estimated post-wildfire debris-flow volumes using an empirical model. This involved:

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

C-1.1 Wildfire Likelihood

The wildfire frequency in the watershed is needed to estimate probabilities of post-fire debris-flow occurrence in the 2 years following a fire, when burned basins are most sensitive to post-wildfire effects (Cannon & Gartner, 2005; Staley, Kean, & Rengers, 2020; De Graff, Cannon, & Gartner, 2015). BGC used provincial burn probability mapping from the BC Wildfire Service based on the Burn-P3 simulation model developed based on observed historical databases by Parisien et al. (2005) for Canada Wildfire. The average probability of a wildfire in the Fairmont Creek watershed is 0.8% (i.e., 125-year return period). BGC then applied the following equation to determine the combined probability of debris-flow occurrence in the 2 years post-fire.

$$P_C = 1 - \left(1 - \frac{1}{T}\right)^n \times P_B \quad [\text{Eq. B-1}]$$

where P_C is the combined probability, T is the rainfall return period, n is the number of years to assess (in this case, 2 years), and P_B is the burn probability.

C-1.2 Post-Wildfire Volume

Empirical models for predicting post-wildfire debris-flow sediment volumes (e.g., Cannon et al., 2010; Gartner, Cannon, & Santi, 2014) can be used to assess hazards posed by debris flows following wildfires. The Gartner et al. (2014) model employed in this study is used by the United States Geological Survey (USGS) for emergency assessments of post-wildfire debris-flow hazards. The model is applicable for up to two years following a wildfire, after which plant re-growth and/or source area sediment depletion render it less reliable. The inputs for the model include:

- The contributing watershed area burned at moderate- and high severity
- The relief of the contributing watershed area
- The storm rainfall intensity measured over a 15-minute duration.

Given that wildfires have not occurred in the study watersheds within the period of settler colonial records, BGC considered a range of different burn proportions: 20%, 40%, and 60% of total forested watershed area were assumed to have burned at moderate to high severity. The watershed relief was measured from lidar digital elevation models.

BGC used a climate-adjusted intensity-duration-frequency (IDF) curve to provide a better representation of expected storm intensities to the end of century (2100). These data were

retrieved using the web-based IDF_CC Tool version 6.0, developed by the University of Western Ontario (Simonovic et al., 2015). The tool combines historical data based on observed precipitation with global circulation models (GCMs) for future scenarios. Given that no nearby climate stations are available, BGC selected a point within the Fairmont Creek watershed to develop the 15-minute rainfall IDF curves to input to the model. A period of 2060 to 2100 and the PCIC – Bias Corrected (CMIP6) – All models (averaged) were selected to generate the IDF. The SSP5.85 scenario⁵ was used, which applies a radiative forcing of 8.5 W/m² by the year 2100 and represents the upper boundary of the range of scenarios currently described in the literature.

In comparison with observed post-wildfire debris flows outside of southern California, BGC and others (e.g., Wall, Murphy, & Bennett, 2021) have found that the Gartner et al. (2014) model generally overpredicts post-wildfire debris-flow volumes in BC, and as such, the model requires adjustment to account for regional differences. When compared to observed BC post-wildfire debris-flow volumes, the Gartner et al. (2014) model has generally overpredicted volumes by a factor of up to 6.4, with a few volumes underpredicting by up to a factor of 0.6 (BGC, March 7, 2025; June 11, 2024; September 25, 2020). BGC applied a 0.5 reduction factor to the predicted volumes for Fairmont Creek, similar to what was applied at Cold Spring Creek (BGC, September 25, 2020).

The debris-flow sediment volume results for 20%, 40% and 60% of the watershed burned at moderate to high intensity scenarios are summarized in the main report.

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APPENDIX D

NUMERICAL DEBRIS-FLOOD AND DEBRIS-FLOW MODELLING METHODS



D-1 MODEL SCENARIOS

Hazard scenarios modelled with HEC-RAS are summarized in Table D-1.

Table D-1 Summary of modelled hazard scenarios and associated probabilities.

