Three Sisters Village ASP

Three Sisters Creek Debris-Flood Mitigation Options Analysis

FINAL Rev 1
November 6, 2020

BGC Project No.:
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Prepared by BGC Engineering Inc. for:
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c/o QuantumPlace Developments Ltd.

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TABLE OF REVISIONS

ISSUE	DATE	REV	REMARKS
INTERIM DRAFT	June 11, 2020	0	to QPD for review in preparation for stakeholder workshop.
INTERIM DRAFT	June 22, 2020	1	to QPD and Town of Canmore for review in preparation for stakeholder workshop.
DRAFT	October 19, 2020	2	to QPD for review.
FINAL	October 22, 2020	0	Final version issued to QPD and Town of Canmore for comment.
FINAL	November 6, 2020	1	Final version issued to QPD and Town of Canmore.

LIMITATIONS

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EXECUTIVE SUMMARY

Three Sisters Mountain Village Properties Ltd. (TSMV) plans to construct a residential development to the west of Three Sisters Creek. Three Sisters Creek is prone to debris floods, which pose a risk to existing development on Three Sisters Creek fan, and parts of TSMV's proposed development. QuantumPlace Development Ltd. (QPD), who is an authorized agent of TSMV, retained BGC Engineering Inc. (BGC) to assess options for mitigating the debris flood risk at existing and proposed development. This report summarizes and compares those options and identifies the preferred options.

The options were compared and evaluated using a range of considerations including risk reduction, costs, land ownership, technical feasibility, aesthetics, maintenance needs, and long-term performance. BGC identified that a combination of multiple mitigation structures is preferred. After ranking the mitigation options and incorporating input from both QPD and the Town of Canmore in multiple workshops, BGC recommends the following combination of measures, in order from upstream to downstream:

- <u>East and west setback berms</u> – These berms are oriented parallel to, and setback from the Three Sisters Creek channel, from near the fan apex to the Golf Course Pond (GCP) on both sides of the creek. The setback berms allow the creek to maintain a natural flow behaviour, change course and deposit substantial volumes of sediment without the need for frequent sediment removal or other maintenance. The wide floodplain could also be re-naturalized and used for recreational purposes. The berms protect existing and proposed development east and west of the creek.
- <u>Woody debris management at the GCP outlet</u> – The AltaLink Bridge at the GCP outlet has sufficient capacity to convey the peak discharge of the 100 to 300-year return period event, and small avulsions at low points of the GCP banks are likely tolerable. To support the performance of the bridge and capture woody debris before it reaches the outlet, woody debris management in the form of a floating boom system is the preferred option.
- <u>Lower channel west setback berms</u> - Setback berms on the west side of the lower channel between the GCP and Three Sisters Parkway (TSP) are desirable to protect the proposed development from debris-flood avulsions and overland flow that occur at the 30 to 100-year return period and higher.
- <u>Replace TSP culvert</u> – The culvert at TSP is currently undersized to convey the peak discharge associated with debris floods with return periods in excess of 100 years accounting for climate change to the end of the century. Flows that pond behind and overtop TSP due to culvert blockage by debris or discharge that exceeds the current culvert capacity could make TSP impassable to vehicle traffic. Moreover, flows that overtop the culvert impact the residential development on the northeast side of the creek, Crossbow Landing. A culvert replacement is the preferred option to alleviate this risk. Alberta Transportion may wish to consider delaying the culvert replacement to the end of the existing culvert design life, which BGC understands to be approximately 30 years, as it has sufficient or close to sufficient capacity to convey the peak discharge associated with debris floods with return periods up to 100-years based on historical and current conditions. For return periods in excess of 100-years, flows would be expected to overtop the culvert. BGC recommends woody debris management as an additional method to protect the TSP crossing if the mitigation budget allows.

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ACRONYMS AND ABBREVIATIONS

Acronyms and abbreviations used in this report:

BVWPP	Bow Valley Wildlife Provincial Park
EDGC	Engineering Design and Construction Guidelines
GCP	Golf Course Pond
IDF	Intensity-duration frequency
KT	Kepner-Tregoe
NPV	Net present value
QPD	QuantumPlace Developments
PDI	Probability of Death of an Individual
RCP	Representative concentration pathway
SCC	Stewart Creek Commercial Area
ToC	Town of Canmore
TSMV	Three Sisters Mountain Village
TSP	Three Sisters Parkway
VSL	Value of a statistical life

1. INTRODUCTION

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 (SCC)) further to the east. In addition, the Town of Canmore (ToC) wishes to provide reasonable mitigation of existing hazard to existing development. Three Sisters Creek is susceptible to debris flood hazards (BGC, October 9, 2020) with the eastern portion (mainly existing development) being more susceptible than the western portions from debris flood impact. Drawing 01 shows the proposed development areas, which are partially located within the Three Sisters Creek fan, juxtaposed against 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.

In June 2013, Three Sisters Creek experienced a debris flood resulting in damage to the golf course infrastructure (pedestrian bridge, pond), and roads (Three Sisters Parkway (TSP) and a golf course access road) in the proposed TSMV development area (BGC, December 11, 2013). In response to the June 2013 event, the ToC retained BGC Engineering Inc. (BGC) to complete hazard and risk assessments on Three Sisters Creek (BGC, October 31, 2014; January 20, 2015).

