THREE SISTERS CREEK ASP

Three Sisters Creek Preliminary Mitigation Design

Final REV 3
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Prepared by BGC Engineering Inc. for:
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c/o QuantumPlace Development Ltd.

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TABLE OF REVISIONS

ISSUE	DATE	REMARKS
DRAFT Rev. A	November 6, 2020	Issued for review by QPD and the ToC
FINAL Rev. 0	November 13, 2020	Issued for review by the ToC
FINAL Rev. 1	December 14, 2020	Issued following integration of ToC review comments.
FINAL Rev 2	December 17, 2020	Issued following review by QPD.
FINAL Rev 3	January 5, 2021	Issued with additional drawings to show residual hazard for scenario with culvert replacement and without culvert replacement at Three Sisters Parkway.

LIMITATIONS

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EXECUTIVE SUMMARY

Three Sisters Creek is subject to clearwater floods and debris floods (BGC, October 9, 2020). BGC completed an updated assessment of debris-flood hazards on Three Sisters Creek in 2020 (October 9, 2020) that showed that the western (yet undeveloped) fan portions are affected substantially less than the eastern (currently developed) fan portions. This is attributable to the western portions being higher than the eastern portions. The assessment shows the need to protect the currently developed areas from debris flooding in a comprehensive mitigation strategy.

This is a design report for a debris-flood mitigation system at Three Sisters Creek. The preferred mitigation system was developed with input from QuantumPlace Developments Ltd. (QPD) an authorized agent of Three Sisters Mountain Village Properties Ltd. (TSMV) and the Town of Canmore (ToC) as part of the mitigation options analysis completed by BGC (November 5, 2020) and includes:

1. Upper channel east and west setback berms oriented parallel to, and set back from the Three Sisters Creek channel, upstream of the Golf Course Pond (GCP) on both sides of the creek. The setback berms establish a wide floodplain allowing for sediment deposition and channel changes.
2. Woody debris management upstream of the GCP outlet to reduce the likelihood of woody debris flow blocking the outlet.
3. Lower channel west setback berms on the west side of Three Sisters Creek channel between the GCP and Three Sisters Parkway (TSP) (lower channel) to protect against avulsions.
4. Culvert replacement at TSP to increase the culvert capacity to convey the peak discharge associated with debris floods with return periods in excess of 100 years[1].
5. Woody debris management upstream of the TSP culvert to reduce the risk of culvert blockages.

BGC's design philosophy appreciates and integrates the morphodynamics of steep creeks in modern steep creek risk management. The main pillar of the design is a wide creek floodplain upstream of the Golf Course Pond. This allows the creek to migrate, deposit sediment and result in lower flow depth, which reduces erosion and entrainment of channel bed and bank sediment. This allows for less effort in bank protection and reduced maintenance effort. The other system components acknowledge reduced sediment load downstream of the GCP and associated geomorphic changes while addressing flood issues. The design thus constitutes a functional and fully integrated design.

The preliminary mitigation designs are sized for a 100 to 300-year return period debris flood with a peak discharge of 50 m^3/s, 24,000 m^3 sediment volume, and 74 m bank erosion in the upper channel between the fan apex and GCP (design event). The event magnitude is based on the 2020 debris-flood hazard assessment update completed by BGC (October 9, 2020). The peak

[1] The existing TSP culvert is sufficiently sized to pass the 100-year return period debris flood peak discharge based on historical and current conditions. It will become insufficiently sized to pass the same return period (100-year) peak discharge under climate change conditions in the latter half of the century (2050-2100) (BGC, October 9, 2020).

discharge of the design event includes climate change impacts projected for the latter half of the century (2050-2100). This design event was chosen because it results in tolerable life-loss risk, and it maximizes the ratio of economic risk reduction benefit versus mitigation costs (BGC, November 5, 2020).

For each mitigation element, the purpose of the proposed works, existing conditions, design details, recommendations for further work, and cost estimate are presented. The cost estimate includes capital costs and operations and maintenance costs over a 50-year period and has an estimated uncertainty of -25% to +50%. The proposed mitigation system is estimated to cost $9.0 Million, including both capital and operations and maintenance costs for each mitigation element over a 50-year period. The costs of the mitigation system are anticipated to be shared between multiple parties including TSMV, the ToC, and Alberta Transportation (AT). As part of a separate scope of work, a proposed cost-sharing framework for consideration was presented by BGC (October 30, 2020). The design is preliminary, and both the cost and design details will change as the design progresses.

A residual hazard assessment was completed for two conditions: 1) the full proposed mitigation system; and 2) the mitigation system without the proposed culvert replacement at the TSP. These two options were juxtaposed as the TSP culvert may not been replaced well after the remainder of the mitigation measures have been implemented. Therefore, an evaluation of the mitigation systems with and without the TSP culvert appeared warranted. The assessments showed that the residual hazard from the 100 to 300-year return period design event is negligible for both existing and proposed development under either case (full system and without TSP culvert replacement). Proposed development is not intersected by modelled flows up to 3,000-year return period debris floods. With the proposed culvert replacement, existing development is only intersected at Crossbow Landing, for the 1,000 to 3,000-year return period flows; whereas without the proposed culvert replacement, existing development at Crossbow Landing is intersected for both the 100 to 300-year and 1,000 to 3,000-year return period flows. At both return periods, flow intensity is low (<1 m^3/s^2) and does not pose a credible life loss threat, but flooding could lead to some economic loss.

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ACRONYMS AND ABBREVIATIONS

Acronyms and abbreviations used in this report:

GCP	Golf Course Pond
QPD	QuantumPlace Developments
SCCA	Stewart Creek Commercial Area
ToC	Town of Canmore
TSMV	Three Sisters Mountain Village
TSP	Three Sisters Parkway

1. INTRODUCTION

1.1. General

The southwestern Alberta mountain front was affected by a high intensity, long duration rainstorm between June 19 and 21, 2013. Direct runoff, coupled with meltwater released from rain-on-snow, caused sudden and prolonged high flows that resulted in high rates and volumes of sediment transport, bank erosion and avulsions on alluvial fans[2]. Multiple steep creeks in the Bow River Valley, including Three Sisters Creek, were affected by debris floods caused by the combined storm and snowmelt runoff. Three Sisters Creek flows through an abandoned golf course and along the west side of existing development upstream of Three Sisters Parkway (TSP) in Canmore before discharging into the Bow River (Drawing 01).

Three Sisters Mountain Village Properties Ltd. (TSMV) wishes to construct a mixed-use resort village partially located on the western Three Sisters Creek alluvial fan as well as a commercial area (Stewart Creek Commercial (SCCA)) east of the fan. In addition, the Town of Canmore (ToC) wishes to provide reasonable mitigation of existing debris-flood hazards to existing development. Drawing 01 shows the proposed development areas, which are partially located within the Three Sisters Creek fan and the hazard mapping completed by BGC (October 9, 2020). Given the location of the proposed developments in relation to Three Sisters Creek, parts of the proposed development areas may be exposed to debris-flood hazards.

QuantumPlace Developments Ltd. (QPD), who is an authorized agent of TSMV, retained BGC Engineering Inc. (BGC) to: 1) complete an update to the debris-flood hazard assessment update (BGC, October 9, 2020); 2) a mitigation options analysis (BGC, November 5, 2020); and 3) provide preliminary design and cost estimates for mitigation measures to protect people and infrastructure in existing and proposed developments adjacent to Three Sisters Creek from damaging effects of future debris floods.

This report provides preliminary-level designs and cost estimates for debris-flood mitigation measures at Three Sisters Creek (Item 3 above). This report forms the third report in a sequence of hazard, risk and mitigation reports as defined in BGC's proposal (April 28, 2020).

1.2. Report Objectives

This report provides preliminary-level designs and cost estimates for Three Sisters Creek debris-flood mitigation, including:

- Description of design constraints and assumptions considered in the preliminary-level design of the debris-flood mitigation measures
- Description of mitigation options that were selected to form the preferred mitigation system
- Technical description and cost estimate of proposed preliminary-level debris-flood mitigation measures

[2] Alluvial fans are fan-shaped deposits of water-transported material (alluvium). They typically form at the outlet of tributary streams into a main valley where there is a marked change in slope angle.

The proposed debris-flood mitigation measures support the ToC's Municipal Development Plan goals to:

1. "manage development to reduce impacts of natural hazards on people and property, recognizing that these hazards may worsen with climate change impacts that are already occurring or are anticipated to occur."
2. "facilitate mitigation measures to reduce the risk of loss of life, property damage, and economic impacts from natural hazards, including flood, debris flood, and wildfire" (ToC, 2016).

1.3. Related Documents and Studies

The following documents provide additional information that is relevant to the Three Sisters Creek debris-flood mitigation design:

- Three Sisters Creek Debris-Flood Hazard Assessment (BGC, October 31, 2014), which provides a hazard assessment of June 2013 debris flood on Three Sisters Creek.
- Three Sisters Creek Debris-Flood Risk Assessment (BGC, January 19, 2015), which provides a quantitative risk assessment for potential damages from a future Three Sisters Creek debris flood.
- Three Sisters Creek Debris-Flood Mitigation Modelling (BGC, October 14, 2016), which provides numerical modelling of debris floods in the lower reaches of Three Sisters Creek with proposed mitigation works layouts from SweetTech Engineering Consultants.
- Three Sisters Creek Debris Flood Risk Assessment Update (BGC, January 11, 2018), which provides an update to the 2015 quantitative risk assessment to include areas downstream of Three Sisters Parkway.
- Three Sisters Creek Debris-Flood Risk Assessment (BGC, October 9, 2020), which provides an update to the hazard assessment on Three Sisters Creek to consider the as-yet undeveloped area on the western portion of the fan.
- Three Sisters Creek Cost Sharing Framework for Consideration (BGC, October 30, 2020), which outlines a cost-sharing framework between different stakeholders for mitigation works on Three Sisters Creek.
- Three Sisters Creek Debris-Flood Mitigations Options Analysis (BGC, November 5, 2020), which provides an analysis of potential mitigation options on the Three Sisters Creek fan to manage debris-flood risk.

This report supersedes the following memorandum which was created during the design development process:

- Three Sisters Creek Workshop 2 Follow-Up on Requests for Additional Analysis (BGC, October 8, 2020) which outlines additional analyses completed in support of selection of the preferred mitigation system on Three Sisters Creek.

1.4. Report Organization

This report is organized as follows:

- Section 2 summarizes the outcomes of the mitigation options analysis completed by BGC with input from the ToC and QPD to determine the preferred mitigation system.
- Section 3 presents the design basis for the proposed preliminary mitigation design.
- Section 4 presents the details about the proposed Three Sisters Creek preliminary design, including the purpose of the proposed mitigation elements, technical details, recommended site investigation and design work, and cost estimates.
- Section 5 presents the assessment of residual hazard on Three Sisters Creek following construction of the proposed mitigation works.
- Section 6 outlines the performance expectations and uncertainties associated with the preliminary design and individual mitigation elements.
- Appendix A provides details of the cost estimates for each mitigation element including the assumed quantities and unit rates.

2. MITIGATION OPTIONS ANALYSIS

Debris-flood hazards affect existing and proposed development on the east and west sides of Three Sisters Creek (BGC, October 9, 2020). The purpose of mitigation works on Three Sisters Creek fan is to reduce risk associated with debris floods to both existing and proposed development. BGC completed a mitigation options analysis that considered the criteria summarized in Table 3-1 in the development and comparison of debris-flood mitigation options on Three Sisters Creek (November 5, 2020). The mitigation options were presented to the ToC and QPD during two workshops that informed a detailed options comparison following the Kepner-Tregoe (KT) method (Kepner & Tregoe, 1965). The KT method was used to evaluate a short-list of mitigation options based on the factors and associated weightings defined in consultation with the ToC and QPD.

The mitigation options analysis identified a preferred mitigation system that includes the following elements:

1. Upper channel east and west setback berms oriented parallel to, and set back from the Three Sisters Creek channel, upstream of the Golf Course Pond (GCP) on both sides of the creek. The setback berms establish a wide floodplain allowing for sediment deposition and channel changes.
2. Woody debris management upstream of the GCP outlet to reduce the likelihood of woody debris flow blocking the outlet.
3. Lower channel west setback berms on the west side of Three Sisters Creek channel between the GCP and TSP (lower channel) to protect against avulsions.
4. Culvert replacement at TSP to increase the culvert capacity to convey the peak discharge associated with debris floods with return periods in excess of 100 years[3].
5. Woody debris management upstream of the TSP culvert to reduce the risk of culvert blockages.

BGC acknowledged that Alberta Transportation may delay the culvert replacement to the end of the existing culvert design life, which BGC understands to be approximately 30 years. The culvert is expected to have sufficient capacity to convey the peak discharge associated with debris floods with return periods up to 100-years based on historical conditions. For return periods in excess of 100-years, flows are expected to overtop the culvert (BGC, November 5, 2020).

[3] The existing TSP culvert is sufficiently sized to pass the 100-year return period debris flood peak discharge based on historical and current conditions. It will become insufficiently sized to pass the same return period (100-year) peak discharge under climate change conditions in the latter half of the century (2050-2100) (BGC, October 9, 2020).

3. DESIGN BASIS

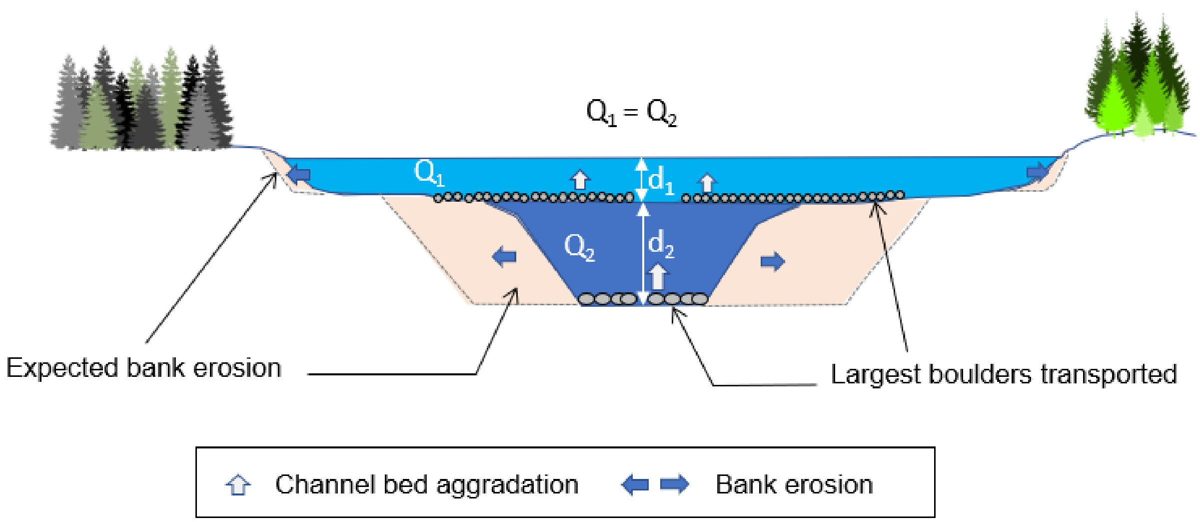
The design basis for the proposed preliminary mitigation design on Three Sisters Creek is summarized in Table 3-1.

Table 3-1. Summary of design basis for debris-flood mitigation on Three Sisters Creek.

Consideration	Summary for Three Sisters Creek
Design Philosophy	Allow the natural tendency of steep creek fan processes to occur without interference to reduce construction and maintenance costs while creating a natural stream corridor appearance where possible.
Design Integration	Creation of a functional design of individual design elements where the respective element is logically integrated with the entire system components
Preliminary design level	The proposed design is at a preliminary level. Each design element is intended as a starting point that will be refined at later stages of design.
Life-loss risk reduction target	Life-loss risk reduction was not a key driver for mitigation design selection. BGC's risk assessment for existing development (BGC, January 19, 2015) demonstrated that the ToC life-loss risk objectives outlined in the Municipal Development Plan (ToC, 2016) are met for existing development without mitigation.
Economic risk reduction target	Economic risk reduction is the key driver for the proposed mitigation design.
Cost	Lifecycle costs including capital costs and operations and maintenance costs, for a 50-year period for all options are estimated at a preliminary level with expected variance of -25% to +50%.
Hazard characterization	The proposed design is based on the 2020 debris-flood hazard assessment update (BGC, October 9, 2020).
Design event	The design event is a 100 to 300-year return period debris flood (Table 3-2).
Maintenance and post-event restoration	A goal of the proposed mitigation design is to minimize the operations and maintenance costs associated with the mitigation elements.
Ownership, access, environment	The proposed design assumes that all land that interacts with proposed structures is available to be used for construction and access to debris-flood mitigation options.
Geotechnical and topographic design parameters	Geotechnical design parameters are based on terrain interpretation from lidar-derived topography and aerial photographs. No subsurface investigations have been conducted to date. Further site investigations and surveying will be required as part of later stages of design.
Risk transfer	The proposed mitigation measures consider risk transfer to other areas on Three Sisters Creek fan. The residual hazard assessment included assessment of risk transfer. Transferred risk is addressed by additional downstream mitigation structures and is less than ToC life-loss risk tolerance criteria. BGC completed a preliminary assessment of the magnitude of risk transfer associated with the
Elements at risk	Elements at risk considered include existing residential development, proposed development at TSMV, proposed development at SCCA, high voltage powerlines operated by AltaLink that cross Three Sisters Creek at the GCP outlet, TSP, and buried utilities below the parkway (Drawing 01).

Consideration	Summary for Three Sisters Creek
Environmental and Social Impact	A goal of the proposed mitigation design is to minimize environmental impacts and strive for aesthetically pleasing, multi-use, and natural designs.
Hazards mitigated	The mitigation is designed specifically to protect development from debris-floods and clearwater floods on Three Sisters Creek. Other potential hazards that could include rock avalanches and wildfires have not been evaluated.

The design philosophy appreciates and integrates the morphodynamics of steep creeks in modern steep creek risk management. The main pillar of the design is a wide creek floodplain upstream of the Golf Course Pond. This allows the creek to migrate, deposit sediment and result in lower flow depth, which reduces erosion and entrainment of channel bed and bank sediment resulting in less bank protection- and reduced maintenance efforts. This is conceptually illustrated in Figure 3-1 showing flow characteristics and bank erosion potential for shallow and wide channels (light blue) as compared with narrow and deep channels (dark blue).



Channel configuration	Flow characteristics and bank erosion potential
Wide channel and floodplain (light blue)	• Low flow depth (d_1) and velocity lead to low shear stresses exerted on channel banks. • Lower bank erosion potential and smaller grain sizes transported. • Lesser erosion protection and channel maintenance requirements.
Narrow channel (dark blue)	• High flow depth (d_2) and velocity lead to high shear stresses exerted on channel banks. • Higher bank erosion potential and larger grain sizes transported. • Greater erosion protection and channel maintenance requirements.

Figure 3-1. Schematic of flow characteristics and bank erosion potential for different channel configurations. Not to scale. Artwork: BGC.