Return Period (Years)	Sediment Volume (m ³)	Peak Discharge (m ³ /s)	Hazard Process Type	Non-Newtonian Parameters	Annual Probability (Years ⁻¹)	Conditional Probability of Model	Figure No.
10 to 30	-	14	Debris flood	Newtonian Assumptions	0.067	1.0	C-2
30 to 100	-	30	Debris flood	Newtonian Assumptions	0.023	1.0	C-3
100 to 300	72,000	240	Debris flow	Generalized Herschel-Bulkley	0.0067	1.0	C-4
300 to 1000	122,000	410	Debris flow	Generalized Herschel-Bulkley	0.0023	1.0	C-5
1000 to 3000	161,000	540	Debris flow	Generalized Herschel-Bulkley	0.00067	1.0	C-6

Note:

1. Individual scenario probability is the product of the annual probability, and conditional probability of model.

D-2 HEC-RAS

D-2.1 Model Overview

BGC used HEC-RAS (version 6.6)¹, a public domain hydraulic modelling program developed and supported by the United States Army Corps of Engineers (USACE), to model the hazard scenarios listed in Table D-1. Two-dimensional unsteady flow routing was employed, applying the Shallow Water Equations, Eulerian-Lagrangian Method (SWE-ELM (Original/Faster)). HEC-RAS uses an irregular mesh to simulate flow over terrain, which allows for varying sizes and orientations of mesh. Irregular meshes improve the numerical efficiency and allows for improved resolution where the flow is changing rapidly. HEC-RAS is able to simulate Newtonian (e.g., clearwater floods and debris floods) and non-Newtonian (e.g., debris flows) fluids. It requires the following inputs:

- A digital elevation model (DEM) of the topography and a computational mesh
- Inflow outflow boundaries
- Terrain roughness parameter to describe how the fluid flows over the topography
- Flow rheology to describe the fluid's flow properties.

D-2.2 Model Topography, Domain, Mesh

The DEM is based on September 2018 lidar with a 0.5 m resolution. The model domain includes the Fairmont Creek fan, extends upstream past the Fairmont Hot Springs Resort (FHSR), and downstream to the Columbia River floodplain. The model domain does not include the Columbia River as it was beyond the scope of this assessment. BGC modified the DEM adding the berm adjacent to the FHSR intake sheds that were constructed since 2018 (observed during the 2024 site visit), blocking bridges and culverts to simulate avulsion scenarios, and removing bridges to simulate bridge washout. The 2D mesh size was 5 m x 5 m on the fan with breaklines, refining the alignment of the cells, and the resolution of the model to 2 m x 2 m along the main channel, road centrelines, and locations where the modelled flow avulsed from the channel.

The three weirs upstream of the fan apex are not captured in the September 2018 lidar surface and were not added in manually to the model topography as the basins' geometry change after events where they are cleaned out which would make it difficult to accurately incorporate them.

D-2.3 Bridges and Culverts

BGC observed 10 bridges and culverts that fall within the model domain during the 2024 site visit (Figure D-1). These were included in the model, as is outlined in Table D-2. The assumptions on whether the structures would be functioning, blocked, or washed out during various return period events were based on the structures' details presented in Appendix A, professional judgement, and observations following the 2012 debris flow event.

¹ US Army Corps of Engineers (USACE). (2024). *Hydrologic Engineering Center – River Analysis System (HEC-RAS) – Hydraulic Reference Manual Version 6.6*.