The BGC risk assessments completed for ToC prior to 2020 considered the existing development on the eastern portion of the fan but did not include the proposed TSMV development on the west side of Three Sisters Creek or the SCC area (BGC, January 20, 2015; January 11, 2018). The previous hazard and risk assessments showed that the western side of the fan generally has a lower likelihood of hazard impact than the eastern (developed) side due to its higher elevation (BGC, October 31, 2014). In 2018, QuantumPlace Development Ltd. (QPD), an authorized agent of TSMV, retained BGC to provide an updated hazard assessment for Three Sisters Creek (BGC, October 9, 2020). The 2020 report builds on the earlier hazard assessment (BGC, October 31, 2014) to integrate quantitative consideration of bank erosion and climate change considerations in the debris-flood hazard. The results show that the debris-flood hazard at Three Sisters Creek impacts the proposed development at TSMV and to a lesser extent the SCC area by shallow overland flow, but the majority of the area impacted by debris-flood hazards is the existing development east of Three Sisters Creek and the existing TSP.

QPD retained BGC to provide an analysis of conceptual mitigation options that would reduce the risk from debris-flood hazards at Three Sisters Creek to both existing and proposed development. This options analysis includes mitigation that protects existing and proposed development on both the eastern and western sections of the fan as well as SCC.

This report summarizes the debris-flood mitigation options analysis. It includes the considerations and workflow used to move through the options analysis, descriptions of the mitigation options considered, and a summary of the detailed options analysis completed to choose the preferred mitigation system. This report is intended to provide a transparent and logical account of how and why the preferred mitigation system was chosen in collaboration with the ToC.

1.1. Scope

BGC provided a proposal to QPD on April 28, 2020 for the mitigation options analysis. The scope of work completed included the following tasks:

- Generation of a comprehensive list of possible mitigation options, followed by preliminary review to eliminate options that do not meet project objectives.
- Development of conceptual level mitigation strategies for options selected for further assessment, allowing for an order of magnitude cost estimate, and descriptions of the advantages and disadvantages of each option.
- Development of a short-list of options and identification of data gaps required to be filled to complete options comparisons.
- Development of evaluation criteria and weighting to compare options.
- Collaboration with QPD and the ToC to complete additional analyses to fill data gaps.
- Preparation of materials for and participation in two options analysis workshops with QPD and the ToC to evaluate the short-list of options and identify the preferred mitigation system.
- Documentation of options analysis work in this report and conceptual level figures and drawing.

2. BACKGROUND

The regional and local watershed geology, geomorphology, and hydrology of Three Sisters Creek are described in BGC's updated hazard assessment (BGC, October 9, 2020). This section provides a brief summary of the June 2013 debris flood, previous work completed at Three Sisters Creek fan relevant to this debris-flood mitigation options analysis, and an overview of the workshops held to discuss the options analysis.

2.1. June 2013 Debris Flood

The 2013 debris flood occurred in response to a large precipitation event from June 19-21. The storm was an extremely rare event because of its long duration and large amount of associated total rainfall. According to BGC's detailed assessment of the hydroclimatic conditions during the event (BGC, August 1, 2014) the 1-day, 2-day and 3-day rainfall totals for this storm at Kananaskis, the nearest long-term climate station to Canmore, were the highest on record since observations began in 1939 and the storm frequency was estimated to have a return period of 235 to 575-years. However, the event was not extreme in terms of short term maximum hourly rainfall intensity, and peaked at approximately a 5-year return period intensity when compared to the Kananaskis station intensity-duration frequency (IDF) curve. Antecedent moisture conditions appear to have been high prior to the storm based on snowpack and preceding rainfall trends and, combined with observations of frozen soils at higher elevations, suggest that a high percentage of the total rainfall translated into storm runoff.

The storm produced a 3-day flood that caused up to 20 m of channel widening on the mid-fan and up to 28 m of channel widening on the upper fan due to bank erosion along the channel reaches between the fan apex and the Golf Course Pond (GCP). Significant aggradation of up to 3 m also occurred within this section of the channel. Although the aggradation increased the potential for avulsion on the right (east) bank, no avulsions occurred as a result of the event.

The GCP was 75% filled with 36,000 m^3 of sediment, which meant that no sediment was transported through and past the GCP as bedload. All bedload mobilized downstream was derived from sources between the pond and Bow River. As there are bedrock-controlled reaches downstream of the GCP, the amount of mobilizable sediment was limited.

Damages included (locations shown on Drawing 01 in BGC (October 9, 2020)):

- Outflanking of the Upper Bridge on both banks
- Destruction of all channel works related to the golf course construction (e.g., grade control structures)
- Infilling of the GCP to about 75% of its capacity
- Destruction of a culverted access road downstream of the GCP
- Bank erosion and channel incision downstream of the GCP, especially downstream of TSP.

BGC estimated that the peak discharge of the June 2013 event ranged from 20 to 25 m^3/s based on measurement of high-water marks above the fan apex (BGC, October 31, 2014). Based on the 2020 updated hazard assessment, the June 2013 event therefore has a return period in the range of 100 to 300-years based on current conditions, and in the range of 30 to 100-years based on climate change adjusted conditions considering RCP 8.5 for the years 2050 to 2100[1]. Numerical modeling conducted in 2014 (BGC, October 31, 2014) and 2020 (BGC, October 9, 2020) suggests that avulsions could occur at this return period if the channel is in an aggraded condition. An avulsion of this nature did not occur in 2013 but the remaining freeboard during the 2013 event was observed to be very little (< 0.3 m) in places and an avulsion could have occurred. This discrepancy emphasizes the somewhat chaotic response of steep creeks to major runoff events.