The design event is a 100 to 300-year debris flood under future climate conditions in years 2050 to 2100 (RCP 8.5[4]). This design event was chosen, because it results in tolerable life loss risk (ToC, 2016), and it maximizes the ratio of economic risk reduction benefit versus mitigation costs (BGC, November 5, 2020). Design event selection was discussed with the ToC and QPD as part of the Three Sisters Creek Mitigation Options Analysis (BGC, November 5, 2020).

The peak discharge and sediment volume estimates for all return periods considered as part of the debris-flood hazard assessment update are summarized in Table 3-2.

Table 3-2. Peak discharge and sediment volumes for Three Sisters Creek under future climate conditions in 2050-2100 (RCP 8.5). The design event is highlighted in light orange.

Return Period (years)	Bulked Peak Discharge[1] (m^3/s)	Sediment Volume (m^3)	
		Best estimate	Maximum estimate
10 to 30	15	14,000	18,000
30 to 100	32	19,000	27,000
100 to 300	50	24,000	37,000
300 to 1,000	80	30,000	48,000
1,000 to 3,000	112	35,000	56,000

Note:

1. Peak discharges are bulked 5 to 10% to account for large woody debris and sediment associated with debris floods (BGC, October 9, 2020).

4 Representative concentration pathways (RCP) describe scenarios of emissions defined by the Intergovernmental Panel on Climate Change (IPCC). RCP 8.5 is a scenario with radiative forcing of 8.5 W/m2 in the year 2100. BGC compared the results for RCP 8.5 and 4.5 as part of the hazard assessment update (BGC, October 9, 2020).

4. THREE SISTERS CREEK PRELIMINARY MITIGATION DESIGN

4.1. General

This section describes the purpose, technical details, recommended further site investigation and design work, and preliminary cost estimate for each design element of the preferred mitigation system on Three Sisters Creek. Design elements are addressed in order, from upstream to downstream.

4.2. Mitigation System Elements

4.2.1. Upper Channel East and West Setback Berms

4.2.1.1. Purpose of Proposed Mitigation Works

The purpose of the upper channel east and west setback berms is to contain debris floods and limit the extent of channel migration while allowing the channel to remain in its natural shallow and wide state. These berms would define a wide floodplain, within which the channel is free to aggrade, erode, and migrate. These berms were selected because they protect existing and proposed development and require minimal routine maintenance. A conceptual sketch of a wide floodplain defined by setback berms is shown in Figure 4-1.

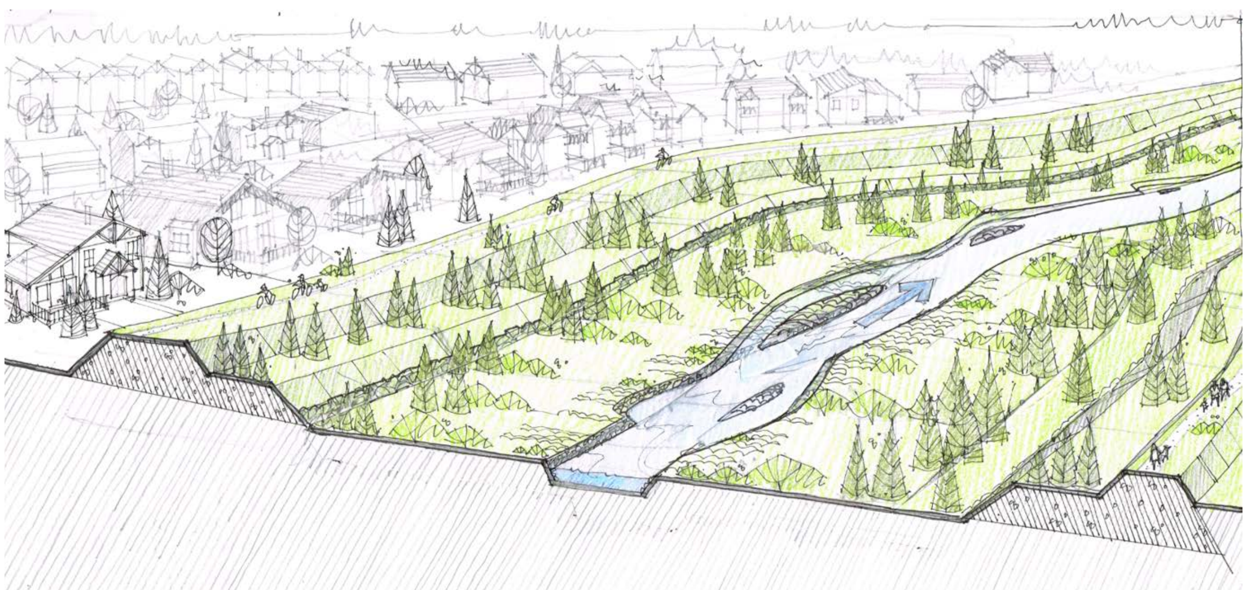


Figure 4-1. Conceptual sketch of wide floodplain defined by setback berms. Artwork by D. Shuttleworth. Dimensions are not to scale and development type and location is hypothetical.

4.2.1.2. Existing Conditions

Three Sisters Creek upstream of the fan apex is deeply incised into a thick sequence of glacial sediments (BGC, October 9, 2020). Downstream of the fan apex, the channel widens and debris-flood modelling completed by BGC indicates the potential for flow avulsion to the east (toward existing development) through an existing potential avulsion channel on the east channel bank (BGC, October 9, 2020).

There is a berm on the east side of the creek downstream of the fan apex that was identified by BGC from the 2015 lidar. The berm appears to have been constructed between 1997 and 2008 based on air photo review, and is approximately 200 m long, 1 m high, 2 m wide at the crest, and 15 m wide at the base (BGC, November 5, 2020). BGC does not consider this berm as providing sufficient protection against avulsions because it is not sufficiently long.

Three Sisters Creek flows through an old golf course to the GCP downstream. The channel width through the old golf course ranges from 15 m to 50 m. Here, the creek was re-channelized and excavated following the June 2013 event (TetraTech EBA, March 17, 2014). Through this reach, the average channel gradient is approximately 10%. At the inlet to the GCP, the channel is approximately 75 m wide and 4.75 m deep at the thalweg. The upstream slopes of the GCP are approximately 9 m high above the waterline with bank slopes between 15° and 17°.

As part of the 2020 debris-flood hazard assessment update, BGC analyzed the potential for bank erosion along Three Sisters Creek using a combination of historical imagery analysis and probabilistic numerical modelling. The expected bank erosion for future climate conditions is summarized in Table 4-1 with the design event and median predicted erosion highlighted.

The erosion listed is the total erosion anticipated for the channel (i.e., the total erosion on both banks combined) but the model cannot predict the relative distribution of erosion on either side of the channel. For this reason, in the absence of a non-erodible barrier, the 100 to 300-year 95% erosion corridor is mapped as 74 m on both sides of the channel, acknowledging that the relative distribution of erosion on either side of the channel is unknown.

Note that the erosion potential differs from avulsion potential which favours the eastern portion of the fan as shown in BGC's debris-flood numerical modelling (BGC, October 9, 2020). Erosion is governed by shear stresses acting on the channel banks whereas the avulsion potential is governed by fan topography.

Table 4-1. Summary of expected erosion for the year 2050 to 2100 (RCP 8.5) climate change scenario.

Return Period (years)	Peak Discharge (m^3/s)	Expected Erosion (m)				
		5%[1]	25%	50% (Median)	75%	95%
10-30	15	2	4	6	8	11
30-100	32	20	25	29	34	41
100-300	50	40	49	55	62	74
300-1,000	80	84	98	110	122	143
1,000-3,000	112	121	141	156	173	202

Note:

1. The percentages represent the probability of non-exceedance. For example, at the 100 to 300-year return period, there is a 5% probability that erosion will not exceed 40 m, and a 95% probability that it will.

4.2.1.3. Proposed Mitigation Design Details

The preliminary design of the proposed upper setback berms is shown on Drawings 02 and 03, with additional description provided in this section. The upper east setback berm extends from the slope on the east side of the fan apex downstream to the GCP. It is set back from the east bank of Three Sisters Creek to define a wide floodplain. The upper west setback berm extends along the top of the west bank from upstream of the proposed TSMV development to the GCP. Erosion protection is included on the upstream slopes of the GCP on both sides of the creek.

The proposed berm heights provide 0.6 m freeboard above modelled (FLO-2D) flow depths with the berms in place (Drawing 06) and using post-2013 topography to account for anticipated sedimentation. This freeboard exceeds the requirements outlined for dike design and construction[5] and conservatively accounts for uncertainty in the flow depth and distribution of deposited sediment. Both the east and west setback berms are 1.5 m high along most of the length with a 4 m crest width and 2H:1V slopes (typical detail on Drawing 03). The berm height is increased locally to provide a consistent, linear berm crest, where the underlying topography is a natural depression, such as in the potential avulsion channel on the east side of Three Sisters Creek. The material and cost estimates presented herein are inclusive of the additional berm material required in these select locations. The crest width was selected to allow for berm fill to be placed and compacted with heavy equipment. This crest width would also allow for the berm to be used as a recreational pathway post-construction. The crest width could be optimized as part of future phases of design to reduce the costs and potential land impacts.

The alignments of the berms are based on the numerical debris-flood modelling showing avulsion locations and overland flow extents as well as the predicted bank erosion extents (BGC, October 9, 2020, Table 4-1). The upper east setback berm extends into the wildlife corridor and Bow Valley Wildland Park upstream of the developed area (Drawing 01) to tie-in to the topographic slope and minimize the potential for avulsions to outflank the berm on the upstream side. Three wildlife crossing ramps are integrated into the design within the wildlife corridor (Drawing 02). The total length of the berm is 878 m. The berm centerline is located a minimum of 74 m from the top of the east bank of Three Sisters Creek, which corresponds with the 95% expected bank erosion extent. During future design phases, the alignment of the east setback berm could be reviewed and optimized.

The toe of the upper east setback berm needs to be protected from erosion down to the elevation of the existing channel, which is 3 to 4.5 m below the ground elevation at the berm position. BGC recognizes that there is a range of potential options for this erosion protection, including: grouted stone pitching installed in a trench, riprap installed in a trench, a combination of trenched riprap and a launch apron, a narrow concrete wall installed in a trench, sheet pile wall, installation of hydraulic structures such as groins, installation of natural features to reduce erosion such as boulder nests, horizontal half-buried logs, vertically half-buried logs, and select bioengineering techniques where appropriate given the anticipated stresses and forces.

5 The BC MoWLAP outlines that the minimum river dike crest elevation is the higher of 1 in 200-year instantaneous flow plus 0.3 m freeboard or 1 in 200-year maximum daily flow plus 0.6 m freeboard (BC MoWLAP, 2003).

Trenched riprap and a launch apron in the potential avulsion channel (Drawing 02) were selected for preliminary design because it is expected to provide sufficient bank protection, without requiring extensive trench excavations. By minimizing the required excavation, ground disturbance during construction is reduced compared to the other options. Detailed performance and cost optimization comparisons of other options is recommended for the detailed design stage.

A launch apron, sometimes referred to as a falling apron, is an erosion protection technique wherein riprap placed at surface “launches” down the eroding slope to self-protect the face of a river bank when erosion occurs (Figure 4-2). The volume of material stored in the launch apron is higher than would be required if placed directly on the bank surface or within an excavated trench, but it allows for natural creek migration and removes the requirement for trench excavation and associated disturbance to the area.

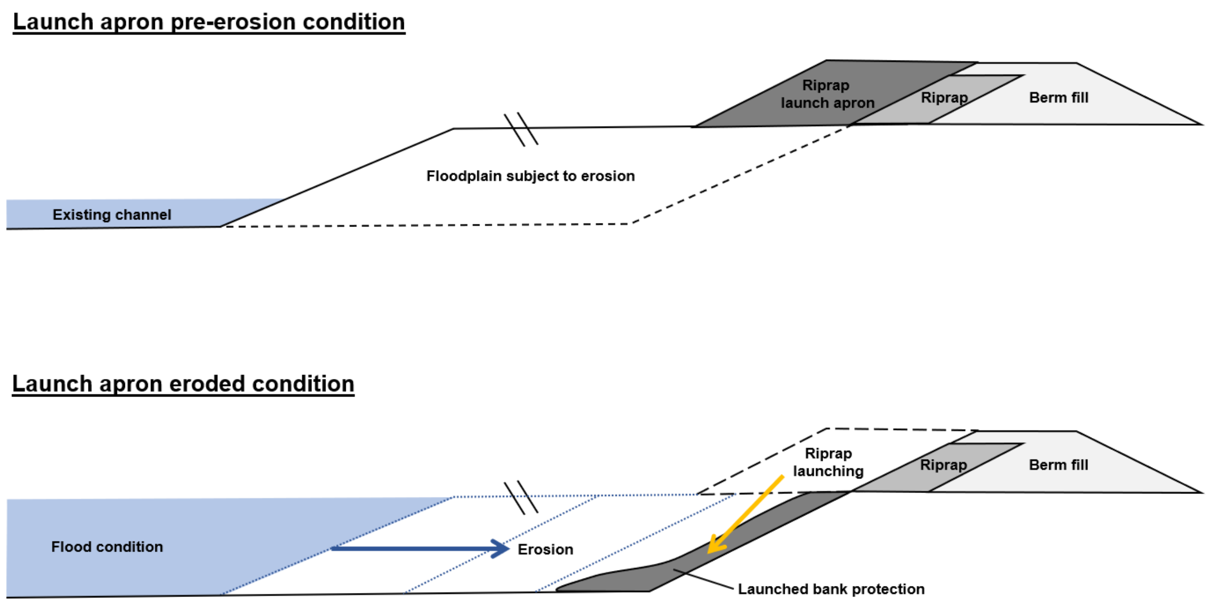


Figure 4-2. Schematic of launch apron in pre-erosion condition (top) and eroded condition (bottom). Schematic by BGC.

Along the length of the channel excluding the launch apron, Class 3 riprap is trenched at the toe and placed up the berm face along the side facing the channel (typical detail on Drawing 03). The launch apron extends from sta. 0+170 to 0+440 (Drawing 02), which is the zone that is most likely to be impacted by Three Sisters Creek during a future debris flood. The launch apron extents are based on FLO-2D modelling (BGC, October 9, 2020), topography, and the presence of potential avulsion channels identified in the lidar. Over the length of channel with the launch apron, the berm height is approximately 2.5 m to maintain the 0.6 m freeboard. The launch apron is an additional 6 m wide to accommodate the additional Class 3 riprap volume as outlined in Table 4-2 (typical detail on Drawing 03). The full berm, including the launch apron can be revegetated to blend with the natural aesthetic and to integrate recreational uses as part of future phases of design.

Table 4-2. Launch apron design characteristics.

Characteristic	Value
Material composition[1]	Class 1 to Class 3 riprap
Average settling height (m)[2]	4
Launch apron width (m)[3]	6
Apron thickness (m)[4]	2.5

Notes:

1. Best practices in launch apron design recommend well graded material where the largest sized material resist hydraulic forces, and the smaller sizes reduce loss of the underlying bank material and help to stabilize the larger particles.
2. Settling height based on average bank height along the adjacent channel length as measured from 2015 lidar.
3. Apron width calculated based on 1.5 times the settling height.
4. Apron thickness based on 4 times the D50 of the riprap where thickness = (3.75 to 4.5)*D50. Well-graded riprap is recommended so BGC used the D50 of Class 2 rip rap of 0.6 m and increased the height to align with the adjacent berm height.

The upper east setback berm prevents overland flow into existing development on the east side of Three Sisters Creek. Given this, the flow is channelized to the GCP and concentrated through the reach downstream. This channelization increases the intensity of the debris flood, as expressed by momentum flux on Drawings 06 and 07 and increased flow at downstream infrastructure including the TSP culvert.

The upper west setback berm extends from upstream of the proposed TSMV development along the west channel bank crest. It is 408 m long and ties-in at the GCP on the downstream side and into a local topographic high on the upstream side. The west setback berm is shorter than the east setback berm as numerical debris-flood modelling does not indicate the potential for overland flooding in the upper sections of the reach in the design event or higher return period debris floods assessed as part of the hazard update (BGC, October 9, 2020). For this reason, the full upper west setback berm is outside of the wildlife corridor and Bow Valley Wildland Park (Drawing 02).

The upper west setback berm is designed with erosion protection on the east facing slope. A variety of techniques are conceivable that could provide suitable erosion protection including grouted stone pitching, riprap, and a combination of one or both of these techniques with bioengineering such as increasing flow resistance through floodplain vegetation, bank protection by partially buried logs. For preliminary design, BGC selected grouted stone pitching that extends down the Three Sisters Creek channel bank because it is preferred by the Town of Canmore and high confidence it will perform as intended. The grouted stone pitching is trenched approximately 0.6 m below the channel thalweg elevation (typical detail on Drawing 03). The stone pitching is designed to prevent bank erosion and lateral migration toward the proposed TSMV for debris floods for all return periods considered as part of the hazard assessment update (BGC, October 9, 2020) that are contained by the berms. The design of the wide floodplain will allow for the channel to aggrade and migrate over time to a more natural condition such that the channel geometry becomes wider and shallower. In this configuration, the erosive power of the flow in the channel is reduced (Eaton et al., 2017). Future design phases could consider modifications to the existing floodplain to further encourage channel widening and migration of the channel away from the west bank. The design of the erosion protection could be optimized in future phases of design in line with any modifications to the floodplain. Natural techniques such as burial of trees with the root wad above ground and angled downstream along the base of the bank could be considered in this process. Such measures instill flow resistance and channel complexity which is desirable from an ecological perspective.

It is assumed that both the upper setback berms will be constructed from locally available, well-graded granular fill that is sourced from the Three Sisters Creek fan or elsewhere within Canmore. Some material processing may be required to remove materials that are greater than about 15 cm diameter, and suitability of this fill source with respect to fines content will need to be confirmed. The berm crests and outside slopes are to be vegetated. It is assumed that the aesthetics and potential recreational or other uses of the berms and wide floodplains, such as for walking trails, will be reviewed in consultation with other stakeholders as part of future phases of design.

At the inlet to the GCP, erosion protection is proposed on both the left (west) and right (east) upstream slopes of the pond. These areas are not anticipated to experience regular flow outside of flood or debris-flood conditions following heavy precipitation events. In this design, grouted stone pitching is proposed (Drawing 02) to protect against erosion and control upstream channel grade. The form of erosion protection and grade control should be refined as part of future phases of design, including evaluation of if a grade control structure is needed at the steep transition from the upper channel to the GCP.

4.2.1.4. Recommended Further Work

The following work is recommended during future design stages.