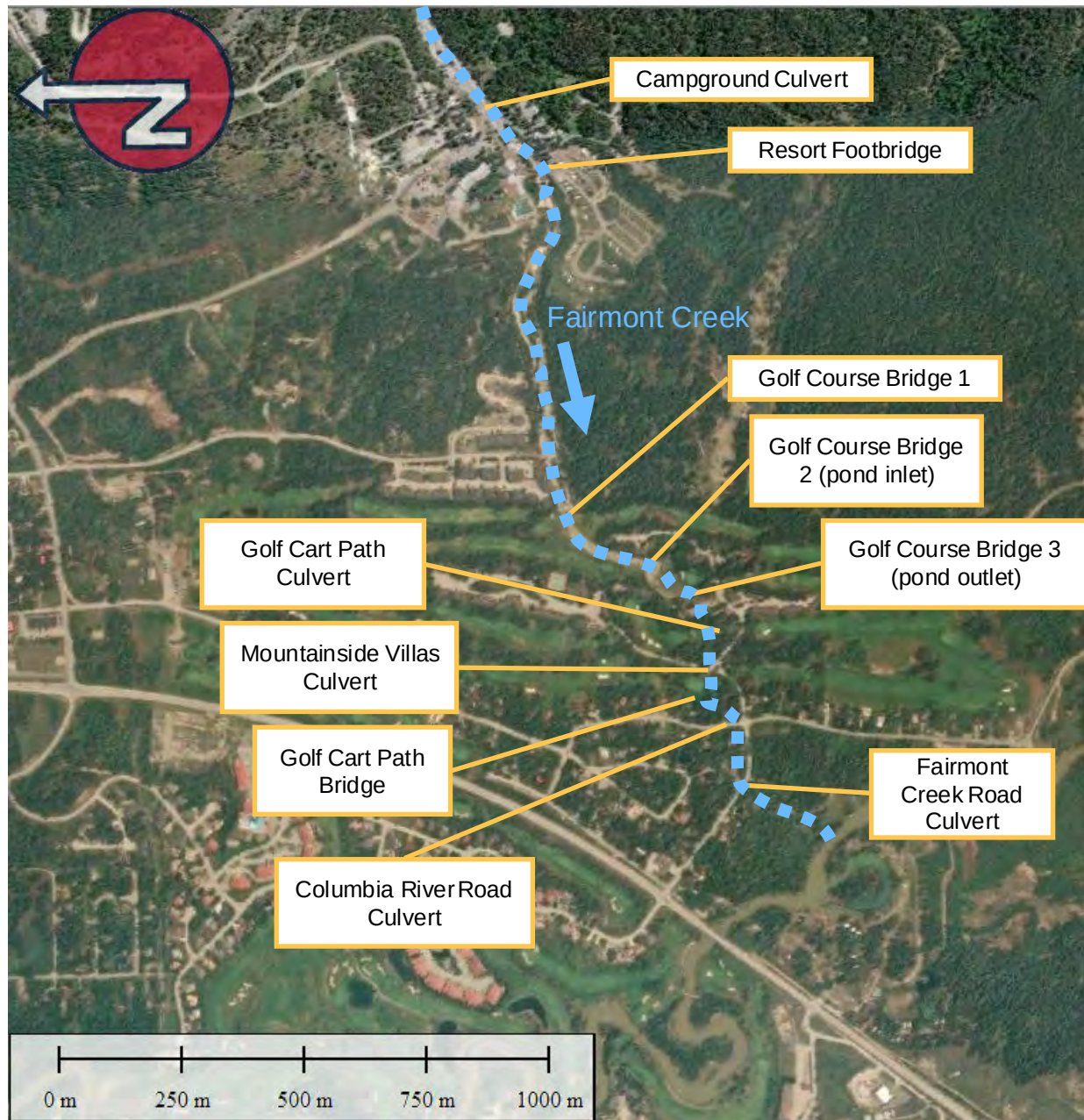


Figure D-1 Location of culverts and bridges included in the Fairmont Creek HEC-RAS model.

Table D-2 Summary of bridges and culverts along Fairmont Creek within the model domain.

Infrastructure	Return Period (years)				
	10 to 30	30 to 100	100 to 300	300 to 1000	1000 to 3000
Campground access road culvert	Functioning	Blocked	Washed Out	Washed Out	Washed Out
Resort footbridge	Functioning	Functioning	Functioning	Functioning	Functioning
Golf course bridge 1	Functioning	Functioning	Washed Out	Washed Out	Washed Out
Golf course bridge 2 (pond inlet)	Functioning	Washed Out	Washed Out	Washed Out	Washed Out
Golf course bridge 3 (pond outlet)	Functioning	Washed Out	Washed Out	Washed Out	Washed Out
Golf cart path culvert	Blocked	Blocked	Blocked	Blocked	Blocked
Mountainside Villas culvert	Blocked	Blocked	Blocked	Blocked	Blocked
Golf cart path bridge	Functioning	Washed Out	Washed Out	Washed Out	Washed Out
Columbia River Road culverts	Functioning	Blocked	Blocked	Blocked	Blocked
Fairmont Creek Road culverts	Functioning	Blocked	Blocked	Blocked	Blocked

D-2.4 Roughness

The roughness of the model dictates how easily a fluid can move over the terrain. A high roughness (e.g., dense trees) will slow fluid flow whereas a low roughness (e.g., roads) will allow flow to move more easily. The roughness is defined in HEC-RAS using a Manning's roughness coefficient (Manning's n).