2.2. Previous Work

2.2.1. BGC Studies

BGC has previously completed hazard and risk assessments on Three Sisters Creek for the ToC (BGC, October 31, 2014; January 19, 2015; January 11, 2018), as well as an update to the hazard assessment for QPD (BGC, October 9, 2020).

In 2016, BGC was also requested by the ToC to provide numerical modelling of debris-flood events for mitigation design to SweetTech Engineering Consultants (BGC, October 14, 2016).

The most recent hazard assessment update for Three Sisters Creek included climate change analysis (RCP 8.5) and improvements in understanding of debris-flood science that were not available when the original 2014 hazard assessment was published (BGC, October 9, 2020). Advancements included a systematic addition of a bulking factor to account for mineral and organic debris included in flow as well as new methods of creating a composite hazard map. The bulking factor accounts for the material load that is entrained in a debris flood and thus is a more representative assessment of anticipated debris-flood impacts. Table 2-1 outlines the frequency-magnitude (F-M) relationships (peak discharge and sediment volume) for Three Sisters Creek. The present mitigation options analysis is based on the updated F-M relationships and modelling results from the 2020 assessment.

[1] BGC estimated the peak discharge of debris floods under current and future conditions considering climate change impacts associated with Representative Concentration Pathway (RCP) 8.5 for return periods ranging from 10 to 3,000-years. The 100-year and 300-year peak discharges for current conditions were 16 m^3/s and 28 m^3/s, respectively. The 30-year and 100-year peak discharges for future climate conditions were 15 m^3/s and 32 m^3/s, respectively. (BGC, October 9, 2020).

Table 2-1. Peak discharge and sediment volumes for Three Sisters Creek under future climate conditions in 2050-2100 (RCP 8.5). Peak discharges are bulked to account for the large woody debris and sediment associated with debris floods. (BGC, October 9, 2020)

Return Period (years)	Bulked Peak Discharge (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

2.2.2. Other Consultant Studies

2.2.2.1. SweetCroft Engineering Consultants Ltd. (2015)

SweetCroft Engineering Consultants Ltd. (SweetCroft) prepared a preliminary debris-flood mitigation design for Three Sisters Creek for the ToC (SweetCroft, April, 2015). Few of the measures proposed by SweetCroft have been implemented to date. Installation and repair of erosion protection around the TSP crossing was constructed in 2018 that was similar to some measures proposed by SweetCroft (April, 2015) (Table 2-2). All of the measures proposed by SweetCroft are considered in BGC's current mitigation options analysis and are compared directly with alternative options proposed by BGC. SweetCroft Engineering Consultants Ltd. became SweetTech Engineering Consultants Ltd. in 2016.

2.2.2.2. SweetTech Engineering Consultants (2018)

SweetTech Engineering Consultants Ltd. (SweetTech) prepared a report that outlines the engineering design basis of the erosion mitigation work around TSP that was completed in 2018 (SweetTech, October 25, 2018). The design objectives were to repair and improve bank erosion measures from the Three Sisters Pathway bridge to the outlet of the TSP crossing (locations shown on Drawing 01 in BGC (October 9, 2020)), to protect the creek banks and culvert and bridge abutments, and remove trees to reduce debris in future events. The design was based on previous BGC model results (BGC, October 31, 2014; October 14, 2016; January 11, 2018). The work completed based on this design report is outlined in Table 2-2.

2.2.3. Previous Mitigation Work

Table 2-2 summarizes debris-flood mitigation works that have already been constructed on Three Sisters Creek. The 2013 debris flood on Three Sisters Creek significantly altered the channel between the fan apex and the GCP, as well as damaging some access road crossings and golf course bridges (BGC, October 31, 2014). Short-term mitigation works were constructed in 2014 with additional mitigation work in 2018.

Table 2-2. Previous debris-flood mitigation work completed on Three Sisters Creek fan.

Item	Years Constructed	Description	Source
Berm near fan apex (Drawing 01)	Between 1997 and 2008	Berm is approximately 200 m long, 1 m high, 2 m wide at the crest and 15 m wide at the base. No design or as-builts are available, dimensions have been measured from 2015 lidar. It appears to have been built to prevent avulsions to the east. BGC does not expect this berm to be effective at preventing all avulsions as it is located further upstream than modelled avulsions and avulsion paths noted in lidar.	BGC, October 9, 2020
Golf course	2004-2009	The partially constructed golf course included constructing the GCP, and some channel works upstream of the GCP including small bridges for pedestrians and golf carts. The GCP functions as a sediment storage pond.	Design drawings of the channel and GCP: Westhoff Engineering Resources, Inc., May 2007
Short-term mitigation works in response to 2013 debris flood	2014	Clearing debris from the GCP and channel upstream; re-channelizing approximately 1400 m of channel upstream of the GCP; installing articulated concrete mats around the outlet of the GCP; armouring the creek with riprap in specific locations downstream of the GCP	TetraTech EBA, March 17, 2014; BGC, October 31, 2014
Erosion mitigation from pedestrian bridge to downstream of TSP	2018	Repair and improvements to erosion protection	SweetTech, October 2018

2.3. Workshops

The options analysis scope originally included one workshop with BGC, QPD and the ToC to identify the preferred overall mitigation system for the fan. The scope was expanded to include a second workshop and memo outlining the additional analyses completed to address data gaps. The following sections give a brief overview of the workshops and subsequent analysis. All workshops were on video conference.