- Selection of the berm alignment should be refined based on landowner input and surveyed topography, in line with additional engineering, environmental, and aesthetics considerations
- The extent and type of erosion protection along the upper setback berms should be refined as part of future phases of design.
- Selection of erosion protection and grade control works at the GCP inlet slopes should be reviewed considering costs, flow velocities, and potential for knickpoint erosion.
- Evaluation of the berm crest width could be completed to optimize the design in line with potential future uses.
- Site investigation is recommended at the berm sites and berm fill borrow area(s), including test pits and material testing to verify the suitability of the borrow material to be used as engineered fill for the berm, and to estimate the depth of excavation required to establish an appropriate foundation for the berm.
- A qualified biologist should be engaged to provide input on the proposed instream works and wildlife ramps in the wildlife corridor for seamless design integration.
- A qualified botanist or bioengineering specialist could be engaged to provide input on revegetation of the floodplain in a manner that contributes to stabilization of the channel.

- The aesthetics and potential recreational uses of the setback berms and wide floodplain should be reviewed with stakeholder input.

4.2.1.5. Cost Estimate

The estimated capital cost of the setback berms and wide floodplain is $5.4 Million (Appendix A). The operation and maintenance costs, in terms of net present value (NPV) over a 50-year period are estimated to be $100,000. Combined, the total mitigation lifecycle cost of this option is $5.5 Million (NPV, 50-year maintenance period). These estimates do not include costs for bioengineering of the floodplain which could be considered as part of future design phases.

4.2.2. Woody Debris Management at the Golf Course Pond Outlet

4.2.2.1. Purpose of Proposed Mitigation Works

The purpose of adding a woody debris management system at the GCP outlet is to capture woody debris upstream of the outlet to minimize the potential for blockage at the AltaLink bridge as well as to reduce the potential for woody debris transport from the upper channel reaches past the GCP to the lower channel. Partial or full blockage of the AltaLink bridge opening would reduce the channel capacity and increase the likelihood of flows overtopping and potentially impacting development in downstream areas or impacting the buried AltaLink electrical line.

4.2.2.2. Existing Conditions

The GCP is located approximately 1 km downstream of the fan apex. The GCP acts as a sedimentation basin during debris floods with an estimated capacity of approximately 40,000 m^3 (BGC, October 9, 2020). Approximately 10 m downstream of the pond outlet, Three Sisters Creek passes under an existing bridge that contains two 138kV powerlines. The bridge is referred to as AltaLink Bridge on Drawing 01, but BGC notes that AltaLink are not the owners of the bridge. The electrical transmission lines (AltaLink 76L/113L) provide power to Calgary and areas west of the city. The transmission lines are buried within the bridge and at each bridge approach. The exact depth of burial at any location is not currently publicly mapped but is believed to be on the order of 1.2 m depth across the alluvial fan due to powerline design considerations (email from Chris Ollenberger, QPD, personal communication, May 25, 2020).

The bridge spans 8.8 m over the creek, is 5 m wide, and there is 2 m height between the channel base and the underside of the bridge (EBA, February 7, 2014). BGC has estimated this opening to have a capacity of 60 m^3/s, which is sufficient to pass the 100 to 300-year return period discharge (Table 3-2). As part of the mitigation options analysis, BGC reviewed the bridge sizing and costs that would be required to convey the 1,000 to 3,000 debris flood and, in consultation, with the ToC and QPD decided that no changes to the configuration of the bridge are recommended at this stage.

Directly upstream and downstream of the bridge the channel is lined by articulated concrete mats to protect from erosion. The articulated concrete matting is designed to withstand flow velocity of up to 6 m/s (email from representative at Armortec Erosion Control Solutions [6], personal communication, October 5, 2020) and extends approximately 20 m upstream and 15 m downstream from the bridge over an 18 m wide area. The peak velocity estimated in the numerical debris-flood modelling completed as part of the hazard assessment (BGC, October 9, 2020) in this area is approximately 6 m/s.

Numerical modelling results (BGC, October 9, 2020) show that for 100 to 300-year return period, when the channel is in an aggraded condition and the GCP capacity is reduced due to sedimentation, shallow overland flow is expected to overtop the downstream side of the GCP. The existing slope configuration will likely direct flow back into the channel on both sides of the creek.

The Alberta Dam and Canal Safety Directive (Alberta Government, 2018) does not provide specific direction on the size or storage volume that classifies a structure or retention pond as a dam. The consequence and safety of the GCP, if classified as a dam, was not assessed for this preliminary design and should be reviewed as part of future phases of design.

4.2.2.3. Proposed Mitigation Design Details

The proposed woody debris protection is a floating boom system as is commonly used on dams and reservoirs. The boom would be anchored on either side of the pond. At this preliminary design stage, an estimated length of approximately 150 m has been used for cost estimation. The design of the floating boom and anchors would need to be refined as part of future phases of design with a contractor who specializes in the design and installation of such systems.

4.2.2.4. Recommended Further Work

The following work is recommended during future design stages.

- Review of as-built documentation for the GCP to determine the liner material, burial depth and extents. This information was not available at the time of writing.
- Evaluation of other woody debris management options to confirm the preferred system.
- If selected as the preferred option, selection of an appropriate boom system in consultation with specialists in the design of floating boom systems.
- Site investigation of the boom anchor points to determine an appropriate anchor design to withstand then anticipated forces associated with the design event.
- Detailed review of the anticipated flow velocities and impact forces to the boom system with qualified specialists in the design of similar systems.
- Development of an operations and maintenance plan to support the operations of the woody debris management system as well as allocation of a maintenance budget.
- The aesthetics of the system should be reviewed with stakeholder input.
- Review of the consequence and safety of the GCP, if classified as a dam.

[6] Armortec Erosion Control Solutions is the manufacturer of the Armorflex concrete mats installed at Three Sisters Creek.

4.2.2.5. Cost Estimate

The estimated capital cost of a floating boom woody debris management is $430,000 (Appendix A). The operation and maintenance costs (NPV) over a 50-year period is estimated to be $360,000. The operations and maintenance costs include the costs to replace the system twice in the 50-year period based on the estimated design life provided by a manufacturer of floating boom systems (email from Berard Kassis of Geniglace, personal communication, September 28, 2020). Combined, the total mitigation lifecycle cost of this option is approximately $790,000.

4.2.3. Lower Channel West Setback Berms

4.2.3.1. Purpose of Proposed Mitigation Works

The purpose of the lower channel west setback berms is to prevent flow that overtops the left (west) Three Sisters Creek channel bank downstream of the GCP from inundating the proposed TSMV development area. Debris-flood modelling completed by BGC (October 9, 2020) indicated the potential for overland flow at two locations downstream of the GCP on the left (west) bank. The potential overland flow exits the channel and flows northwest between bedrock ridges and intersects TSP west of the main channel crossing. Debris-flood modelling with the proposed upstream mitigation works in place informed the selection of berm extensions as outlined below.

4.2.3.2. Existing Conditions

Three Sisters Creek outlets from the GCP and passes through the bridge that conveys the AltaLink powerlines approximately 10 m downstream. The bridge is connected to an access road on both the east and west sides of the channel (Drawing 01). There is a pedestrian path, which no longer crosses Three Sisters Creek, approximately 35 m downstream of the bridge. The channel between the GCP and TSP is partially bedrock-confined with till outcrops (BGC, October 9, 2020). The presence of bedrock in the channel base and banks will limit bank erosion and downcutting in these areas. The extents of the bedrock outcrops have not been mapped to date.

Approximately 130 m upstream of TSP the channel passes below the Three Sisters Pathway bridge that connects a hiking trail across the east and west sides of the channel (Drawing 01). According to previous work, the capacity of the pedestrian bridge is approximately 120 m^3/s (BGC, October 14, 2016). Downstream of the pathway bridge, debris-flood modelling indicated the potential for overland flow on the right (east) bank. Based on the work completed to date, the flood extents and depths are not substantially increased by upstream mitigation works and no additional mitigation works are anticipated at this location.

4.2.3.3. Proposed Mitigation Design Details

The three proposed berms are referred to as lower west setback berm A, lower setback berm B, and lower west setback berm C in order from upstream (southern) to downstream (northern) (Drawings 01, 04). Lower west setback berms A and B are a combined length of approximately 130 m, while lower west setback berm C is approximately 193 m long. Lower west setback berms A and B are two segments on the upstream and downstream sides of the access road to the bridge at the GCP outlet. The berms are divided to maintain the use of the access road and to maintain the existing cover over the AltaLink power lines. Downstream of the access road, the berms are tied-in to bedrock ridges to prevent outflanking and reduce the length required.

The modelling with the upstream berms in place (Drawing 6) informed the berm height selection as the upstream berms channelize the flow and have the potential to increase flow depth and velocity downstream. The setback berms are 1.5 m high with a 4 m crest width and 2H:1V slopes (typical detail on Drawing 05), which provides a minimum of 0.6 m freeboard. As outlined for the upper setback berms, this freeboard exceeds the requirements outlined for dike design and construction[7] and accounts for uncertainty in the flow depth and distribution of woody debris and sediment. In this lower reach, less sedimentation is anticipated as the sediment from the watershed and upper channel are anticipated to be captured in the GCP. The crest width was selected to allow for berm fill to be placed and compacted with heavy equipment. This crest width could also allow for the berm to be used as a recreational pathway post-construction. The crest width could be optimized as part of future phases of design to reduce costs and potential land impacts.

The berms are setback from the top of bank by approximately 10 to 20 m, and existing vegetation at the bank and top of bank is intended to be undisturbed by the berm construction. For erosion protection, Class 3 riprap is trenched at the toe and placed up the berm face along the side facing the channel (typical detail on Drawing 05). Unlike the channel upstream of the GCP where significant bank erosion is anticipated, the channel reach between the GCP and TSP is anticipated to experience less bank erosion. This is due to a combination of the presence of bedrock outcrops in the channel bed and banks, vegetation of the channel banks and top of banks that increase the erosion resistance through root strength, and the historical record of erosion based on aerial imagery review completed as part of the hazard assessment update (BGC, October 9, 2020). In the event of bank erosion to the west, it is anticipated that the trenched section of the riprap would operate as a small falling apron that would contribute to stabilization of the bank. Mapping of bedrock in the channel bed and banks should be completed to inform future phases of design. If bedrock is of sufficiently shallow depth, the erosion protection could be tied in to the bedrock.

The lower west setback berms prevents overland flow into proposed development on the west side of Three Sisters Creek. Given this, the flow is channelized and concentrated through the reach downstream resulting in increased flow at downstream infrastructure including the TSP culvert as compared with the unmitigated condition.

BGC assumes that the lower setback berms will be constructed from locally available, well-graded granular fill that is sourced from the Three Sisters Creek fan or elsewhere within Canmore. Some material processing may be required to remove materials that are greater than about 15 cm diameter, and suitability of this fill source with respect to fines content will need to be confirmed. The berm crests and outside slopes are to be vegetated. It is assumed that the aesthetics and

[7] The BC MoWLAP outlines that the minimum river dike crest elevation is the higher of 1 in 200-year instantaneous flow plus 0.3 m freeboard or 1 in 200-year maximum daily flow plus 0.6 m freeboard (BC MoWLAP, 2003).

potential recreational or other uses of the berms, for example for walking trails, will be reviewed in consultation with other stakeholders as part of future phases of design.

4.2.3.4. Recommended Further Work

The following work is recommended during future design stages.

- Mapping of bedrock in the channel bed and banks should be completed to inform future phases of design.
- Selection of the berm alignment should be confirmed based on landowner input and surveyed topography.
- The alignment of lower west setback berms A and B should be reviewed along with additional details on the AltaLink burial depths and alignment of the access road.
- The extents of bedrock and vegetation should be mapped and used to support the selection of a berm alignment that minimizes disturbance to vegetation that stabilizes the existing bank and top of bank.
- Site investigation is recommended at the berm sites and berm fill borrow area(s), including test pits and material testing to verify the suitability of the borrow material to be used as engineered fill for the berm, and to estimate the depth of excavation required to establish an appropriate foundation for the berm.
- The proposed erosion protection works should be reviewed following mapping of bedrock extents in the channel bed and banks to evaluate the suitability and if additional erosion protection works are required in select locations.
- The aesthetics and potential recreational uses of the setback berms should be reviewed with stakeholder input.

4.2.3.5. Cost Estimate

The estimated capital cost of the lower setback berms is $840,000 (Appendix A). The operation and maintenance costs (NPV) over a 50-year period is estimated to be $100,000. Combined, the total mitigation lifecycle cost is $940,000 (50-year NPV).

4.2.4. Culvert Replacement at Three Sisters Parkway with Woody Debris Management Upstream

4.2.4.1. Purpose of Proposed Mitigation Works

The purpose of the culvert replacement at TSP is to increase the capacity of the culvert to convey the design event. Increased capacity at the culvert reduces the potential for flow to pond upstream of the culvert and overtop the channel banks as well as the potential for flow to overtop TSP and impact the parkway and development on the northeast side of the crossing at Crossbow Landing. The purpose of a woody debris management system upstream of the culvert is to reduce the potential for partial or full blockage of the culvert associated with woody debris in the channel.

4.2.4.2. Existing Conditions

Three Sisters Creek passes beneath TSP in a concrete box culvert owned and maintained by Alberta Transportation. The culvert is 2.44 m wide by 2.44 m high (Sweetcroft, April, 2015) and approximately 50 m long (BGC, October 31, 2014) with concrete interlocking block wingwalls at the inlet. The culvert capacity [8] has been reported in other reports with a range of capacities from 23 m^3/s to 40 m^3/s. As part of the mitigation options analysis, BGC completed a preliminary assessment of the culvert capacity (BGC, November 5, 2020). A culvert capacity of 23 m^3/s was applied for the analysis and preliminary design presented. At higher discharges, flow overtops TSP and impacts Crossbow Landing to the northeast as well as flows west along and to the north of the parkway toward Bow River.

The existing culvert is sufficiently sized to pass the 100-year return period debris flood peak discharge of 16 m^3/s based on historical and current conditions [9] but will become insufficiently sized to pass the same return period (100-year) peak discharge of 32 m^3/s under climate change conditions in the latter half of the century (2050-2100) (BGC, October 9, 2020). For debris floods with return periods greater than 100 years, water and sediment begin to back-water and flow across the road as suggested by numerical modelling (BGC, October 9, 2020). The design event of mitigation measures considered in this options analysis is the 100 to 300-year return period debris flood with a peak discharge of 50 m^3/s that accounts for climate change. As such, the proposed design is sized to achieve the higher peak discharge of 50 m^3/s.

4.2.4.3. Proposed Mitigation Design Details

The proposed culvert replacement is a concrete box culvert sized to convey 50 m^3/s with angled wingwalls at the inlet and no headwall above the thickness of the precast slab. The minimum culvert opening is approximately 7 m wide by 2.6 m high. The culvert dimensions were estimated assuming no surcharge at the inlet [10].

As part of the mitigation options analysis, BGC presented multiple options for woody debris management upstream of the TSP culvert:

- Selective tree removal to reduce woody debris sources
- Installation of a woody debris management system upstream of the TSP culvert, consisting of one of:
    - Woody debris grillage
    - In-channel posts
    - Flexible debris net

[8] SweetTech estimated the culvert capacity to be 23 m^3/s using the hydrologic model HY-8 (USDOT, 2016) (BGC, October 14, 2016). SweetCroft (April, 2015) reported the culvert capacity to be 40 m^3/s.

[9] The historical and current conditions are based on BGC's updated hazard assessment with an estimated peak discharge of 15 m^3/s plus 5% sediment bulking as applied for debris floods with return periods in the range of 10 to 300-years.

[10] Surcharge, as it pertains to culvert design, is the depth of water above the top of the culvert inlet. For example, if at the inlet to a culvert, a pond has developed that is 1 m higher than the top of the culvert, there is a 1 m surcharge on the culvert.

Based on discussions with the ToC and QPD, BGC understands that the preferred approach is a combination of selective tree removal with installation of a woody debris management system upstream of the culvert. Selection of the final woody debris management system should involve consultation with Alberta Transportation and other regulatory agencies and landowners to balance the design, cost, aesthetics, and public safety concerns.

4.2.4.4. Recommended Further Work

The following work is recommended during future design stages:

- Alberta Transportation should review the design with regards to the proposed life cycle of the existing culvert and requirements for culvert sizes on steep creeks.
- Review the assumed pond inflow and starting water level conditions, in addition to the downstream water levels, and re-assess and optimize the required culvert capacity, alignment, and dimensions.
- Numerical modelling of preferred woody debris management structure to evaluate the potential avulsion paths if blockage occurs should be undertaken.
- Optimize the culvert inlet protection design to prevent culvert blockage with sediment or woody debris.
- A qualified biologist should be engaged to provide input on the proposed instream works.
- The aesthetics of the woody debris management system should be reviewed with stakeholder input.

4.2.4.5. Cost Estimate

The estimated capital cost of the TSP culvert replacement is $1.3 Million (Appendix A). The operation and maintenance costs (NPV) over a 50-year period are estimated to be $180,000. Combined, the total mitigation lifecycle cost is $1.5 Million (50-year NPV).

The estimated capital cost of the woody debris management system is $140,000 (Appendix A). The operation and maintenance costs (NPV) over a 50-year period, including tree removal is estimated to be $100,000. Combined, the total mitigation lifecycle cost of this option is $240,000.

The combined total for the culvert replacement and installation of a woody debris management system is $1.4 Million in capital costs and $280,000 in operation and maintenance costs (NPV) over a 50-year project lifecycle. Combined, the total mitigation lifecycle cost is approximately $1.7 Million.

4.3. Mitigation System Cost Estimate

The full mitigation system is estimated to cost $9.0 Million over a 50-year period, as outlined in Table 4-3, including both capital costs and operations and maintenance costs over a 50-year lifecycle for each mitigation element. The costs of the mitigation system are anticipated to be shared between multiple parties including TSMV, the ToC, and Alberta Transportation (AT). As part of a separate scope of work, a proposed cost-sharing framework for consideration was presented by BGC (October 30, 2020). Additional details on the costs for each mitigation element are included in Appendix A.

Table 4-3. Summary of proposed mitigation system cost.

Option	Capital Cost	Operations and Maintenance Costs (50 year NPV)	Total Life Cycle Cost for 50-year Period
Upper channel east and west setback berms	$5,420,000	$100,000	$5,500,000
Woody debris management at the GCP outlet	$430,000	$360,000	$790,000
Lower channel west setback berms	$840,000	$100,000	$940,000
Culvert replacement at TSP	$1,300,000	$180,000	$1,480,000
Woody debris management upstream of TSP culvert	$140,000	$100,000	$240,000
Total	**$8,130,000**	**$840,000**	**$ 8,970,000**

5. RESIDUAL HAZARD

At the request of QPD, a residual hazard assessment was completed to evaluate the potential post-mitigation impacts of Three Sisters Creek floods and debris floods. A residual hazard assessment aims to quantify the hazard remaining after installation of the preferred mitigation option. The assessment included:

- Steep creek hazard modelling that accounts for the proposed mitigation design.
- An assessment of the potential residual hazard to existing and proposed development.
- An assessment of whether the mitigation design results in risk transfer.

As the proposed mitigation includes a culvert replacement at TSP that may not be completed until the end of the existing culvert design life, BGC evaluated the residual hazard for two conditions: with and without the culvert replacement at TSP. BGC understands that the remaining design life of the existing culvert is approximately 30 years (i.e., design life extending to approximately the year 2050).