The Manning's n values were assigned to the mesh using the open-source Canadian Land Cover Map². The in-channel Manning's n was delineated separately within the model and was adjusted based on the modelled Froude number. The Manning's n values assigned to various land types are shown in Table D-3.

² Government of Canada. (2020). *2020 Land Cover Map of Canada*.
<https://open.canada.ca/data/en/dataset/ee1580ab-a23d-4f86-a09b-79763677eb47>

Table D-3 Summary of modelled hazard scenarios and associated probabilities.

Land Cover Type	Manning's n
In-channel	0.08
Forest	0.1
Grassland (including golf course)	0.035
Estuarine Scrub-Shrub Wetland (including developed areas)	0.07
Estuarine Forested Wetland	0.044

D-2.5 Flow Boundary Conditions

Flow boundary conditions define where and how a fluid enters or exits the model domain. The inflow boundary at Fairmont Creek was defined by a flow hydrograph upstream of FHSR.

The upstream boundary for the debris floods was defined using a hydrograph in which the peak flow was maintained at a constant rate until the simulated flows within the model reached a steady state. This is a conservative approach to debris flood modelling, which sometimes results in an overestimation of ponding. In this case, it was deemed appropriate, due to the nature of the assessment, and because the simulated ponding seemed reasonable.

The hydrograph for the debris-flow process type is an idealized triangular hydrograph with a 1/6 rising limb to the peak discharge and a 5/6 falling limb. The total volume of flow passing is equal to the combined volume of sediment and water, assuming a volumetric sediment concentration of 50%.

A normal depth of 0.05 m/m, measured from the DEM, was set as the outflow boundary condition just upstream of the Columbia River.

D-2.6 Flow Rheology

The flow rheology defines how a fluid behaves under stress. In HEC-RAS, flows can be binned into two types: Newtonian and non-Newtonian. Newtonian fluids like water have a constant viscosity, so they deform (move) under any applied stress. Non-Newtonian fluids are those whose viscosity changes when force is exerted on the fluid making it behave more like a liquid or more like a solid. Different flow rheologies were applied to debris floods and debris flows within the model, as shown in Table C-1.

D-2.6.1 Debris Floods

BGC used Newtonian assumptions to simulate the debris floods. Although debris-flood flow is not explicitly non-Newtonian and does include sediment transport, there is no computationally efficient and accurate model available that simulates debris-flood sediment transport, and concentration of sediment is generally small enough (<5%) to make its effects negligible. Therefore, it is currently industry best practice to model debris floods with Newtonian behaviour.

D-2.6.2 Debris Flows

BGC used the Herschel-Bulkley model to simulate the non-Newtonian behaviour of debris flows. Herschel-Bulkley is a viscoplastic model with a non-linear relationship between shear stress and shear described by Equation C-1.

$$\tau = \tau_y + K\dot{\gamma}^n \quad [\text{Eq. C-1}]$$

where τ is the shear stress (Pa), τ_y is the yield stress (Pa), K is the consistency index ($\text{Pa}\cdot\text{s}^n$), $\dot{\gamma}$ is the shear rate (s^{-1}), and n is the shear exponent. The shear exponent n determines whether the flow has shear-thickening or shear-thinning behaviour, with $n < 1$ meaning as the applied shear increases, the fluid becomes easier to shear (deform, move). Parameter ranges applied at Fairmont Creek (Table C-4) were initially informed by parameter relationships developed by the Restauration des Terrains en Montagne (RTM), described as having a significant clay content and potentially a large grain size range up to large boulders (email from Clement Misset, personal communication, February 6, 2024). This differs from Fairmont Creek where the fines content is less than 20%, requiring additional calibration.

BGC selected rheological parameters for Fairmont Creek (Table C-4) through calibration to the 2012 debris flow event. The 2012 debris flow was simulated using the known event volume and peak flow. The rheology of the event was altered to best match the modelled runout extents and deposition depth to the runout extents and deposition observed following the 2012 event. The selected rheology (Table C-4) was then applied to all modelled debris flows. BGC assumed a volumetric sediment concentration of 50% for all modelled debris flows.

Table D-4 Herschel-Bulkley parameters used with HEC-RAS to model debris flows on Fairmont Creek.