2.3.1. Workshop 1

Workshop 1 was on July 2, 2020 with attendees from BGC, QPD and the ToC. BGC presented all mitigation options considered and provided recommendations on those that could be rejected or selected for further assessment. BGC also introduced the decision analysis framework discussed in detail in Section 6. As part of the workshop additional data gaps for analysis were identified.

2.3.2. Workshop 2

Workshop 2 was on August 4, 2020 with attendees from BGC, QPD and the ToC. BGC presented further analysis on topics discussed in Workshop 1 and facilitated the selection of the preferred mitigation options at select locations on the fan. Additional requests for analyses to finalize the selection of the preferred mitigation system were identified, as follows:

1. Confirm life safety risk at Crossbow Landing.
2. Evaluate the influence of pond water elevation and sediment in the GCP on the model results.
3. Estimate the cost to repair TSP to be included in the risk reduction benefit of mitigation options at TSP.
4. Add woody debris management as an option at the GCP.
5. Evaluate debris flood impacts to existing development with proposed mitigation in place.
6. Consider reducing the GCP capacity.

2.3.3. Workshop 2 Memo

As a follow up to action items from Workshop 2, BGC issued a memo to outline the additional analyses completed (BGC, October 8, 2020). The analyses completed informed the preferred mitigation system for Three Sisters Creek presented in this report. It is included as Appendix A.

3. OPTIONS ANALYSIS CONSIDERATIONS

This section describes the basis, constraints, and assumptions considered as part of the debris-flood mitigation options analysis.

- **Conceptual design level**: All design options are at a conceptual level. Design options have been developed to a stage that allows the technical merit and relative costs of different options to be compared. Details of the design options, including final dimensions and layout of design elements and budgetary level cost estimates, are beyond the scope of the conceptual design.
- **Life-loss risk reduction target**: Life-loss risk reduction is not a key driver for mitigation options comparison or design selection. The Town of Canmore's Municipal Development Plan (adopted September 27, 2016, updated January 16, 2020) sets life-loss risk objectives: annual individual risk (PDI) shall not exceed 1:10,000 at existing development, and shall not exceed 1:100,000 at new development. A risk assessment for existing development (BGC, January 19, 2015) concluded that all existing development meets this risk target without further mitigation. The flow depth in the proposed development is dominantly <0.3 m with select locations of channelized flow up to 1.5 m (BGC, October 9, 2020). Based on the vulnerability criteria used in the 2015 risk assessment, when the flow depth is less than 0.3 m, the life loss vulnerability is zero (BGC, January 19, 2015). For flow depths in excess of 0.3 m, life loss vulnerability is determined by the intensity of the flow $(velocity^2 x\, flow\ depth)$. The conceptual mitigation designs proposed in this report are intended to prevent events smaller than and including the 100 to 300-year return period debris flood from impacting the proposed development.
- **Economic risk reduction target:** Given that life loss risk criteria are likely met for the existing and new development for the return period events considered, economic risk reduction is the key risk for mitigation option comparison and design selection. Economic risk is distributed among residential buildings in the existing development and based on the risk assessment completed by BGC (January 19, 2015). Economic risk reduction targets have been outlined in the Engineering Design and Construction Guidelines (June 22, 2020). The guidelines specify that although economic risk tolerance criteria have not been established, economic risk shall be minimized and that a maximum annualized cost of $500/year/dwelling unit should be targeted. The proposed development is not at a level of design to specify dwelling units at the time of this options analysis, but it is anticipated that this economic risk target will be met with the options proposed. This will be confirmed at a later stage of analysis, under a separate scope of work.
- **Lifecycle cost:** Lifecycle cost includes capital costs and operations and maintenance costs. Operation and maintenance costs are estimated for a 50-year time period for all options. At the conceptual design stage, cost estimates are rough estimates, with expected variance from approximately -50% to +100%. These costs are developed to support a comparison between alternatives and should not be used to set budgets for mitigation works. Costs are estimated based on approximate volumes and dimensions of proposed mitigation structures and unit costs derived primarily from April 2020 contractor bids for debris-flood protection works at Heart Creek in the nearby hamlet of Lac des Arcs

and supplemented with other relevant project experience and personal communication with QPD.