5.1. Hazard Modelling Update

Previous numerical modelling for Three Sisters Creek (BGC, October 9, 2020) was updated to include the proposed mitigation system. This was completed both for the proposed culvert replacement at TSP and without the proposed culvert replacement that represents the time period until the culvert is replaced[11]. For both conditions, the upper east and west setback berms and the lower channel west setback berms were added to the topography using Muck3D Formation (MineBridge Software Inc., 2019).

For each of the conditions (with and without culvert replacement), two scenarios were modelled with the proposed berms in place: the 100 to 300-year return period and the 1,000 to 3,000-year return period, under the assumption of an aggraded channel (2013 lidar). The two scenarios were selected for the residual hazard modelling because the 100 to 300-year return period debris flood is the design event, and the 1,000 to 3,000-year return period debris flood represents an extreme-event scenario. The 300 to 1,000-year return period debris flood was not modelled because mitigation that is sufficient for the 1,000 to 3,000-year return period would also be sufficient for the 300 to 1,000-year return period. The 2013 lidar-generated topography was selected because it represents the long-term conditions with a wide floodplain and limited channel capacity due to sediment accumulation. The results of the residual hazard modelling are shown on Drawings 06 and 09.

5.2. Residual Hazard Assessment

The objective of the residual hazard assessment was to identify areas where steep creek hazards pose a credible life-loss risk to persons in buildings after mitigation. This was completed by overlaying the post-mitigation numerical modelling results (Section 5.1) with the proposed development area boundary, and existing development building footprints. Flow depth and

[11] The modelled scenarios are for the peak discharge under climate change conditions in the latter half of the century (2050-2100) (BGC, October 9, 2020). For this reason, the residual hazard assessment for the time until the end of the existing culvert design life (approximately year 2050) is somewhat conservative.

velocity values were extracted from the modelling results within intersected areas to calculate the associated hazard momentum flux [12] (Prieto et al., 2018). Areas where the momentum flux exceeds 1 m^3/s^2 correlate with areas of a credible life-loss risk to persons inside buildings (see BGC, January 19, 2015). The proposed development area boundary was provided by QPD on April 22, 2020 (email from Chris Ollenberger, pers. comm, April 22, 2020). Existing development building footprints were obtained from the ToC open data portal (ToC, 2020).

The residual hazard assessment showed that, for both conditions (i.e., with or without TSP culvert replacement):

- Residual hazard from 100 to 300-year return period flows (i.e., the design event) at both existing and proposed development is negligible [13].
- There are no areas where the modelled flows from the 100 to 300-year or 1,000 to 3,000-year return period debris floods intersect the proposed development. Therefore, life-loss and economic risk to proposed development is considered negligible after mitigation.
- There are no building footprints in existing development where the modelled momentum flux exceeds 1 m^3/s^2 for either return period[14]. Therefore, life-loss risk to people within buildings at existing development from steep creek hazards is considered negligible after site mitigation.
- Flows with a modelled momentum flux less than 1 m^3/s^2 could impact buildings within Crossbow landing (Table 5-1). These flows could cause damage that results in economic loss.

The proposed culvert replacement at TSP changes the residual hazard as follows:

- Modelled flows from the 100 to 300-year return period debris flood intersect existing building footprints if the culvert is not replaced, but do not intersect existing building footprints if the TSP culvert is replaced.
- If the TSP culvert is replaced, the number of properties that could be impacted by flows in Crossbow Landing resulting in economic losses decreases to zero for the 100 to 300-year return period debris flood and to two for the 1,000 to 3,000-year return period debris flood (Table 5-1, Figure 5-1).

[12] Equivalent to “intensity – debris flow” (IDF) as used in previous studies for Town of Canmore.
[13] In this report, negligible risk means there is a nearly 0% probability (<< 1%) that a person in a building will suffer fatal injuries in the specific modeled scenario because the modeled hazard intensity and associated vulnerability to persons in buildings is nearly 0%.
[14] BGC notes that the modelled debris flood momentum flux at the building footprint within Parcel ID 1965702 exceeds 1 m^3/s^2 for the 1,000 to 3,000-year return period. However, this occurs at a ramp which descends below grade into a parking garage causing the modelled flows depths to be locally higher than the surrounding area. The residual hazard assessment considers life-loss risk to individuals within the main living areas of buildings and is not designed to assess life-loss risk outside of the main living areas.

Table 5-1. Parcel Identifiers (PID)s with buildings that could be impacted by Three Sisters Creek hazards after mitigation for specific return periods.

Mitigation System	Return Period	PIDs with buildings that could potentially be impacted resulting in economic loss.
Full proposed mitigation system (with culvert replacement at TSP)	1,000 to 3,000	1965702; 2019134
Proposed mitigation system without culvert replacement at TSP	100 to 300	1965702; 2019134
	1,000 to 3,000	1965702; 1686071; 2019134; 1997775

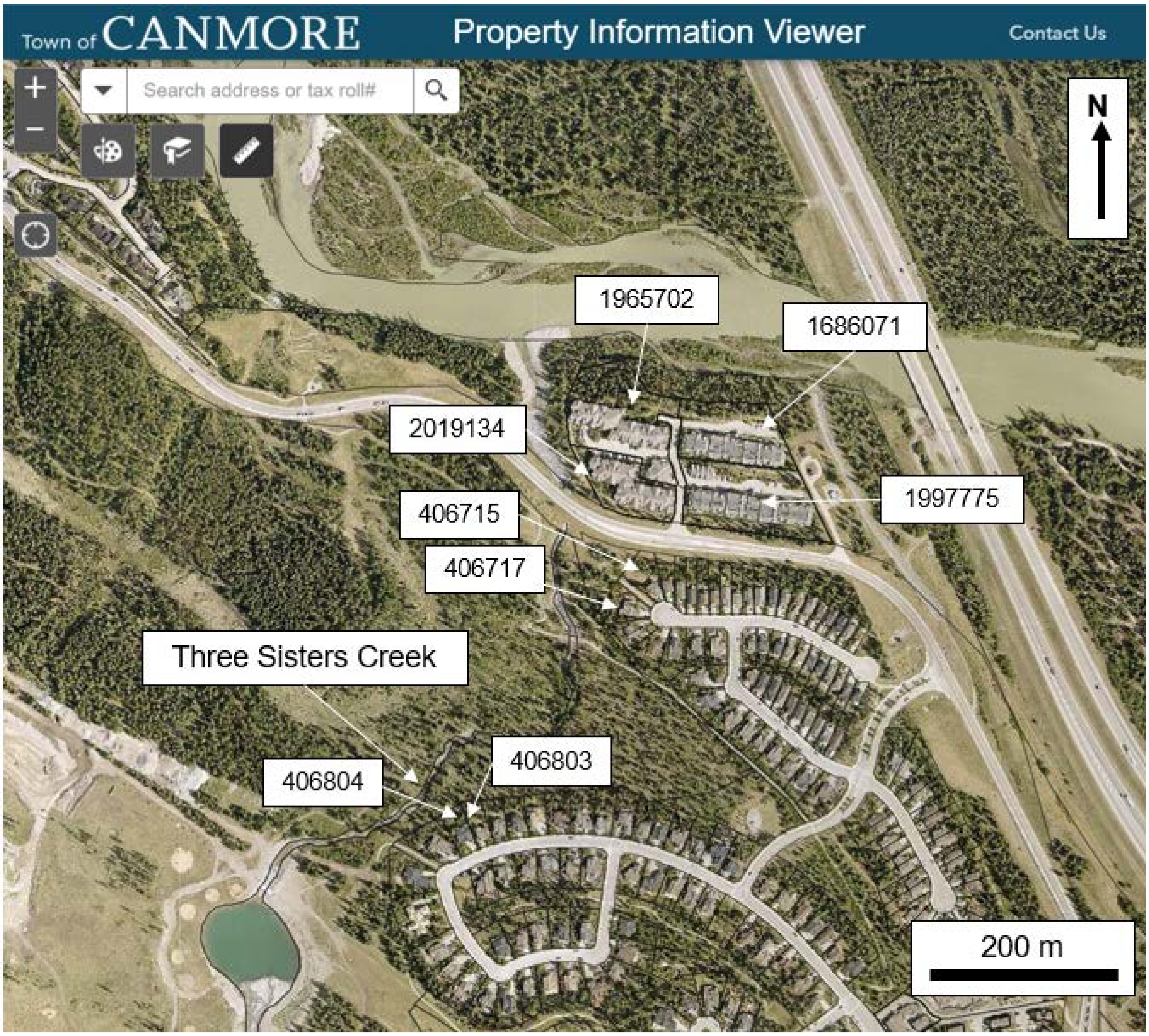


Figure 5-1. PIDs near Three Sisters Parkway. Basemap from ToC Property Information Viewer.

5.3. Risk Transfer

Risk transfer is an increase in risk at one location caused by changes at another location, such as the construction of mitigation, topographic changes or buildings placed in the path of geohazards. For example, creek channelization has the potential to increase the flow volume and peak flow that remains in the channel, which can increase the hazard downstream.

To investigate potential risk transfer associated with the proposed mitigation design on Three Sisters Creek, BGC compared the baseline steep creek hazard numerical modelling results (BGC, October 9, 2020) with the updated numerical modelling results (Section 5.1). The assessment identified that:

1. Flow velocity and depth increase downstream of the GCP - The setback berms protect against upstream avulsions and therefore increase flow depth and velocity of debris floods downstream of the GCP (Drawings 08, 11).
2. Life loss risk transfer to people within buildings is negligible – With the mitigation system in place, no buildings or parcels are impacted with flows that have momentum flux greater than 1 m^3/s^2, for all modelled return periods, including the 1,000 to 3,000 year return period debris flood[14]. Therefore, life loss risk transfer to people within buildings is interpreted to be negligible (Drawings 06, 07, 09, 10).
3. Culvert replacement at Three Sisters Parkway is needed to avoid economic risk transfer in the design event – If the existing Three Sisters Parkway culvert remains in place, the 100 to 300-year return period debris flood spills out of the channel at Three Sisters Parkway and may impact Crossbow Landing (PIDs 1965702, 201913). Momentum flux of these flows is less than 1 m^3/s^2 and they are unlikely to cause life loss to people within buildings, but may cause economic loss.
4. Economic risk transfer occurs for extreme events – The proposed mitigation system (including the Three Sisters Parkway culvert replacement) results in flows overtopping the channel downstream of the GCP in a 1,000 to 3,000-year return period event. These flows intersect parcels (PIDs 406717, 406715, 406803, 406804), but do not intersect buildings. The momentum flux increase at these parcels is less than 1 m^3/s^2. Flows that overtop the Three Sisters Parkway culvert may intersect buildings at Crossbow Landing (PIDs 1965702, 2019134 when the culvert is replaced; and PIDs 1965702, 1686071, 2019134, 1997775 without the culvert replacement). Comparing the mitigated to unmitigated scenarios at these parcels, the modelled 1,000 to 3,000-year return period flow velocity increased by 20% from a maximum of 2 m/s to 2.4m/s. The momentum flux of these flows is less than 1 m^3/s^2 in all above grade areas where there are living quarters and therefore these flows are unlikely to cause life loss to people within buildings, but may cause economic loss.
5. Deflection berm at Crossbow Landing could mitigate risk transfer – A deflection berm could be installed immediately upstream of Crossbow Landing and downstream of Three Sisters Parkway to mitigate the potential economic risk transfer.

5.4. Assumptions

The interpretations presented in this section assume that the mitigation design, particularly the berms, remain intact even during 1,000 to 3,000-year return period flows. At this stage of design, assessment of the proposed mitigation performance in return periods higher than the design event has not been completed. If the mitigation design becomes damaged in larger debris floods, for example by excessive erosion, the associated numerical modelling and residual hazard assessment results may differ from those presented above.

The residual hazard assessment identified that the residual hazard from 100 to 300-year return period flows (i.e., the design event) are negligible. Should further stages of design identify that the performance of the mitigation in larger return period flows may be compromised (e.g. loss of erosion protection), the residual hazard and risk from debris floods above 100- to 300-years may need to be re-assessed.

6. PERFORMANCE EXPECTATIONS AND UNCERTAINTIES

This section describes the expected performance of the debris-flood mitigation and its effect on adjacent areas and infrastructure.

6.1. Upper Channel East and West Setback Berms

The upper channel east and west setback berms are designed to minimize maintenance by allowing the channel to aggrade, migrate and erode in places without the immediate need for sediment removal. The erosion protection on the upper west setback berm, which may be impacted by relatively frequent flows, should be inspected regularly following major storm events and at regular intervals throughout the design life to review the condition and identify any needs for repair.

Channel blockage in the upper channel could direct flows to the east to an area not protected by the launch apron and result in localized damage to the setback berm that requires repair following the event.

6.2. Woody Debris Management at the Golf Course Pond

The floating boom system is designed to capture large woody debris before it reaches the bridge at the GCP outlet to reduce the potential for partial to full blockage of the bridge or transport to the downstream channel reaches. The floating boom system will require regular maintenance to remove debris and to inspect the condition of the system. The efficacy of floating boom systems during debris floods is not well understood as these systems are more commonly employed in locations with little to no flow velocity. If such a system were to fail, it could contribute to reduced capacity or blockage of the bridge.

6.3. Lower Channel West Setback Berms

The lower channel west setback berms are designed to prevent overland flow that overtops the Three Sisters Creek channel at the west bank from reaching the proposed development. Woody debris blockage in the lower channel reach could locally reduce the channel capacity, leading to avulsions impacting areas beyond the extents of the proposed berms. Woody debris management at the upstream GCP and selective tree removal from the channel bank or top of bank with the potential to fall into and compromise the channel capacity can be used to manage this risk.

The erosion protection on the berms should be inspected regularly following major storm events and at regular intervals throughout the design life to review the condition and identify any needs for repair.

6.4. Culvert Replacement at Three Sisters Parkway and Upstream Woody Debris Management

The culvert replacement at Three Sisters Parkway is designed to convey the 100 to 300-year return period debris flood. If debris floods with return periods in excess of this occur, some ponding and overtopping of the parkway could be expected. The culvert was selected as a single opening to minimize the operations and maintenance costs by allowing for a larger opening. Nevertheless, regular maintenance is required to remove sediment or debris that may reduce the capacity of the culvert. Following major storm events, the condition of the culvert inlet and outlet should be inspected for damage and to identify the need for any localized repairs.

The woody debris management system proposed to capture large woody debris during high flow events is recommended for regular inspection following major storms to identify any damage. The efficacy of the system could be compromised if vandalized or damaged outside of the intended use.

7. CLOSURE

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

Yours sincerely,

BGC ENGINEERING INC.
per:

PROFESSIONAL ENGINEER
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The Association of Professional Engineers and Geoscientists of Alberta (APEGA)

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APPENDIX A
COST ESTIMATE TABLES

A.1. COST ESTIMATE INTRODUCTION

This appendix contains the cost estimates of the preferred mitigation system selected for preliminary design. All unit costs are from the average Heart Creek mitigation construction bid from April 2020 unless otherwise noted in the table. Option total costs are rounded to the nearest $100,000 so as to not give a sense of exactness, these cost estimates may vary -25% to +50%. Volumes, areas and lengths are estimated using approximate geometries and layouts and are subject to change as part of future phases of design.

A.2. COST ESTIMATE TABLES

Table A-1. Cost estimate for upper east setback berm with riprap launch apron and grouted stone pitching on upstream approach slope to Golf Course Pond (GCP).

Item	Quantity	Unit	Cost per Unit	Item Total Cost
Access construction	880	m	$100	$88,000
Clearing, grubbing and disposal	13,800	m^2	$6	$83,000
Excavation	6,500	m^3	$6	$39,000
Off-site sediment disposal	3,300	m^3	$16	$53,000
Berm fill (supply and placement)	9,900	m^3	$34	$337,000
Class 3 riprap (supply and placement)	9,900	m^3	$137	$1,356,000
Grouted stone pitching	1,600	m^2	$360	$576,000
Seeding, planting and site restoration	14,500	m^2	$5	$73,000
			Direct costs subtotal	**$2,605,000**
Contractor general	1	Lump sum	15%	$391,000
Contingency (unlisted items)	1	Lump sum	10%	$261,000
Engineering and permitting	1	Lump sum	15%	$391,000
			Indirect costs subtotal	**$1,043,000**
			Option total	**$3,650,000**

Table A-2. Cost estimate for upper west setback berm with grouted stone pitching along berm and channel face and upstream approach slope to Golf Course Pond (GCP).

Item	Quantity	Unit	Cost per Unit	Item Total Cost
Access construction	410	m	$100	$41,000
Clearing, grubbing and disposal	3,100	m^2	$6	$19,000
Excavation	300	m^3	$6	$2,000
Off-site sediment disposal	300	m^3	$16	$5,000
Berm fill (supply and placement)	4,000	m^3	$34	$136,000
Class 3 riprap (supply and placement)	0	m^3	$137	$0
Grouted stone pitching	2,900	m^2	$360	$1,044,000
Seeding, planting and site restoration	3,100	m^2	$5	$16,000
			Direct costs subtotal	**$1,263,000**
Contractor general	1	Lump sum	15%	$189,000
Contingency (unlisted items)	1	Lump sum	10%	$126,000
Engineering and permitting	1	Lump sum	15%	$189,000
			Indirect costs subtotal	**$504,000**
			Option total	**$1,770,000**

Table A-3. Cost estimate for lower west setback berms with riprap erosion protection.

Item	Quantity	Unit	Cost per Unit	Item Total Cost
Access construction	330	m	$100	$33,000
Clearing, grubbing and disposal	4,500	m^2	$6	$27,000
Excavation	3,500	m^3	$6	$21,000
Off-site sediment disposal	3,500	m^3	$16	$56,000
Berm fill (supply and placement)	2,700	m^3	$34	$92,000
Class 3 riprap (supply and placement)	2,500	m^3	$137	$343,000
Grouted stone pitching	-	m^2	$360	$-
Seeding, planting and site restoration	4,700	m^2	$5	$24,000
Direct costs subtotal				**$600,000**
Contractor general	1	Lump sum	15%	$90,000
Contingency (unlisted items)	1	Lump sum	10%	$60,000
Engineering and permitting	1	Lump sum	15%	$90,000
Indirect costs subtotal				**$240,000**
Option total				**$840,000**

Notes:

1. For the purposes of cost estimation, BGC has estimated the cost of erosion protection using Class 3 riprap. The type of erosion protection (riprap, stone pitching, etc.) can be refined as part of future scopes of work.

Table A-4. Cost estimate for woody debris management at Golf Course Pond.

Item	Quantity	Unit	Cost per Unit	Item Total Cost
Anchoring	1	Lump sum	$50,000	$50,000
Boom	150	m	$1,000	$150,000
Design basis & drawing package (external contractor)	1	Lump sum	$10,000	$10,000
Installation and commissioning	1	Lump sum	$25,000	$25,000
Direct costs subtotal				**$240,000**
Contractor general	1	Lump sum	15%	$36,000
Contingency (unlisted items)	1	Lump sum	10%	$120,000
Engineering and permitting	1	Lump sum	15%	$36,000
Indirect costs subtotal				**$190,000**
Option total				**$430,000**

Note:

1. Cost estimate based on quotation from Versatech Products Inc. (email from Omid Javadi, personal communication, August 28, 2020).