Herschel-Bulkley Parameter	Typical Values or Equations ⁽¹⁾	Value Applied
Yield Stress, τ_y (Pa)	500 – 10,000	500
Consistency Index ⁽²⁾ , K ($\text{Pa}\cdot\text{s}^n$)	$K/\tau_c = 0.1 - 0.3$	0.2
Shear Exponent, n	0.3	0.3

Note:

1. Typical values based on input from the RTM (email from Clement Misset, personal communication, February 6, 2024).

D-2.7 Post-Processing and Results

Peak flow depth and velocity rasters were exported from HEC-RAS at a grid size of 5 m. Since the peak impact pressure cannot be exported from HEC-RAS, BGC calculated it using the peak depth and velocity rasters, assuming the peak impact pressure either occurs at the time of peak velocity or peak depth, recording the maximum impact pressure between the two calculations. The impact pressure calculations are discussed in Section 4.1 in the main report.

Figures showing peak flow depth for each modelled hazard scenario are provided in Figure D-2 to Figure D-6. Raw model results are on file at BGC and available upon request.



Figure D-2 10 to 30- year return period debris flood maximum modelled depth.



Figure D-3 30 to 100- year return period debris flood maximum modelled depth.

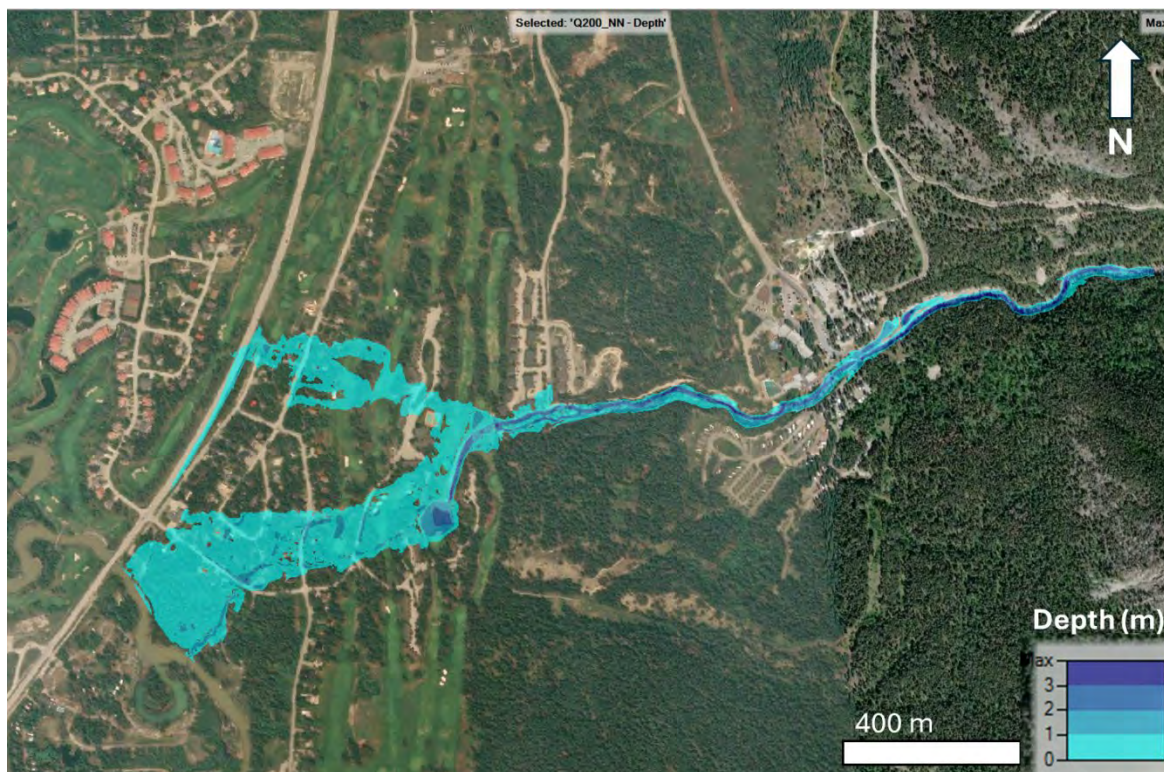


Figure D-4 100 to 300- year return period debris flood maximum modelled depth.