- **Cost-benefit ratio:** Cost-benefit ratios of mitigation options are important for option comparison as they unite cost and risk reduction in one value. Benefits are presented in terms of economic risk reduction over a 50-year period and compared with lifecycle cost of the mitigation option. The economic risk reduction includes building damage, TSP damage and closure costs, and monetized life loss risk. A description of the process employed to determine the risk reduction and cost-benefit ratio is included in Section 4. A cost-benefit ratio less than one implies that more is spent on installing and maintaining the mitigation than is saved from reducing the risk, this may occur for an option that only protects a small portion of development. Conversely, a ratio larger than one shows that more is saved by reducing risk than is spent on the mitigation, which is a desired attribute.
- **Hazard characterization:** The options are intended to protect against debris floods, which are floods that mobilize the channel bed, convey large volumes of sediment and large woody debris, and cause extensive bank erosion. The 2013 flood was a debris flood. The options analysis is based on the 2020 updated hazard assessment parameters (BGC, October 9, 2020).
- **Design event:** The Town of Canmore's Engineering Design and Construction Guidelines (EDGC) (June 22, 2020) specify that stormwater infrastructure in Canmore is designed for the 1:100-year event and that for steep creek hazards, the design flood will be based on the risk reduction required following basin-scale and site-specific hazard and risk assessments and notes that most creeks will use a 100 to 300-year event (Table 2: Glossary of Terms in ToC EDCG guidelines (June 22, 2020)). The designs considered in the options comparison meet or exceed these standards. The total cost and cost-benefit ratio of designs sized for both the 100 to 300-year- and 1,000 to 3,000-year return period debris-flood scenarios are compared. A different design event may be appropriate for final design depending on the risk tolerance of stakeholders. Preliminary design parameters are based on maximum sediment volumes estimates and include (BGC, October 9, 2020):
  - 100 to 300-year sediment volume[2] = ~37,000 m^3
  - 100 to 300-year peak flow = ~50 m^3/s
  - 1,000 to 3,000-year sediment volume[1] = ~56,000 m^3
  - 1,000 to 3,000-year peak flow = ~110 m^3/s.

  At the preliminary design stage, the design input parameters could be changed to best estimates pending input from the ToC and QPD, although sediment volumes have little impact on the design of most debris-flood mitigation options except for the fan apex debris basin.

  Following Workshop 1, the 100 to 300-year return period debris flood was chosen as the design event as it more closely aligns to other stakeholder requirements for mitigation. For all mitigation options the requirements to mitigate the 1,000 to 3,000-year return period debris flood were considered in this options analysis report for comparison and

[2] BGC (October 9, 2020) reports both best estimate and maximum sediment volumes for each return period class, the values here are the maximum sediment volumes estimated for these return period classes.

completeness. Where there are significant differences in the design required to mitigate the higher return period, two options are presented for comparison. In some locations, the mitigation design did not differ significantly and therefore only one option that mitigates both return period events is presented.

- **Maintenance and post-event restoration**: Although specific maintenance requirements and restoration plans have not been defined at this stage, all options require periodic inspection, maintenance, and restoration following flood and debris-flood events. Operations and maintenance costs included in the lifecycle cost estimate are approximate and intended for options comparison and not to develop maintenance budgets. Restoration of the debris-flood mitigation structures following debris floods may include disposal of debris retained by structures or deposited in channels, and repair to structures and erosion protection, if needed. Design options that allow for substantial aggradation without the need for gravel removal were viewed favorably in the options comparison.
- **Ownership, access, environment:** The conceptual designs assume that all land is available to be used for construction or access to debris-flood mitigation structures. Potential for challenges related to permitting and land use are considered in the options comparison.
- **Geotechnical and topographic design parameters**: Geotechnical design parameters are assumed based on terrain interpretation from lidar-derived topography and aerial photographs. No subsurface conditions have been investigated for the mitigation designs as part of this scope of work. BGC conducted a test pitting program during the initial 2014 debris-flood hazard assessment (BGC, October 31, 2014). Based on the findings from test pitting, the mitigation options analysis assumes that soils on site are granular, including sand, gravel, cobbles, with some large boulders, and that the water table is typically below the deepest portion of all proposed channel options except in the immediate vicinity of the GCP. At this stage, bedrock (except where exposed at the surface downstream of the GCP) and groundwater are assumed to have no bearing on the proposed designs. BGC has not investigated the extent of underground coal mining adits and shafts and assumes that these workings (if present) will not interact with the proposed designs. Position coordinates, areas, alignments, and volumes are estimated based on the currently available LiDAR topography provided by McElhanney, flown September 2015. Further site investigations and surveying will be required to validate assumptions listed above and to complete final designs once a design is selected.
- **Risk transfer:** Risk transfer occurs when mitigation measures designed to reduce risk at one site affect risk at another location. Berms that prevent creek avulsion at one location transfer risk downstream along the channel because they increase the peak discharge and sediment volume that stays within the channel. The options comparison identifies options that transfer risk. Transferred risk must be addressed by additional downstream mitigation structures or tolerated by stakeholders if risk is within acceptable tolerance criteria.
- **Elements at Risk:** The following elements that require protection from debris floods were considered as the mitigation options were compared:
    - Existing residential development located primarily to the east of Three Sisters Creek on the active fan.

- Proposed development at TSMV (Drawing 01), located west of Three Sisters Creek.
- Proposed development at SCC located east of Three Sisters Creek beyond the distal end of Three Sisters Creek fan (Drawing 01), but in a zone of potential flooding.
- High voltage powerlines operated by AltaLink that are generally buried below surface at approximately 1.2 m below grade or shallower[3] and cross Three Sisters Creek in a pedestrian bridge located at the GCP outlet.
- Three Sisters Parkway that provides secondary emergency access into Canmore and crosses the distal end of the fan. The ToC has also indicated that there are some minor buried utilities present within the road right of way that were considered in the risk reduction benefit calculations.

[3] Burial depth of the transmission lines across the fan has been estimated by QPD at 1.2 m (email from Chris Ollenberger, QPD, personal communication, May 25, 2020). This depth is an estimated average and will need to be refined, with AltaLink's involvement, during future design stages, although it is known that such transmission lines are not conducive to deeper burial.