Table A-5. Cost estimate for woody debris management upstream of Three Sisters Parkway.

Item	Quantity	Unit	Cost per Unit	Item Total Cost
Access construction	50	m	$100	$5,000
Woody debris management system[1]	1	Lump sum	$45,000	$45,000
Selective tree removal	5	Day	$2,000	$10,000
Channel restoration[2]	500	m^2	$60	$30,000
Seeding, planting and site restoration	500	m^2	$5	$2,500
			Direct costs subtotal	**$90,000**
Contractor general	1	Lump sum	15%	$13,500
Contingency (unlisted items)[3]	1	Lump sum	15%	$13,500
Engineering and permitting[3]	1	Lump sum	20%	$18,000
			Indirect costs subtotal	**$50,000**
			Option total	**$140,000**

Note:

1. Cost estimate for woody debris management system is based on costs for similar systems installed in the District of North Vancouver (DNV) and an estimate for a flexible debris net based on estimate from Trumer Schutzbauten (email from Ahren Bichler, personal communication, June 2, 2020).
2. Channel restoration costs based on the unit rate for channel formation and bank protection used at Thames Creek in District of North Vancouver.
3. Contingency and engineering and permitting costs are increased to 15% and 20%, respectively to reflect the increased uncertainty of these line items given that the preferred woody debris management system has not been selected.

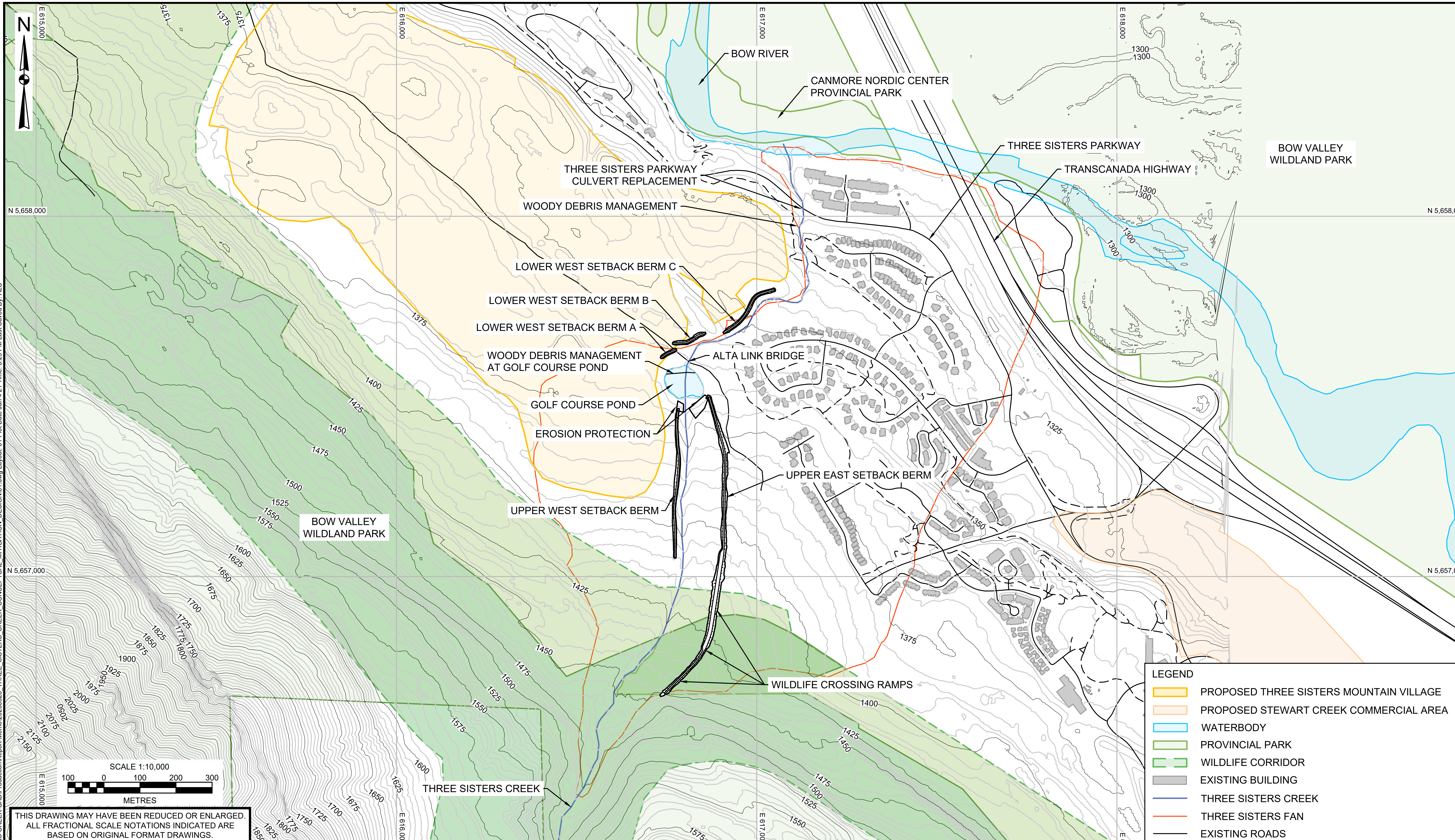
Table A-6. Cost estimate to replace Three Sisters Parkway Culvert for 100 to 300-year debris flood design event.

Item	Quantity	Unit	Cost per Unit	Item Total Cost
Concrete box culvert[1]	1	Lump sum	$900,000	$900,000
Seeding, planting and site restoration	4,000	m^2	$5	$20,000
			Direct costs subtotal	**$920,000**
Contractor general	1	Lump sum	15%	$138,000
Contingency (unlisted items)	1	Lump sum	10%	$92,000
Engineering and permitting	1	Lump sum	15%	$138,000
			Indirect costs subtotal	**$370,000**
			Option total	**$1,300,000**

Note:

1. Concrete box culvert cost provided as an estimate from Alberta Transportation based on Jura Creek culvert replacement.

DRAWINGS



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TITLE: GENERAL ARRANGEMENT

PROJECT No.: 1531005

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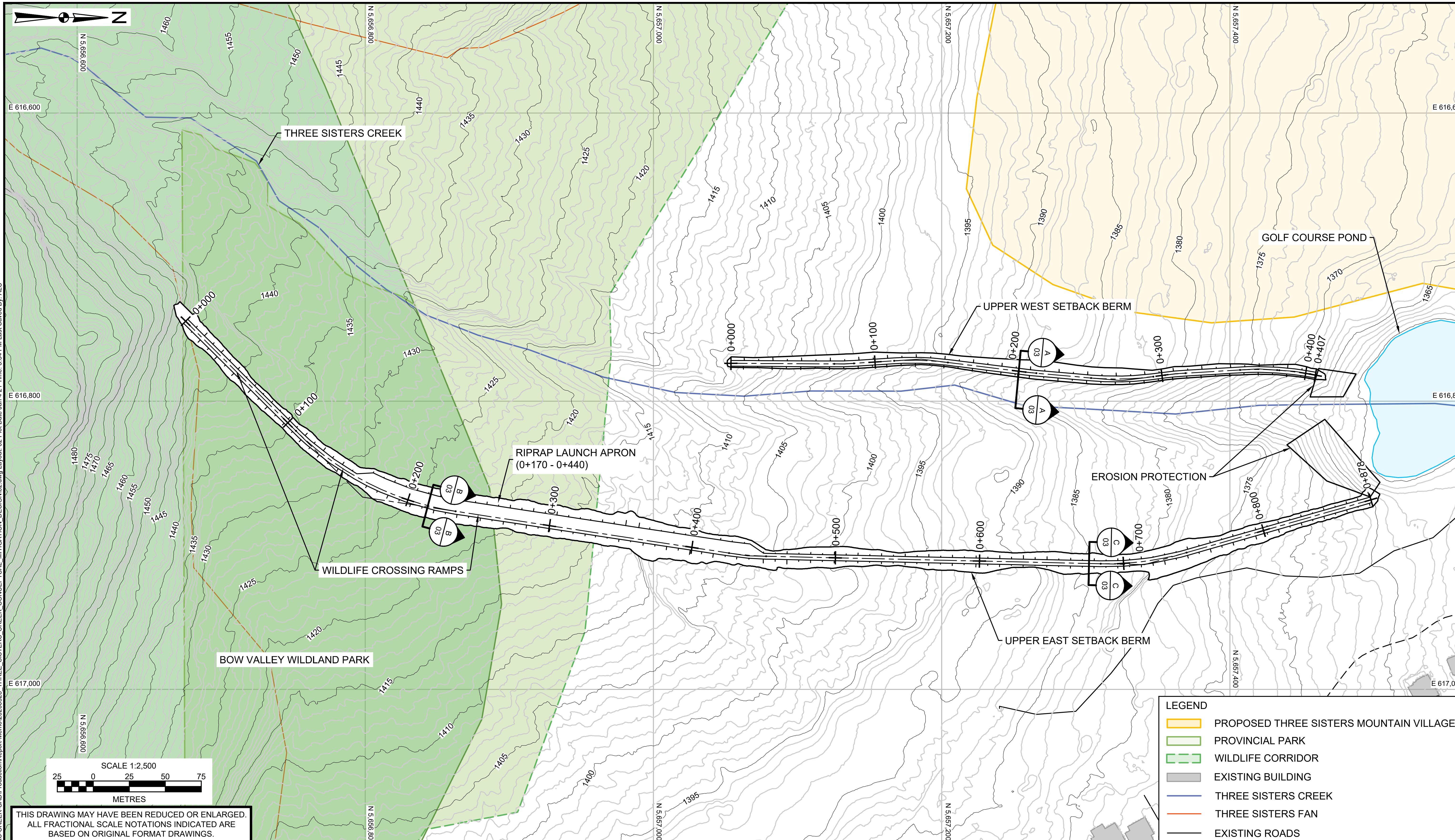

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TITLE: UPPER EAST AND WEST SETBACK BERMS - PLAN

PROJECT No.: 1531005

DWG No.: 02

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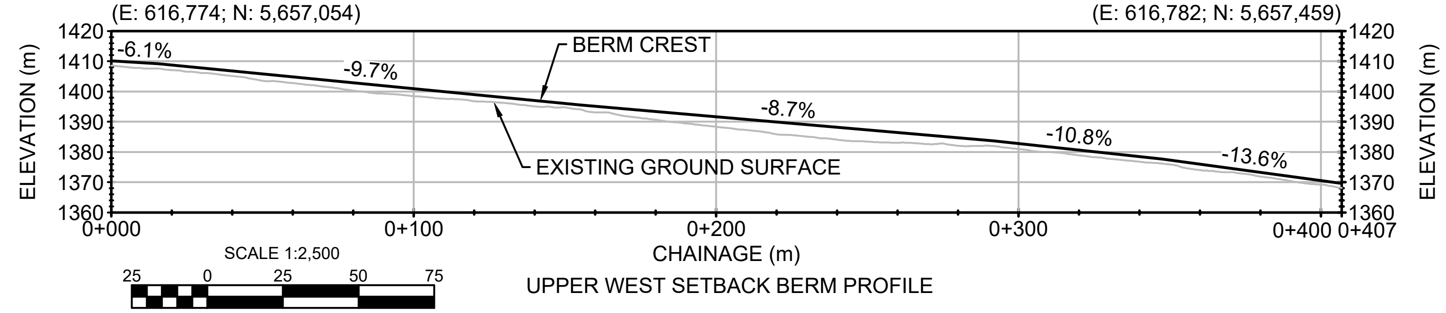
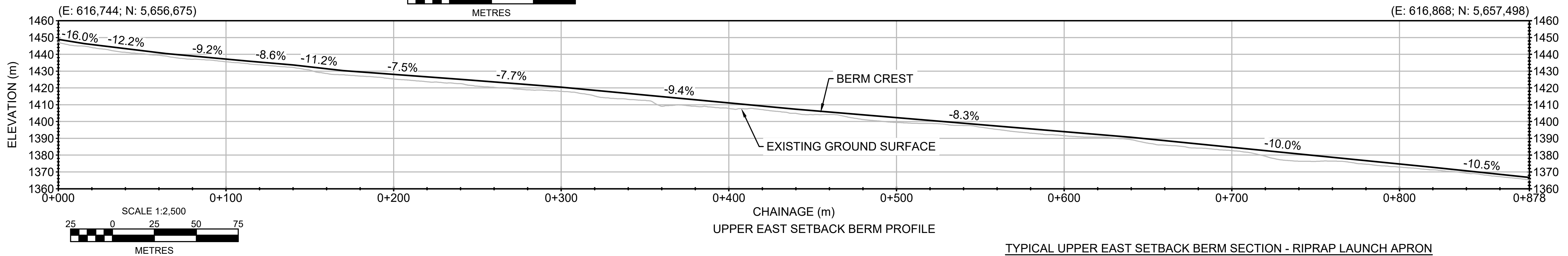


UPPER WEST SETBACK BERM PROFILE



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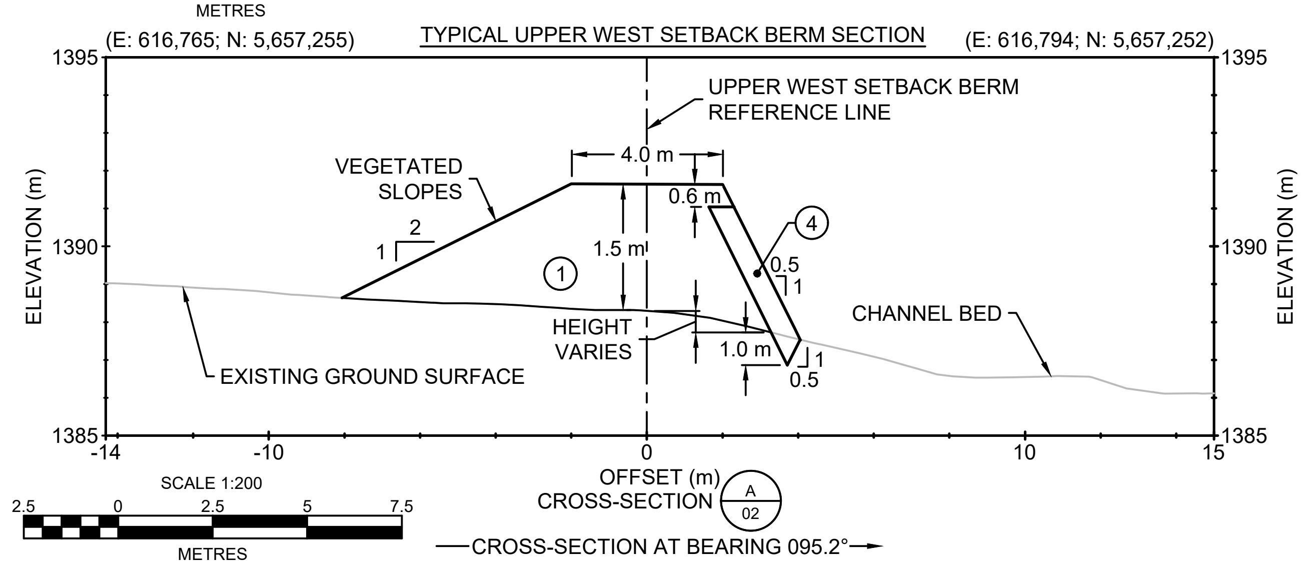

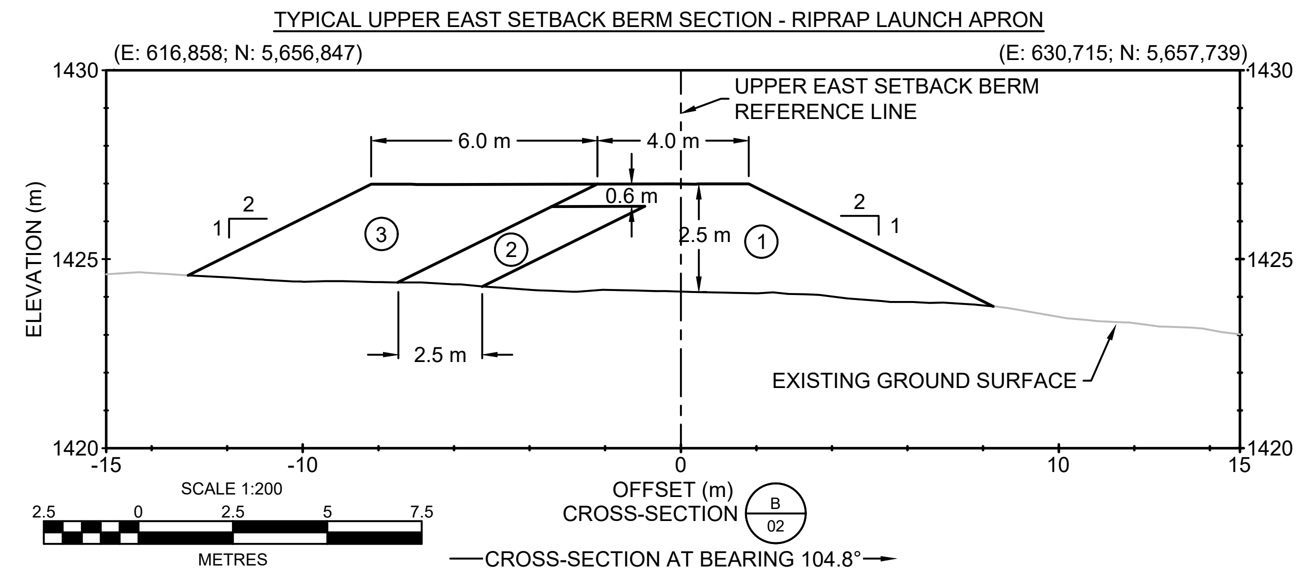

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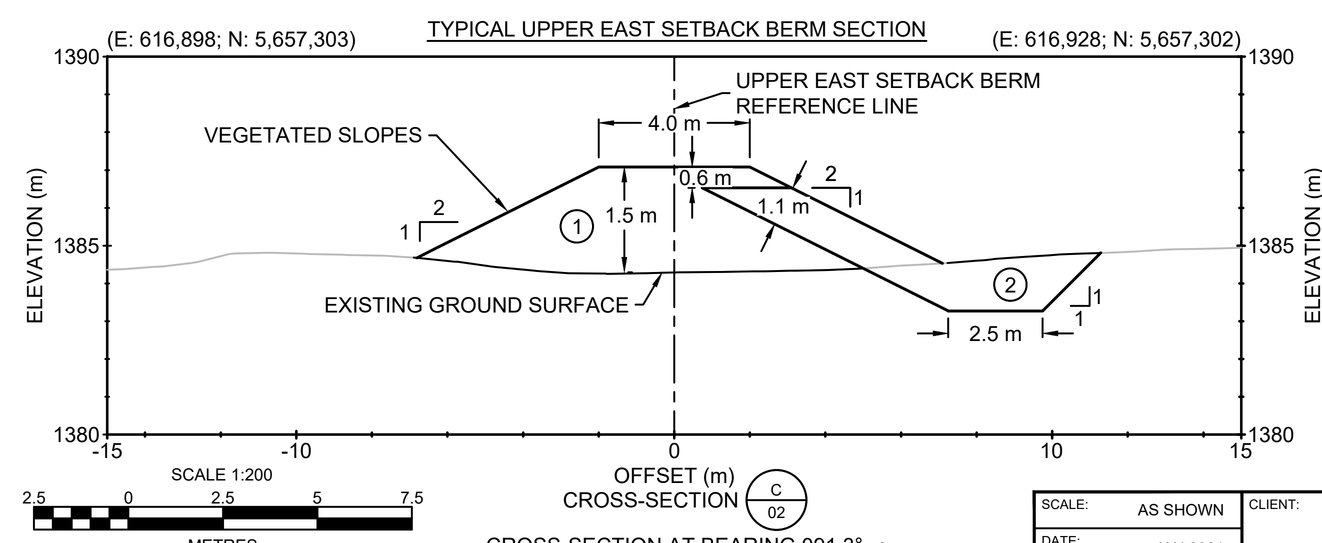