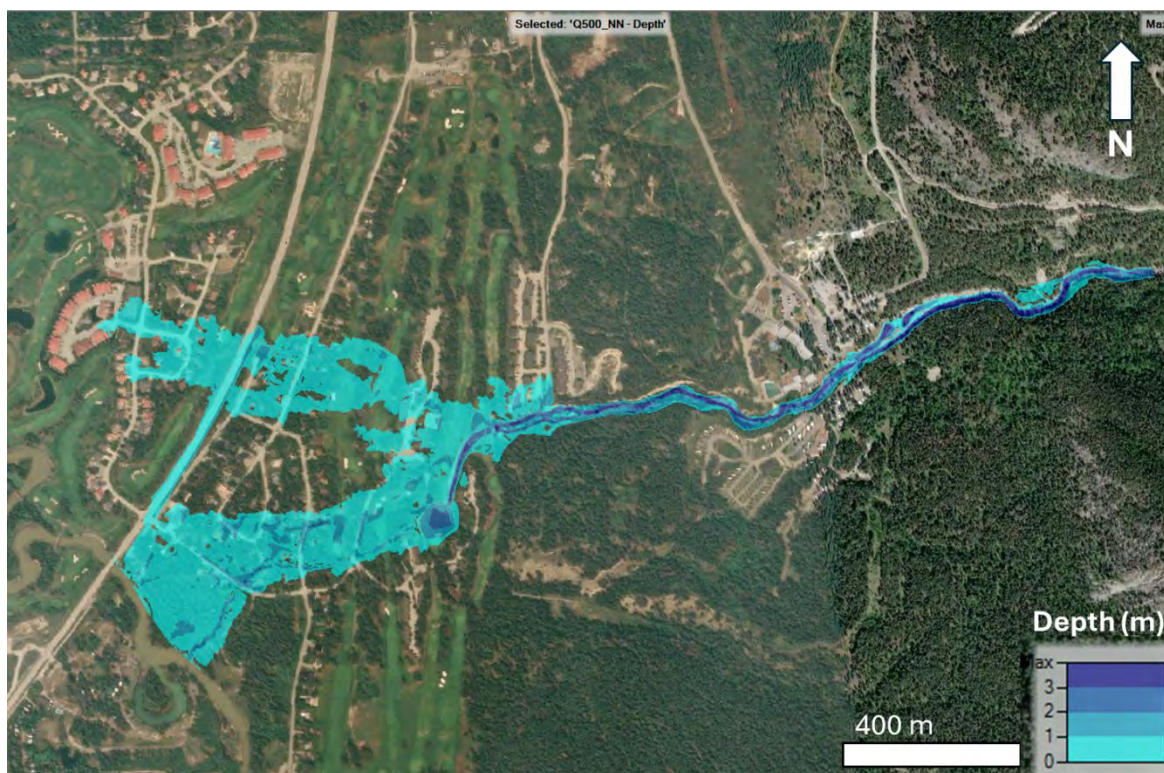


Figure D-5 300 to 1000- year return period debris flood maximum modelled depth.