4. METHODOLOGY

4.1. Options Analysis Workflow

BGC used the following workflow, with input from QPD and other stakeholders, to work through the options analysis and arrive at a preferred mitigation system for the Three Sisters Creek fan (Figure 4-1).

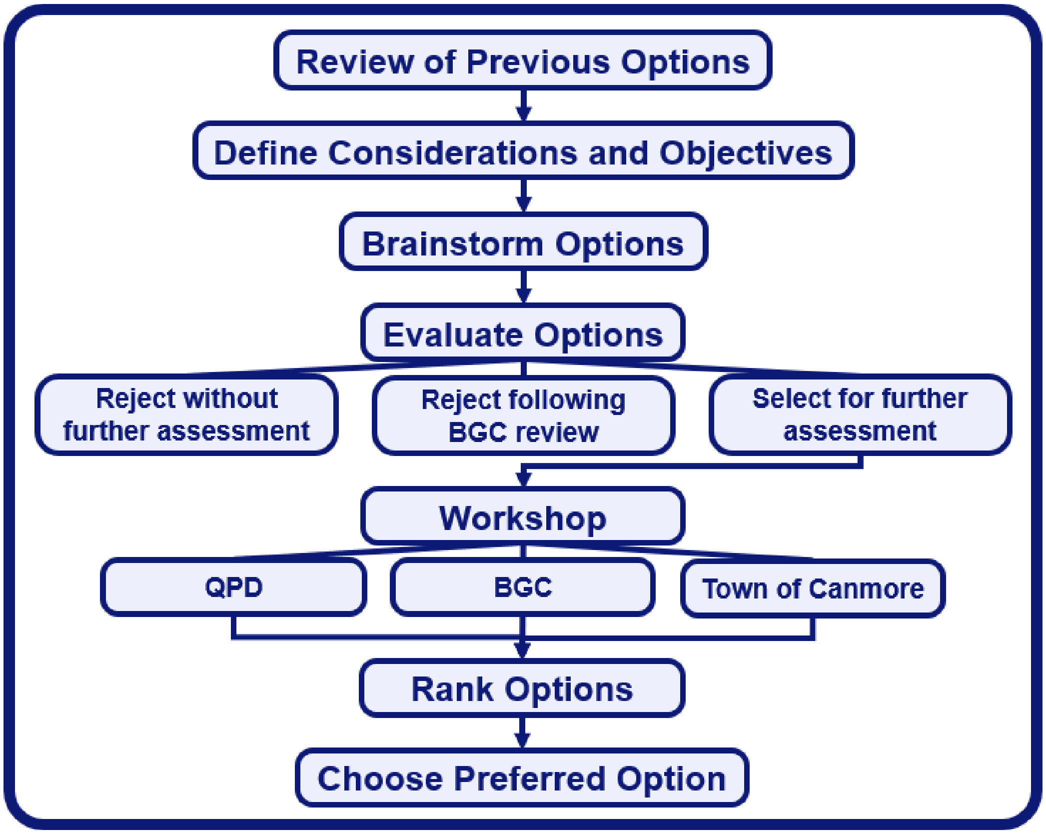

Figure 4-1. Flowchart showing workflow of options analysis. Review with other stakeholders was beyond the current scope of work.

1. **Review of previous options (Section 2)**: In light of the updated hazard report (BGC, October 9, 2020), previous reports and mitigation works were reviewed and collated.
2. **Define mitigation considerations and objectives (Section 3)**: Considerations and objectives were defined, accounting for local policy and client needs. These mitigation considerations were then used to define the design basis, constraints, and assumptions that go into developing the mitigation options.
3. **Brainstorm mitigation options (Section 5)**: A comprehensive list of mitigation options was compiled from previous reports and BGC's team deliberations.
4. **Evaluate options for further assessment (Section 5)**: The full list of mitigation options was categorized by area and status to condense the list to options meeting objectives and technical feasibility. This short-list of options was the basis for further assessment wherein conceptual level designs were created to define approximate dimensions, layouts, and lifecycle costs to facilitate option comparison.

5. **Workshop with QPD and the ToC (Section 5)**: Two workshops with QPD, the ToC and BGC in attendance were held to determine criteria and weightings for ranking of the mitigation option short-list.
6. **Rank options (Section 6)**: A short-list of options was ranked by chosen criteria and weightings from the workshop.
7. **Choose preferred mitigation system (Section 7)**: From the final ranking of the options with all stakeholder input, a preferred mitigation system was chosen.

This workflow generally follows the Kepner-Tregoe (KT) Method of problem analysis (Kepner & Tregoe, 1965). The KT Method is a model in which the "problem" is disconnected from the "decision". The KT Method uses three terms: problem, task, and approach. A situation analysis is used to identify the specific tasks and problems for the project. Examples of these terms applied to this project are given as follows:

- **Problem**: Without mitigation, debris floods will impact areas of the existing and proposed development on Three Sisters Creek fan.
- **Task:** Evaluate the proposed mitigation options that reduce risk of debris-flood impact to existing and proposed developments. The evaluation aims to identify the combination of mitigation options that optimizes the risk reduction benefit considering a broad range of factors that are important to the key stakeholders with the available funding.
- **Approach:** Reduce the list of all potential mitigation options to a subset of reasonable ones based on experience and judgment (those "selected for further assessment" (Section 5)). Analyze the "short-list" of options using factors and representative weightings defined in partnership with key stakeholders to arrive at a logical and defensible outcome.