LEGEND

MATERIALS

1. BERM FILL
2. CLASS 3 RIPRAP
3. WELL GRADED RIPRAP (CLASS 1-3)
4. GROUTED STONE PITCHING

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TITLE: UPPER EAST AND WEST SETBACK BERMS - SECTIONS

PROJECT No.: 1531005

DWG No.: 03

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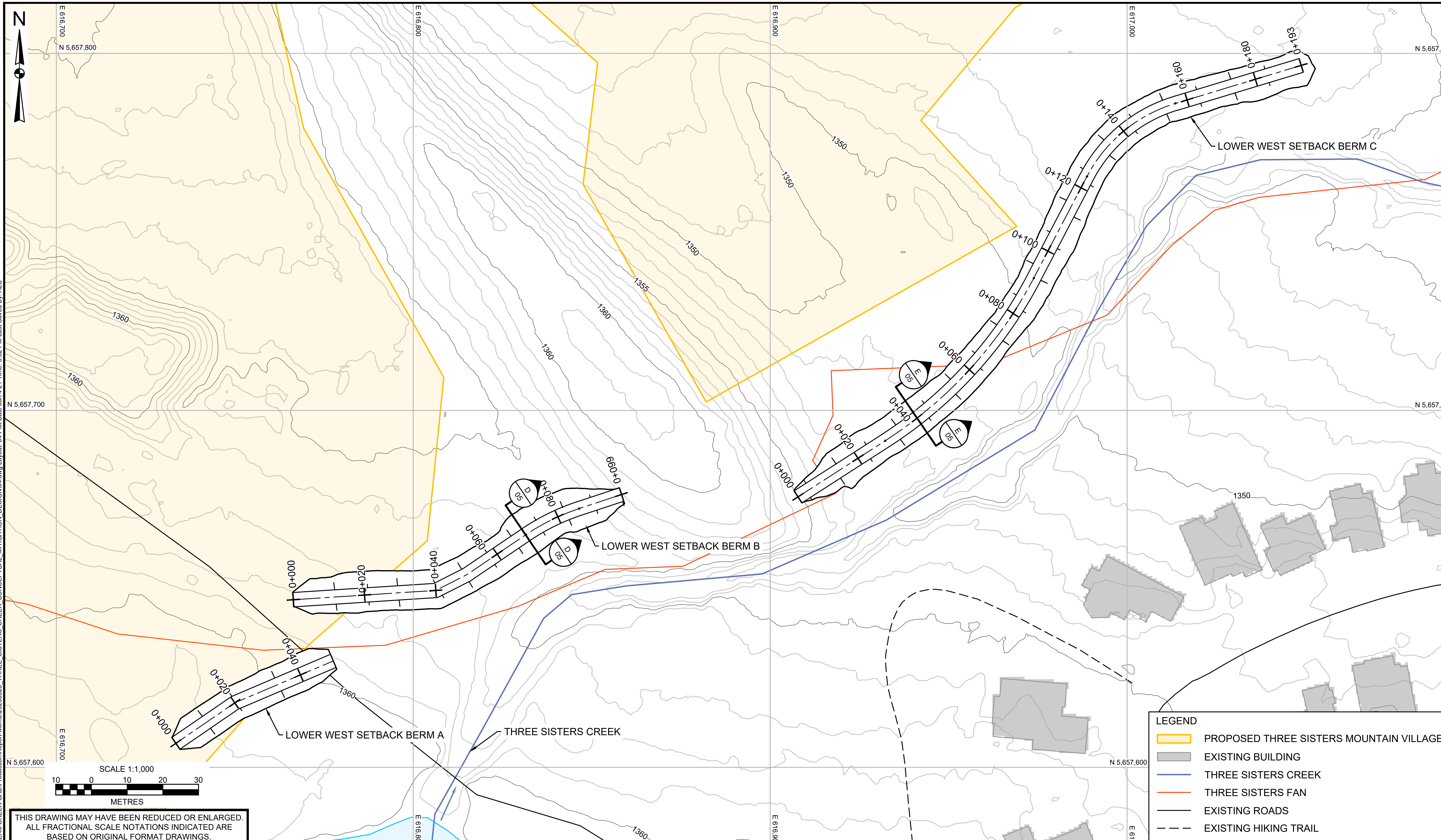

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TITLE: LOWER WEST SETBACK BERMS - PLAN

PROJECT No.: 1531005

DWG No.: 04

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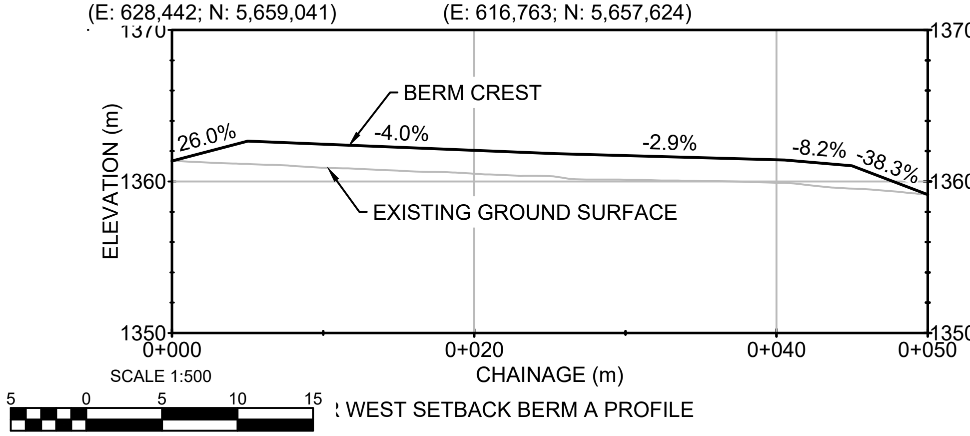
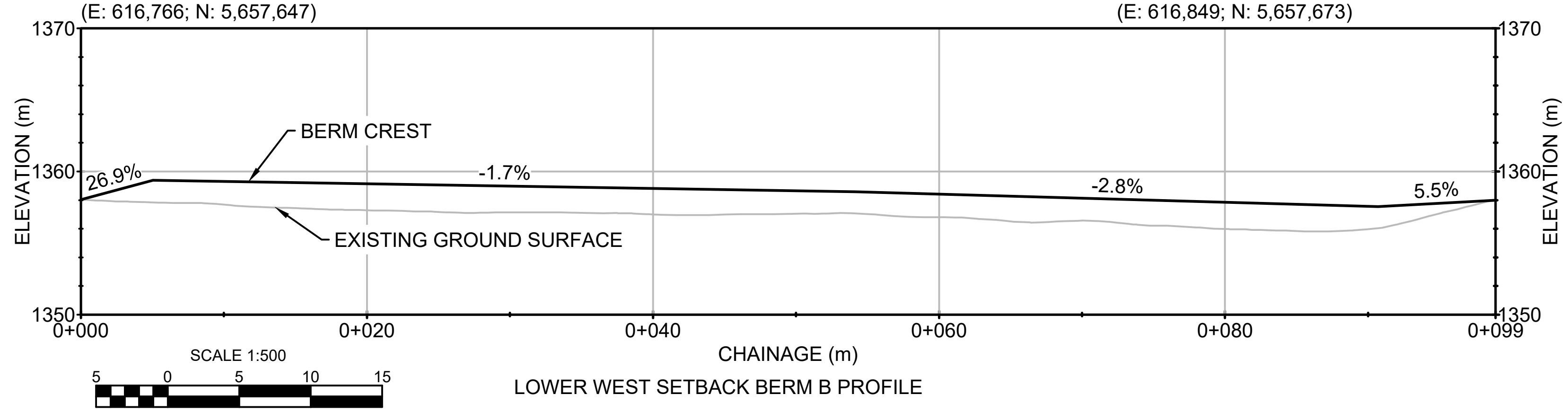


LOWER WEST SETBACK BERM A PROFILE



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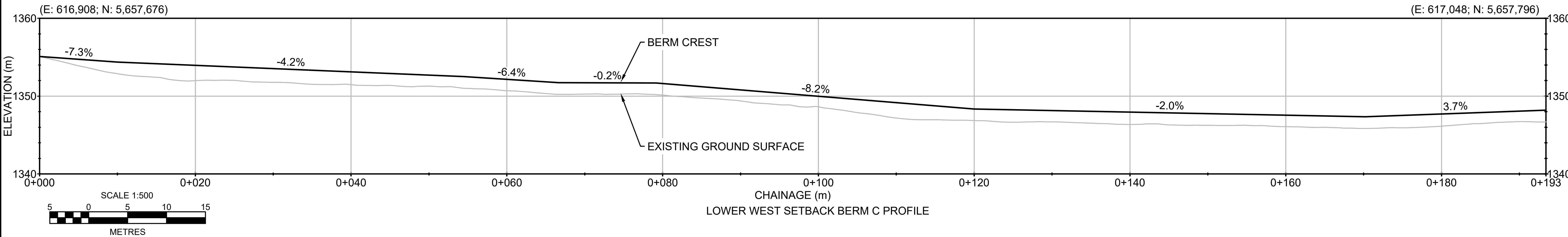
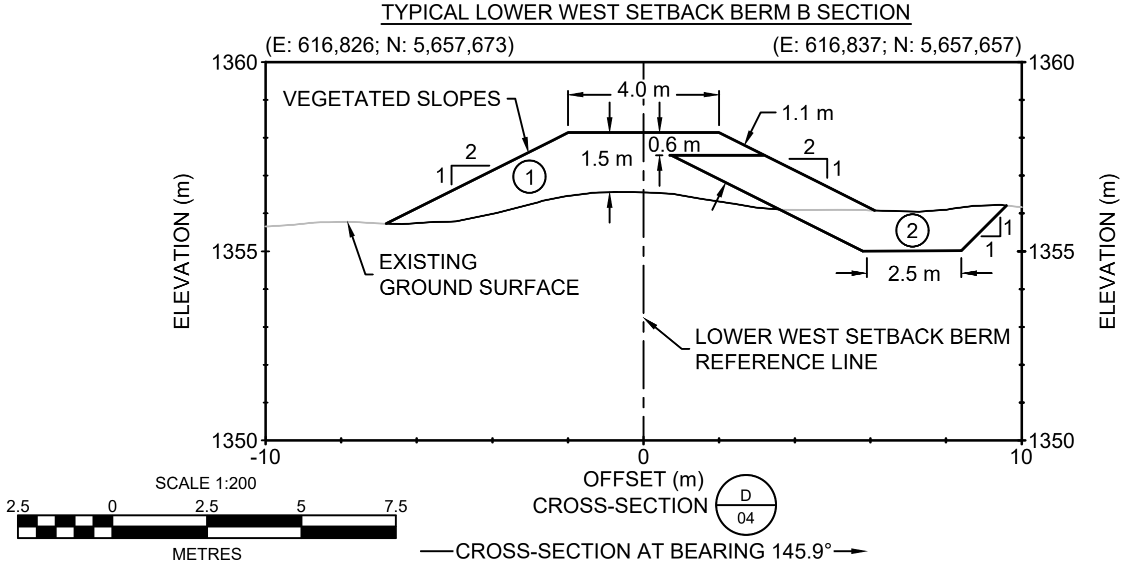
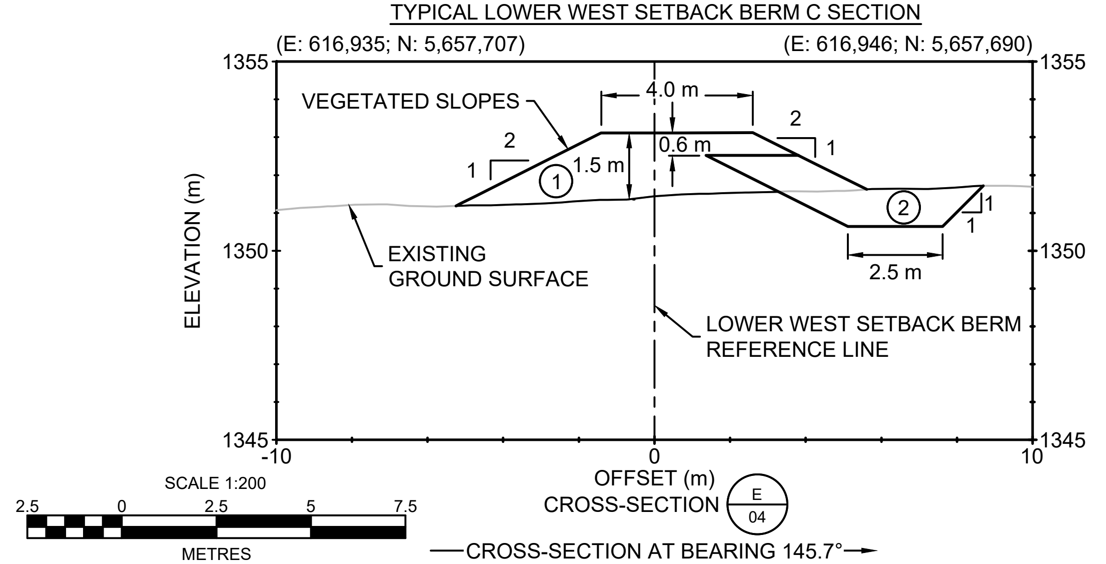


LOWER WEST SETBACK BERM C PROFILE

TYPICAL LOWER WEST SETBACK BERM B SECTION



TYPICAL LOWER WEST SETBACK BERM C SECTION



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LEGEND

MATERIALS

1 BERM FILL

2 CLASS 3 RIPRAP

NOTES:
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2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "THREE SISTERS CREEK - PRELIMINARY MITIGATION DESIGN", AND DATED JANUARY 2021.
3. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY AIRBORNE IMAGING, DATED SEPTEMBER 11, 2015.
4. COORDINATE SYSTEM IS NAD83 UTM ZONE 11N. VERTICAL DATUM IS UNKNOWN.
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SCALE:	AS SHOWN
DATE:	JAN 2021
DRAWN:	LS/AL
REVIEW:	ABS
APPROVED:	LCH

CLIENT: THREE SISTERS mountain village

BGC

PROJECT: THREE SISTERS CREEK - PRELIMINARY MITIGATION DESIGN

TITLE: LOWER WEST SETBACK BERMS - SECTIONS

PROJECT No.: 1531005

DWG No.: 05

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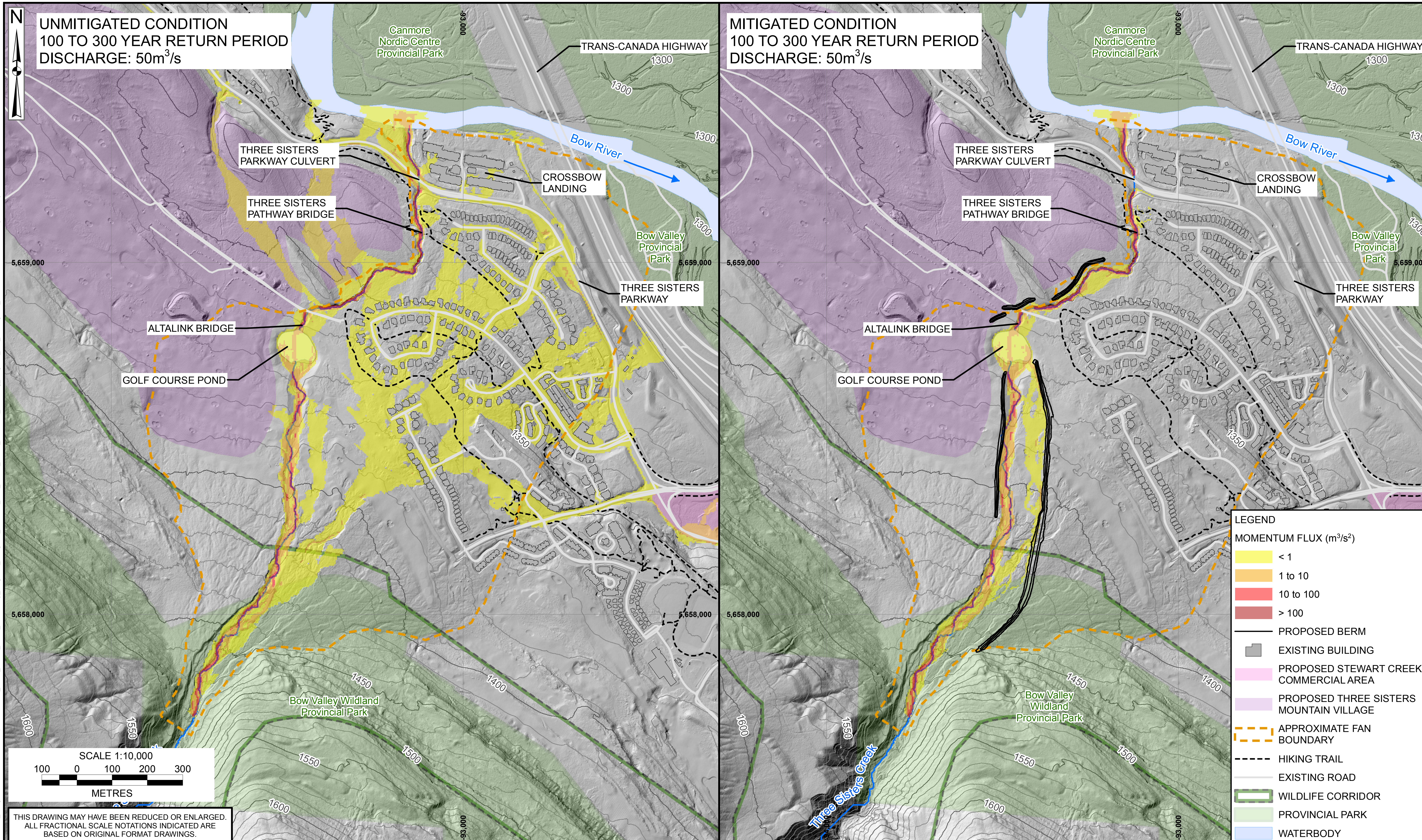