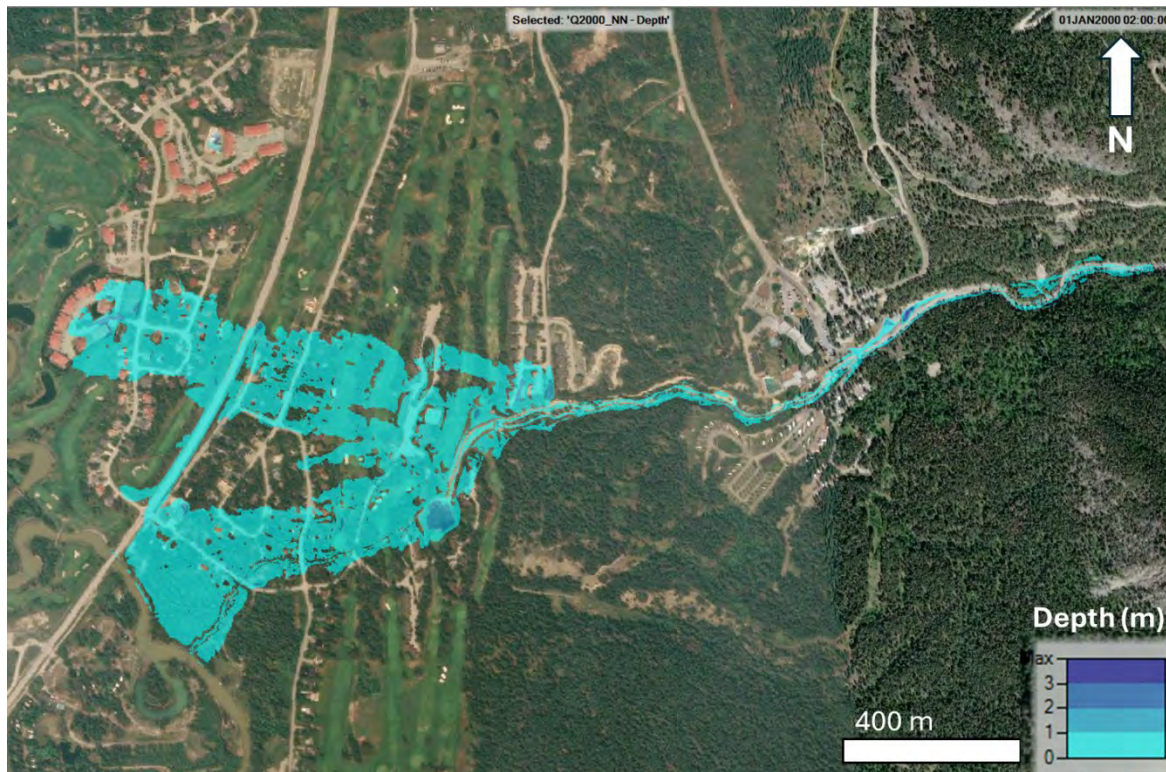


Figure D-6 1000 to 3000- year return period debris flood maximum modelled depth.

D-3 UNCERTAINTIES AND LIMITATIONS

The numerical modelling results do not provide a precise or exact prediction of real debris-flood or debris-flow events. BGC modelled hazard scenarios that represent a broader range of behaviour than possible to model directly. The uncertainties and limitations of the numerical modelling are summarized below:

Natural Processes:

- Steep creek hazards are natural processes with complex behavioural feedback mechanisms associated with meteorological, orographic, and topographic factors. Such interactions are complicated by future change associated with a changing climate and natural or human-made modifications to the landscape. Given this, there is a stochastic or unpredictable nature to these process types that lead to inherent uncertainty and limitations to the accuracy of numerical models.

Model Inputs:

- The model topography is generally based on the September 2018 lidar with few modifications and can be considered a 'snapshot in time'. Future changes (e.g., development, mitigation, geohazard events) may warrant a change in the depicted hazard extents and intensities.

- The topography is 'bare-earth' meaning it does not include three-dimensional natural (e.g., trees) and human-made (e.g., buildings) structures that influence flow behaviour through flow restriction, concentration, and redirection.
- While the selected rheological parameters are calibrated to a real event on Fairmont Creek (the 2012 debris flow event), rheology varies between debris flow events, even within the same creek, depending on factors such as what material is entrained within the event. Rheology of future events along Fairmont Creek may vary, impacting factors such as runout extents and intensity.
- Although debris flows often occur in multiple surges during a single event, BGC assumed the debris flows occur as a single surge, represented by a simplified triangular hydrograph, since surge sequencing cannot be predicted with certainty. Modelling flows as a single surge typically results in higher peak impact pressures and was deemed reasonable for the purposes of risk assessment.

Model Limitations:

- HEC-RAS does not model physical changes to the topography during an event (e.g., dynamic erosion and deposition). As such, there is uncertainty in the precise flow behavior of each modelled scenario, as this can influence the flow path(s) and associated flow intensities. BGC had to manually modify the topography, adding berms constructed since 2018 and bridge blockages to force avulsion scenarios in the models. These locations are selected a-priori based on expert judgement rather than process-based modelling.
- HEC-RAS assumes a homogeneous fluid, meaning the water and sediment in a debris flow are treated as a single fluid rather than a multi-phase flow. The model cannot replicate true debris-flow behaviour involving the complex interaction of the fluid phase with the solids phase (e.g., boulders, large woody debris). For instance, the model cannot explicitly simulate flooding and sedimentation that may occur beyond the toe of a bouldery deposit. Furthermore, the model assumes a constant solids concentration, which would typically vary throughout the duration of a debris flow. For instance, the model cannot replicate fast-flowing muddy surges between bouldery surges, or flooding and sedimentation that may occur beyond the toe of a bouldery deposit.

BGC has interpreted the modelling results for the purposes of the Fairmont Creek risk assessment and hazard mapping with these limitations in mind.