4.2. Cost-Benefit Assessment

The inputs into the cost-benefit assessment used to determine a cost-benefit ratio are capital cost, operation and maintenance cost over a 50-year time period, and value of the mitigated risk (benefit). Capital cost and operation and maintenance cost[4] are combined into the lifecycle cost and presented as net present value (NPV). The mitigated risk value is determined based on the proportion of the economic and life-loss risk estimated by BGC (BGC, January 19, 2015) that is protected by the mitigation option. Economic risk includes the following parameters based off the risk assessment completed for the existing development (BGC, January 19, 2015):

- Building risk: Annualized cost of building damage and business revenue loss, assuming the building risk is spread evenly across all residential buildings in the development.
- Road risk: Annualized cost of road damage and road closure economic cost for TSP as it is the secondary access into Canmore if the TransCanada Highway were to be rendered impassable.

To facilitate comparison of risk-reduction benefits with mitigation options costs, a monetized value of a statistical life (VSL) was used. The Canadian Cost-Benefit Analysis Guide for Regulatory Proposals (Treasury Board of Canada, 2007) recommends the use of $6.11 Million in 2004 dollars

[4] Operation and management costs for a 50-year lifecycle of a mitigation option were calculated in net present value terms using a 4% discount rate as suggested by Alberta Transport (2017).

as the VSL. Adjusting for inflation from 2004 to 2020, this translates to a VSL of $7.9 Million. Therefore, in this analysis a VSL of $7.9 Million CAD was used.

BGC estimated the proportion of the economic and life loss risk reduction based off of the numerical modelling results completed by BGC (BGC, October 9, 2020). The resultant mitigated risk parameters are summed to determine the total benefit of the option. The benefit is divided by the lifecycle cost to calculate the cost-benefit ratio. The cost-benefit ratio in this analysis does not include added benefit from protecting AltaLink infrastructure or the proposed developments as the economic and life-loss risk has not been calculated for these.

5. MITIGATION OPTIONS

5.1. Overview

BGC developed a list of 25 potential debris-flood mitigation options at Three Sisters Creek based on the preliminary design report prepared by SweetCroft (April, 2015) and additional ideas proposed by members of BGC's team through brainstorming. This initial list of options is divided into five zones based on the area of the fan where they would be implemented (Figure 5-1):

A. **Fan Apex**
B. **Upper Channel**
C. **Golf Course Pond**
D. **Lower Channel**
E. **Three Sisters Parkway Crossing.**

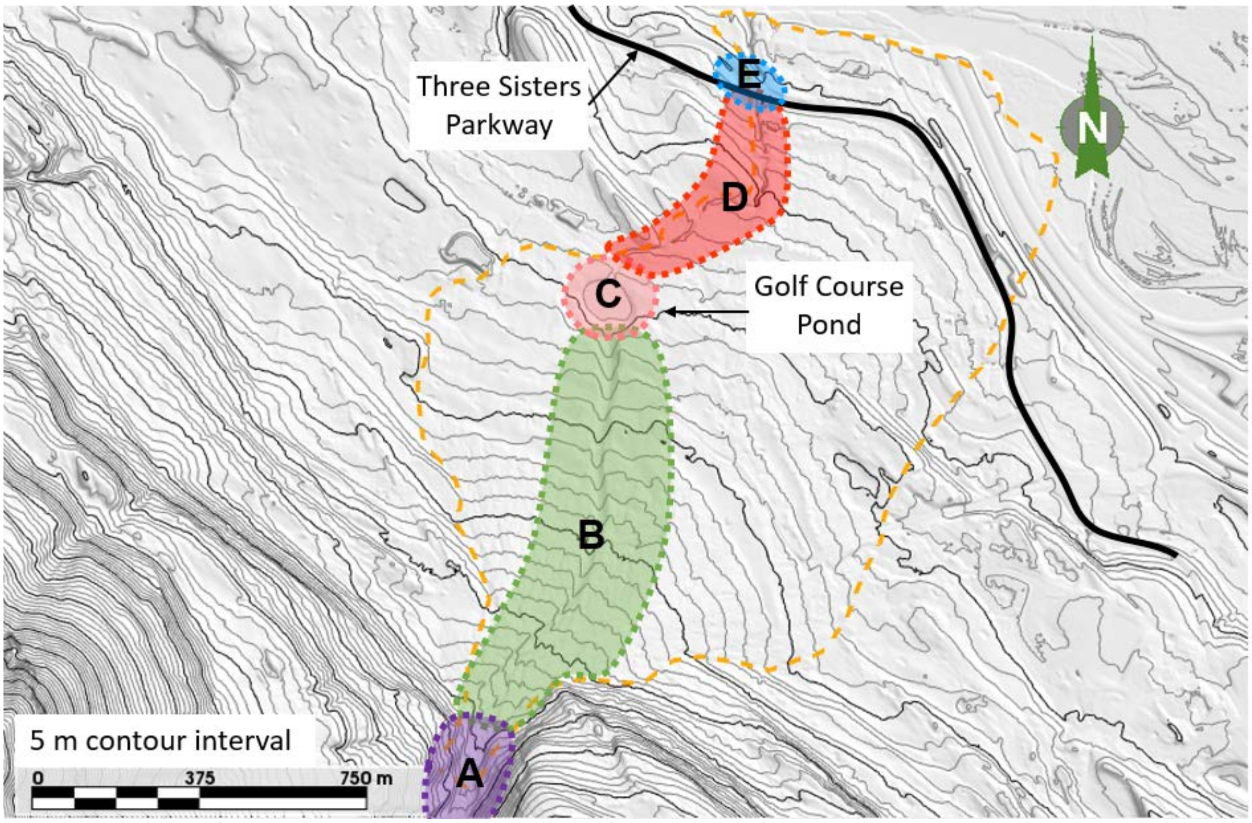

Figure 5-1. Zones of mitigation shown in shaded areas. Three Sisters Creek fan is shown with dashed orange line. Topography based on lidar flown in September 2015.