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7. PROJECTION IS NAD 83 3TM 114. VERTICAL DATUM IS CGVD28.
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DATE:	JAN 2021
DRAWN:	JDC
CHECKED:	PL
APPROVED:	LH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
THREE SISTERS mountain village

PROJECT:
THREE SISTERS CREEK
PRELIMINARY MITIGATION DESIGN

TITLE:
100 TO 300 YEAR RETURN PERIOD
NUMERICAL MODELLING MITIGATED AND
UNMITIGATED CONDITION WITH CULVERT REPLACEMENT

PROJECT No.:	DWG No:
1531 005	06

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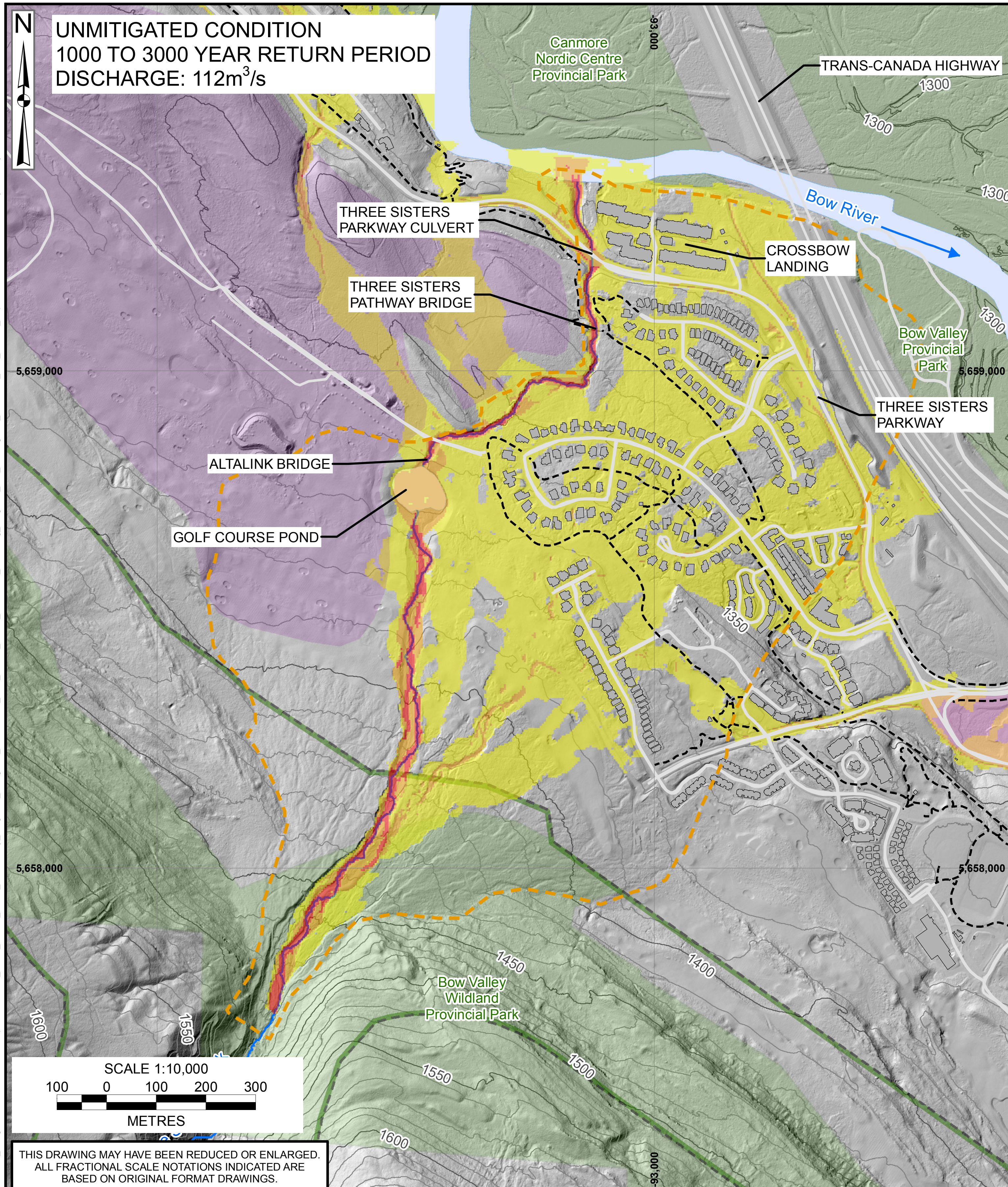

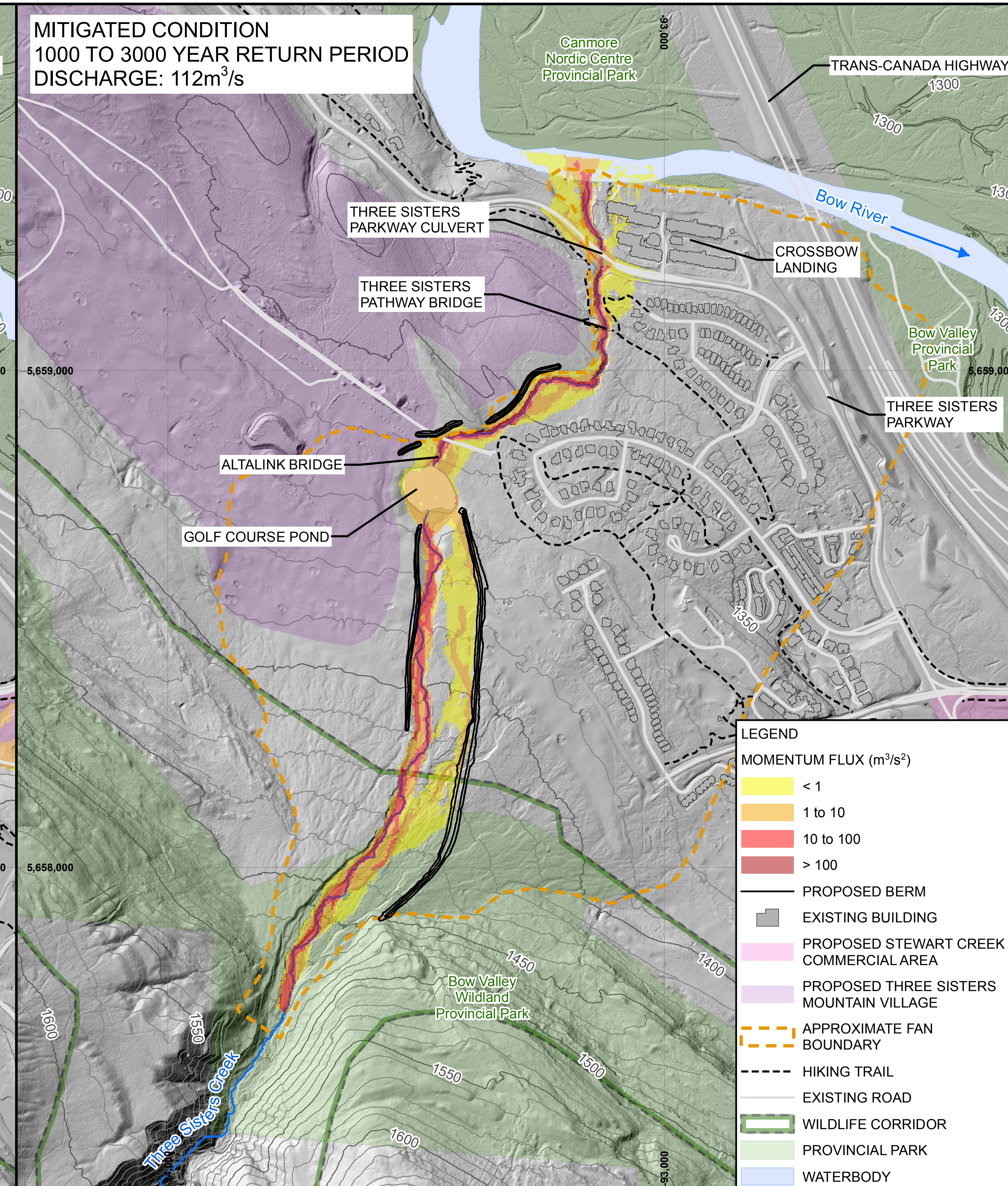

NOTES:
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3. LIDAR DATA PROVIDED BY AIRBORNE IMAGING, DATED SEPTEMBER 2015, AND BY LIDAR SERVICES INC. (LSI), DATED JUNE 28, 2013. CONTOUR INTERVAL IS 10 m.
4. ROADS, STREAM AND WATERBODY DATA FROM CANVEC, AND THREE SISTERS CREEK DIGITIZED BASED ON LIDAR DATED JUNE 2013. PARKS DATA FROM THE GOVERNMENT OF ALBERTA, DATED NOVEMBER 2012. BUILDINGS, PARCELS AND HIKING TRAILS OBTAINED FROM THE TOWN OF CANMORE.
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DATE:	JAN 2021
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CHECKED:	PL
APPROVED:	LH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: THREE SISTERS mountain village

PROJECT: THREE SISTERS CREEK PRELIMINARY MITIGATION DESIGN

TITLE: 1000 TO 3000 YEAR RETURN PERIOD NUMERICAL MODELLING MITIGATED AND UNMITIGATED CONDITION WITH CULVERT REPLACEMENT

PROJECT No.:	DWG No:
1531 005	07

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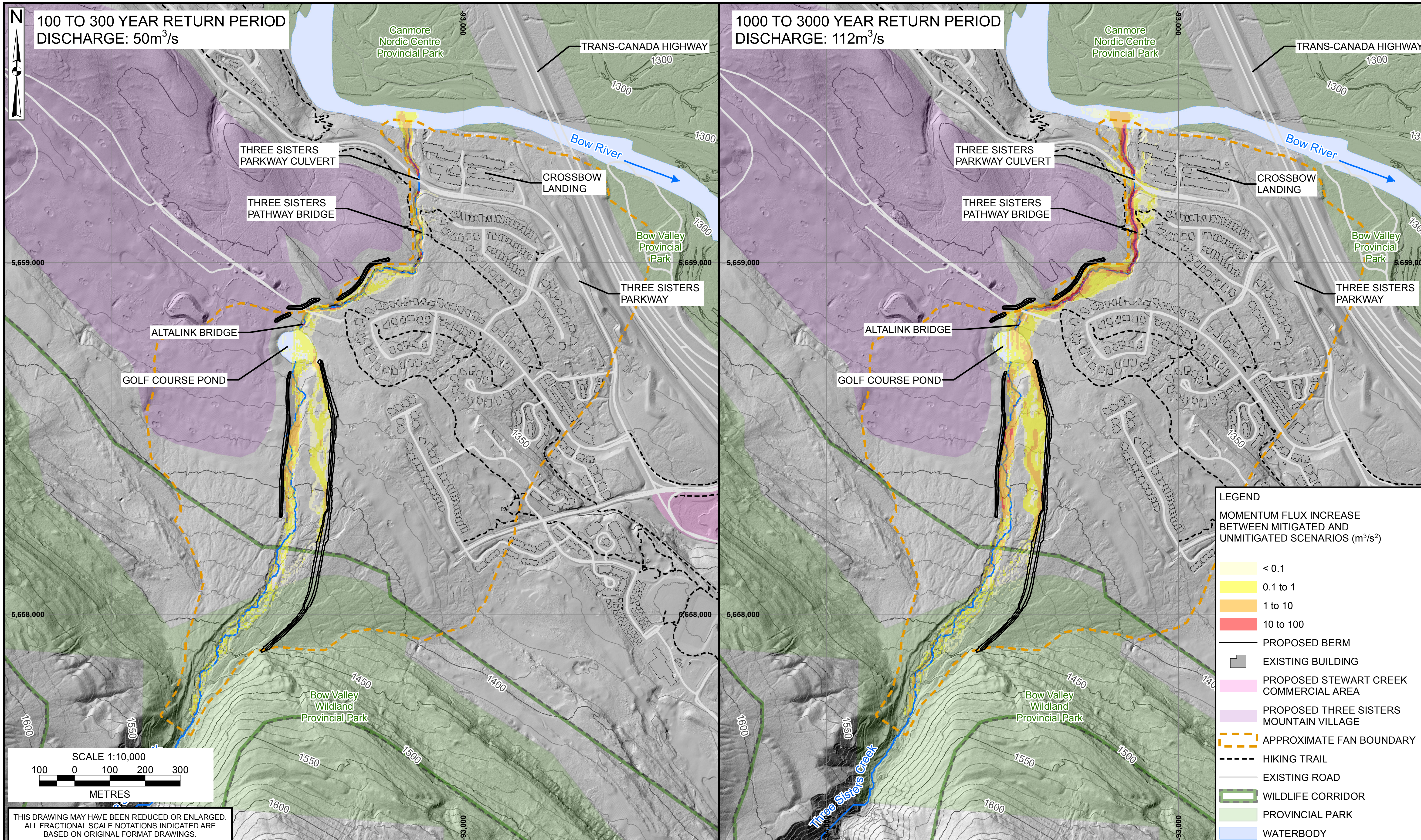

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APPROVED:	LH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: THREE SISTERS mountain village

PROJECT: THREE SISTERS CREEK PRELIMINARY MITIGATION DESIGN

TITLE: MOMENTUM FLUX INCREASE BETWEEN THE UNMITIGATED AND MITIGATED SCENARIOS WITH CULVERT REPLACEMENT

PROJECT No.:	DWG No:
1531 005	08

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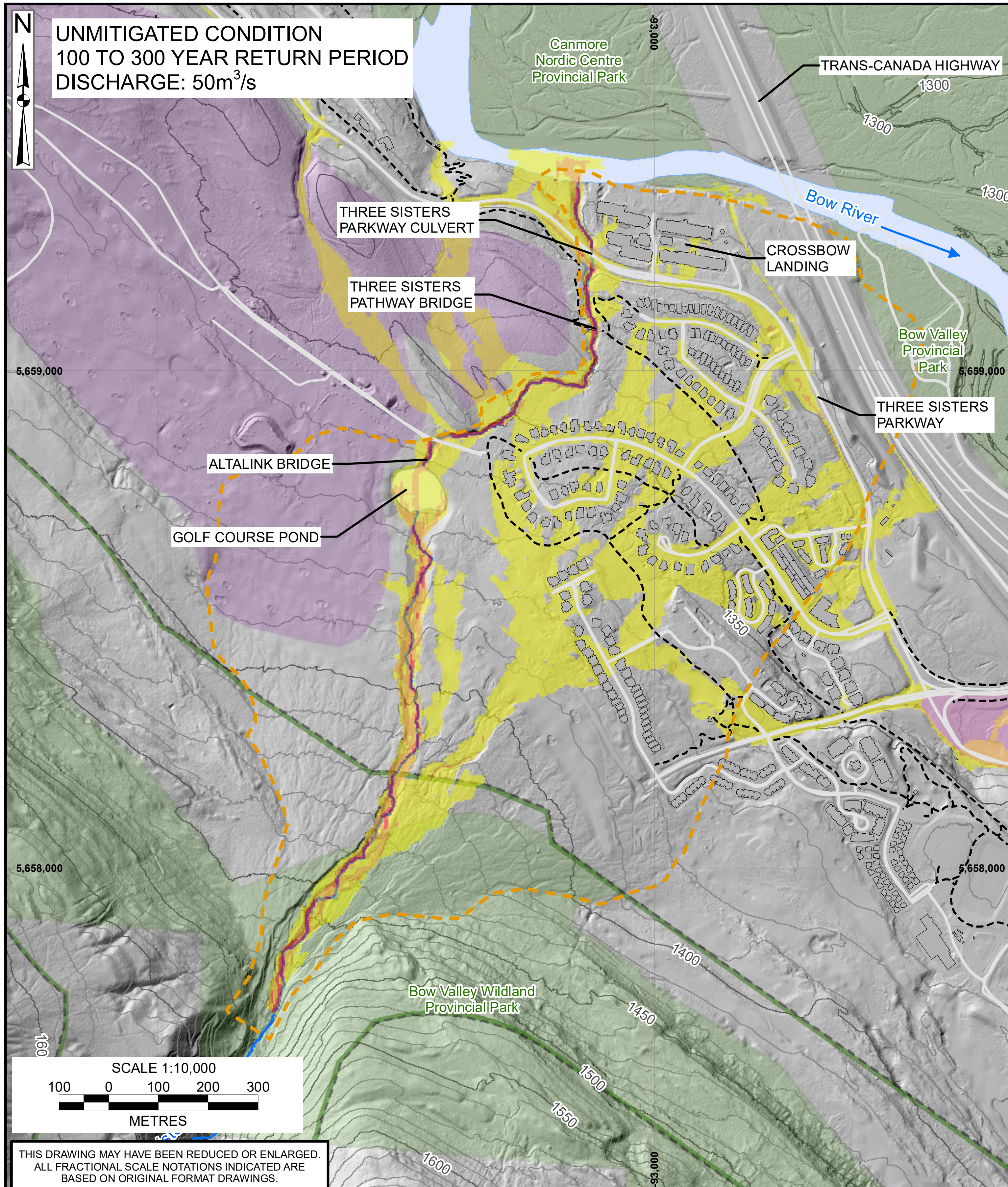

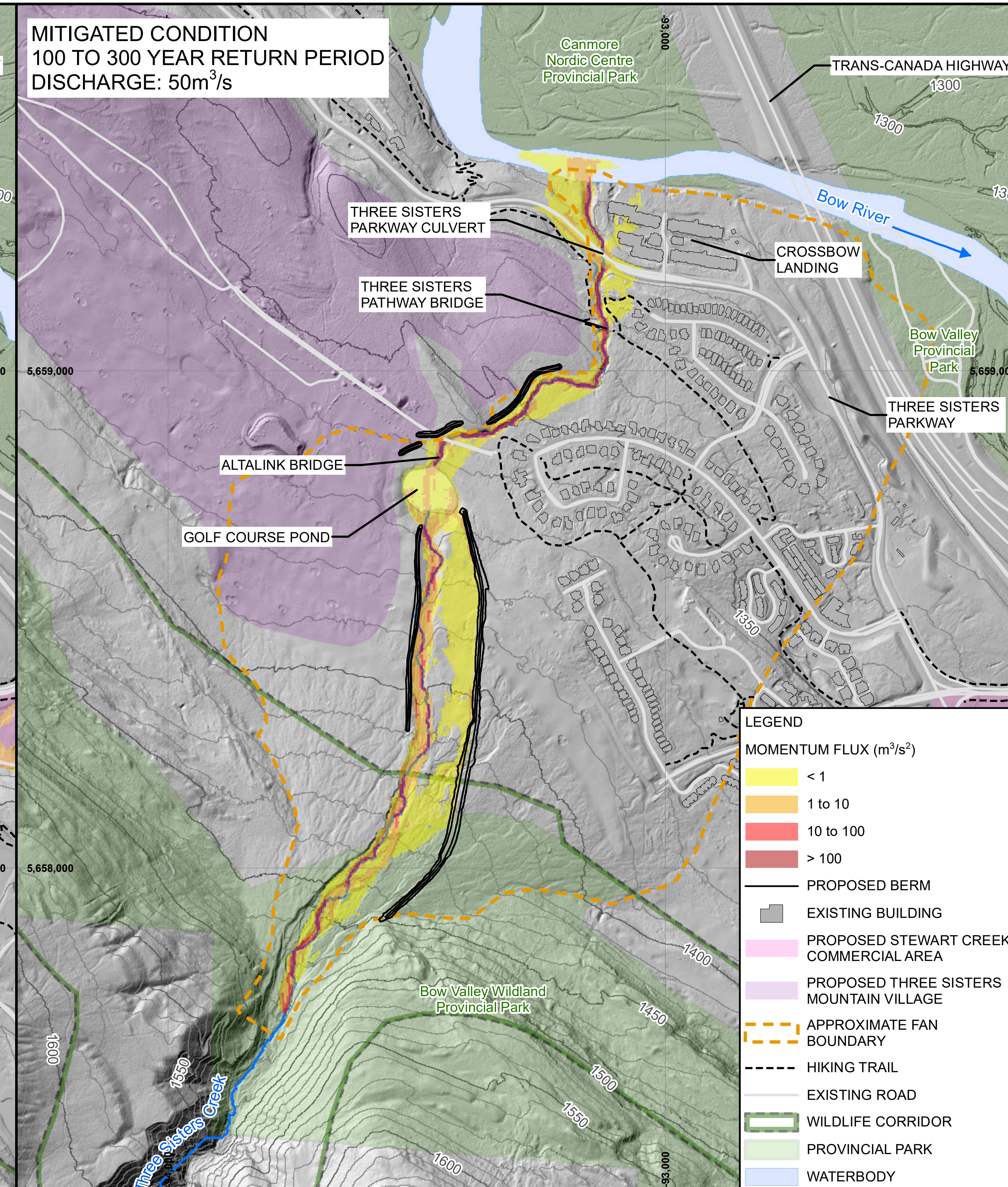

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APPROVED:	LH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: THREE SISTERS mountain village

PROJECT: THREE SISTERS CREEK PRELIMINARY MITIGATION DESIGN

TITLE: 100 TO 300 YEAR RETURN PERIOD NUMERICAL MODELLING, MITIGATED AND UNMITIGATED CONDITION WITHOUT CULVERT REPLACEMENT

PROJECT No.:	DWG No:
1531 005	09

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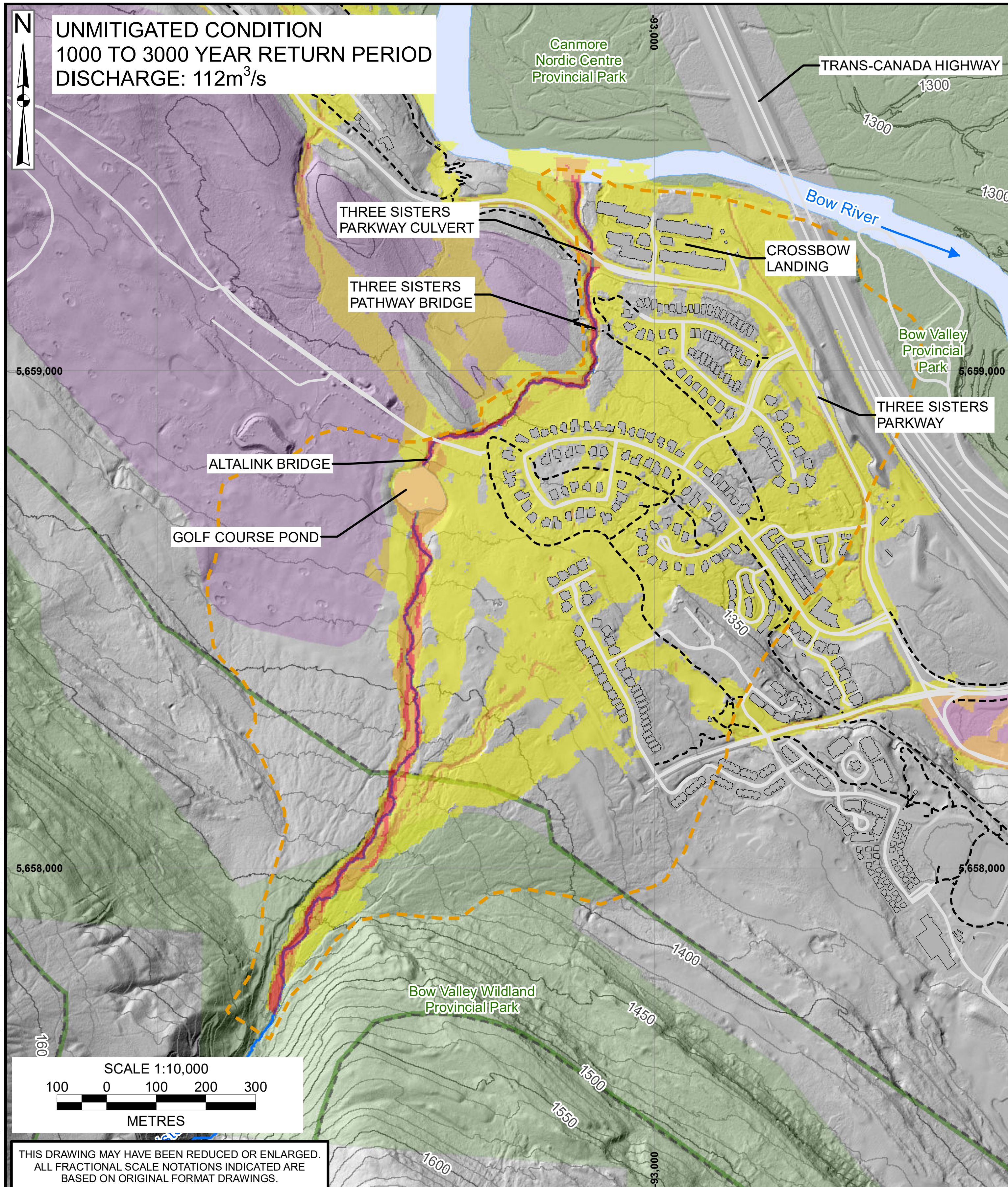

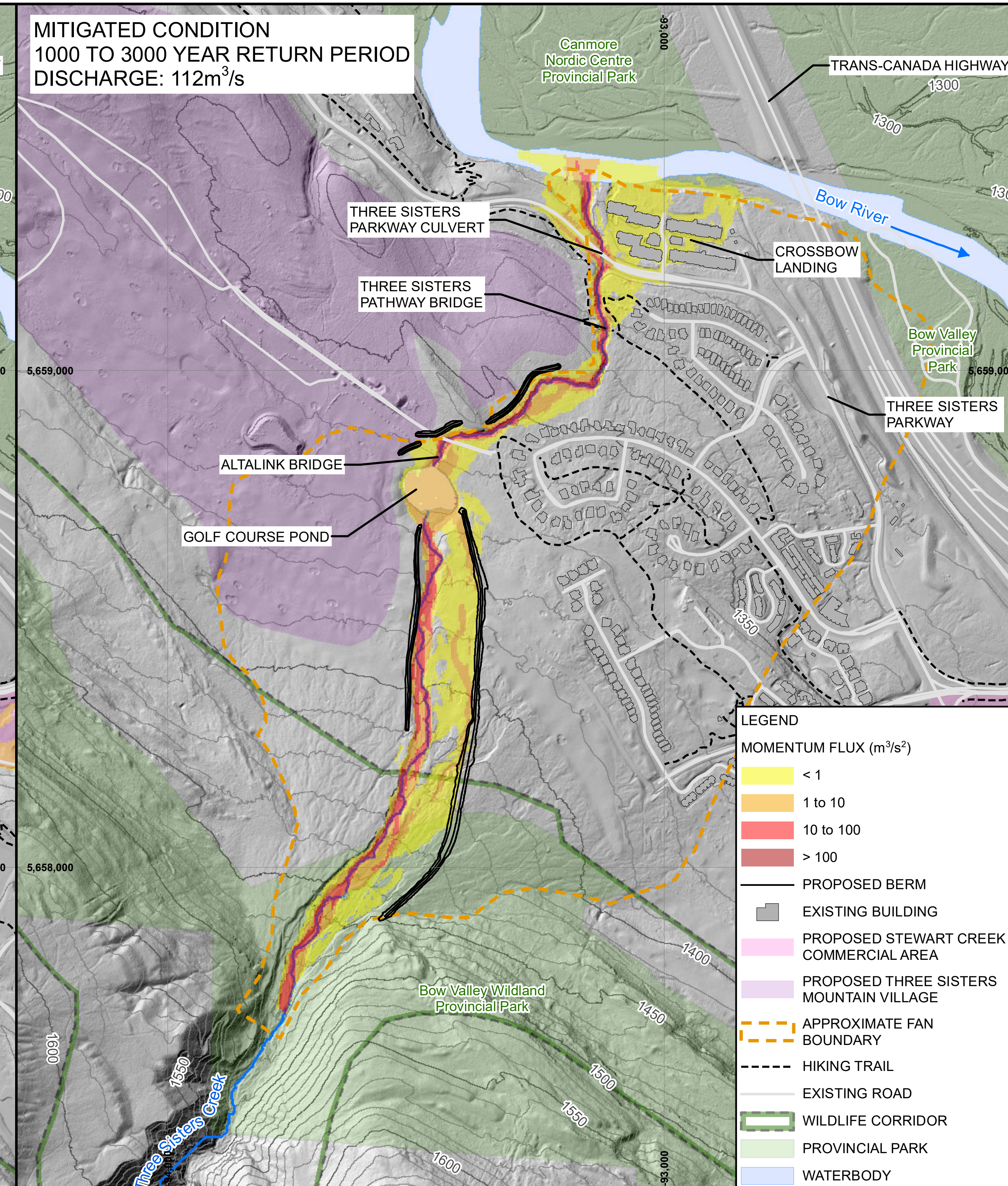

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DATE:	JAN 2021
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CHECKED:	PL
APPROVED:	LH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

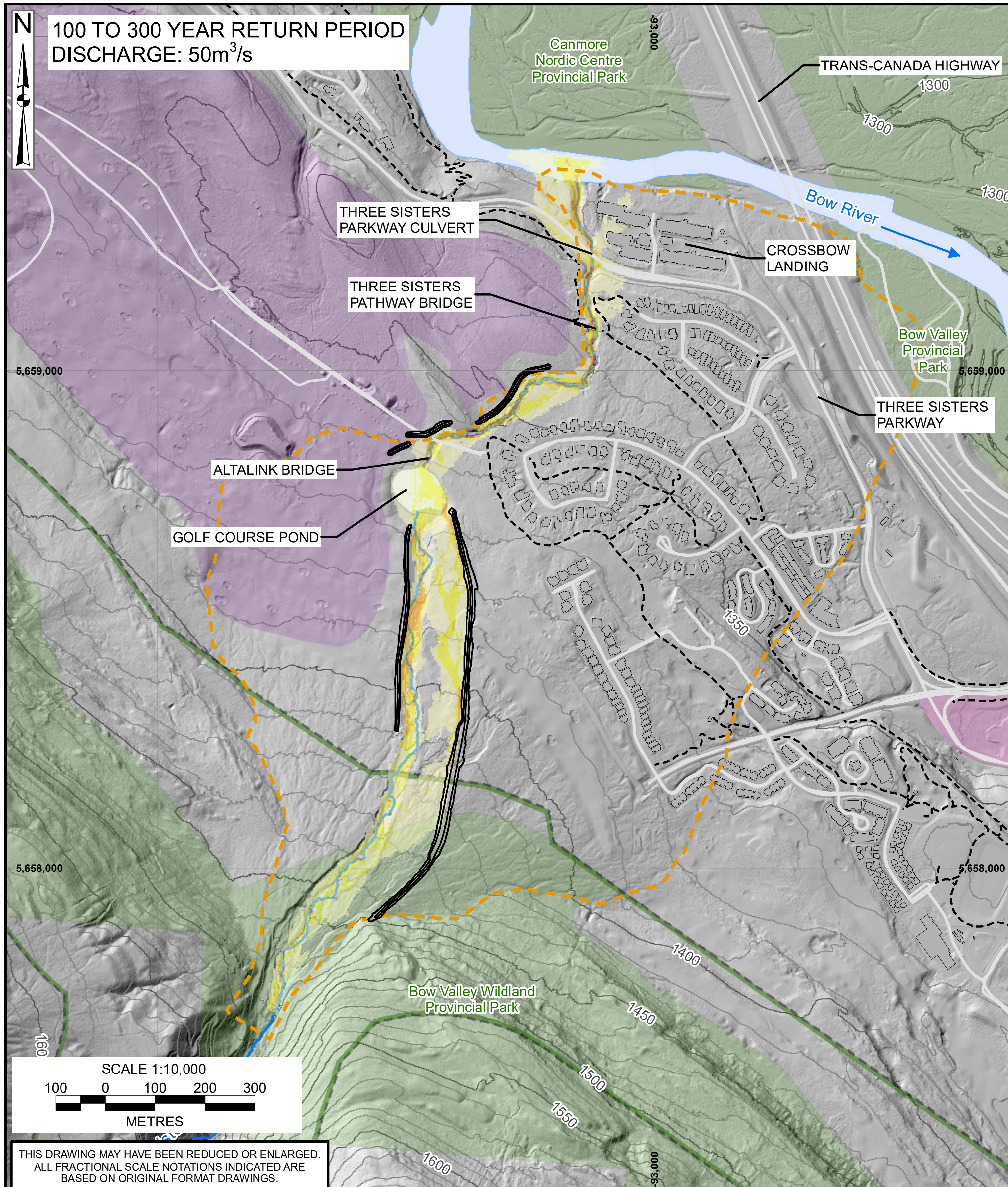
CLIENT: THREE SISTERS mountain village

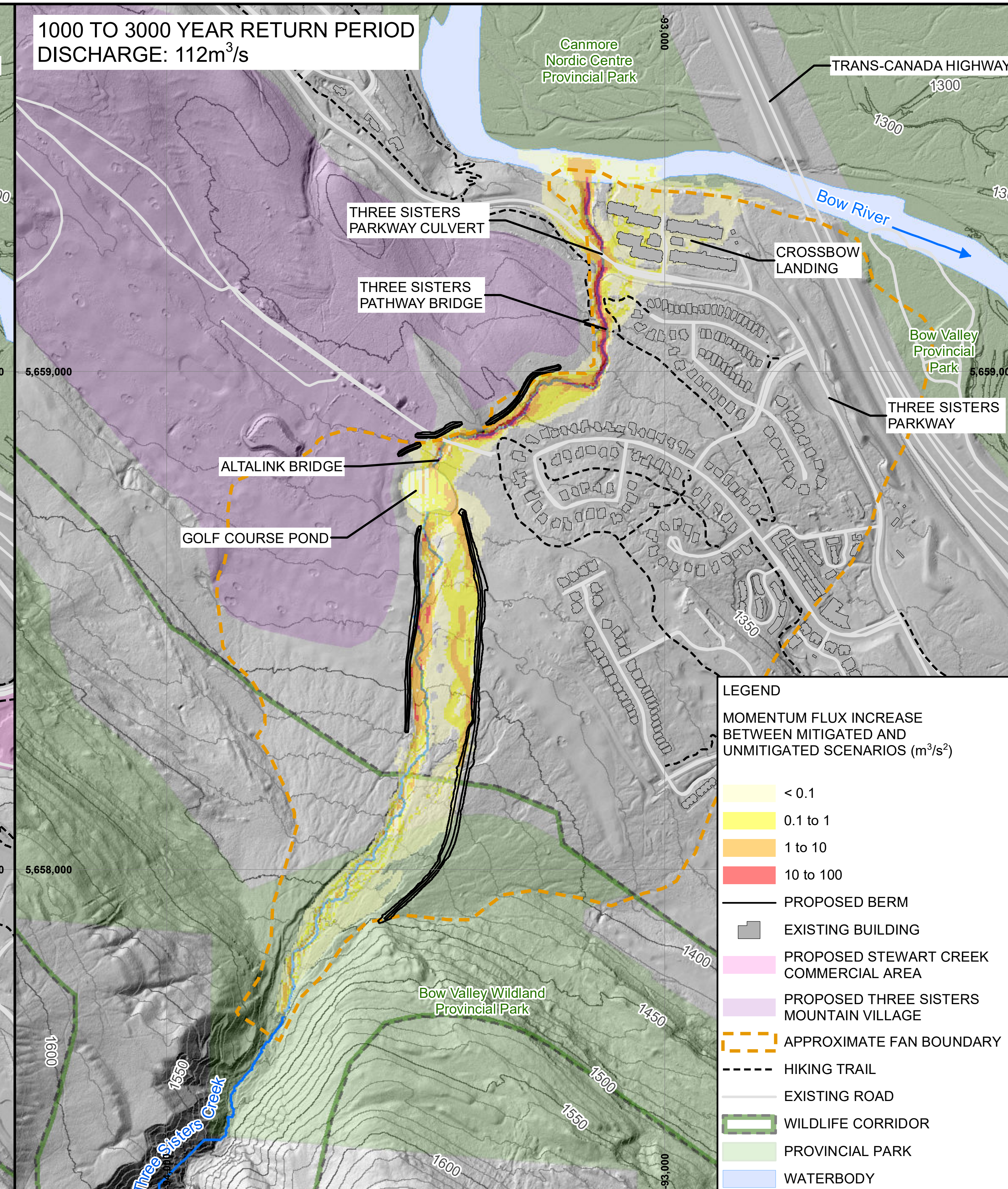
PROJECT: THREE SISTERS CREEK PRELIMINARY MITIGATION DESIGN

TITLE: 1000 TO 3000 YEAR RETURN PERIOD NUMERICAL MODELLING, MITIGATED AND UNMITIGATED CONDITION WITHOUT CULVERT REPLACEMENT

PROJECT No.:	DWG No:
1531 005	10

X:\Projects\1531_Three_Sisters_Mountain_Village\005\GIS\Production\Report\20201102_Three_Sisters_Creek_Preliminary_Mitigation_Design\07_1000to3000_Year_Return_Period_Numerical_Modelling_Mitigated_and_Unmitigated_Condition.mxd





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DATE:	JAN 2021
DRAWN:	JDC
CHECKED:	PL
APPROVED:	LH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: THREE SISTERS mountain village

PROJECT:	THREE SISTERS CREEK PRELIMINARY MITIGATION DESIGN
TITLE:	MOMENTUM FLUX INCREASE BETWEEN THE UNMITIGATED AND MITIGATED SCENARIOS WITHOUT CULVERT REPLACEMENT
PROJECT No.: 1531 005	DWG No: 11