The hazard and mitigation objective(s) in each zone were outlined along with the various mitigation options to reach the objective(s). Each option was then categorized into one of the following groups:

- **Rejected without further assessment**: Of the initial 25 options, four options were rejected by BGC based on a preliminary conceptual review because they are interpreted to be either ineffective at reducing debris-flood risk, or unlikely to be feasible or reasonable to permit and construct. These options are not illustrated on Drawing 02.

- **Rejected following BGC review**: The remaining 21 options were assessed by BGC using the KT Method, using factor weights and scores selected by BGC. Six options that scored low in BGC's assessment were rejected. Design sketches and cost estimates were not developed for options rejected following BGC review. These options are illustrated on Drawing 02 and include the suffix (R) to indicate that the option was rejected following review.
- **Selected for further assessment**: Fourteen options were assessed by BGC and carried forward to the more detailed options analysis that involved QPD and the ToC. BGC developed conceptual level design sketches, cost estimates (Appendix B), and cost-benefit ratios for these options.

For those options that were selected for further assessment, the advantages, disadvantages, costs, and benefits were assessed. The costs and benefits of each option were assessed individually as though the option would be implemented in isolation. The final mitigation system will be a combination of multiple options with elements at each area of the fan (Figure 5-1). Section 6.4 provides a recommendation and discussion on the combination of mitigation elements to achieve the best cost-benefit and risk reduction on the fan.

In addition to the mitigation options presented, a possible path forward would be to not implement any new mitigation measures (baseline conditions). Baseline debris-flood consequences and risk to existing development are described in BGC's updated risk assessment (January 11, 2018). This option is included in the KT and cost-benefit ratio comparisons as a baseline for comparison for the mitigation systems that include elements across the full Three Sisters Creek fan. This option was rejected without further assessment as impacts to the proposed TSMV development are not acceptable to QPD and impacts to existing development are not acceptable to the ToC and therefore this option does not meet overall design objectives.

At particular zones, a do-nothing option is included as a comparison to other options and the advantages and disadvantages of doing nothing at that particular area are discussed in each zone.

In the subsequent sections, each mitigation zone is introduced along with the mitigation options identified. All mitigation options are described and listed as one of the above three categories (rejected without further assessment, rejected following BGC review, or selected for further assessment). For those options selected for further assessment, the advantages and disadvantages are discussed. Each subsection concludes with a summary comparison of the mitigation options in the zone and their associated costs and benefits.

5.2. Fan Apex Options

5.2.1. Mitigation Objectives

Three Sisters Creek enters the fan through a valley incised several tens of meters into Pleistocene (the last 2.6 Million years to 12,000 years ago) sediments. Downstream of the fan apex, Three

Sisters Creek is poorly confined and numerical modelling results indicate that debris floods may avulse to the east. Shallow overland flow extends into the existing residential development down to TSP, along Three Sisters Boulevard, and to the TransCanada Highway as shown in Drawing 01.

Avulsions downstream of the fan apex may occur during debris floods due to the loss of channel cross-sectional area associated with aggradation that reduces the channel capacity. For this reason, mitigation at the fan apex or along the upper channel is recommended. If mitigation at the fan apex is selected, the mitigation objectives are to:

i. Provide capacity for sediment deposition
ii. Reduce the peak discharge entering the fan during a debris flood.

5.2.2. Mitigation Options

Two mitigation options were considered at the fan apex (Table 5-1). The following sections describe these mitigation options in more detail.

Table 5-1. Fan apex mitigation options and options analysis status.

Option	Description	Option Analysis Status
Option A-1	Flood Attenuation Basin at Fan Apex	Rejected without further assessment
Option A-2	Debris Retention Basin at Fan Apex	Selected for further assessment

5.2.2.1. Option A-1 – Flood Attenuation Basin at Fan Apex

A flood attenuation basin at the Three Sisters Creek fan apex could capture sediment and attenuate (lower) the peak discharge exiting the basin to a level that can pass downstream culverts and bridge openings (Figure 5-2). For effective attenuation a large (several hundred thousand cubic meter) basin is needed. It is assumed that such a structure would need to be of a similar scale to the barrier proposed at Cougar Creek. The proposed Cougar Creek barrier is 30 m high, with an estimated $33 Million capital cost.

This option was **rejected without further assessment** at Three Sisters Creek because it is expected that the design objectives can be achieved at much lower capital and maintenance cost through a combination of the other options considered in this assessment. This option would also be very operationally intensive as sediment accumulation would require regular clean outs. Finally, it would be classified as a dam by the Alberta Dam and Canal Safety Directive (Alberta Government, 2018) requiring an in-depth and lengthy approval process.

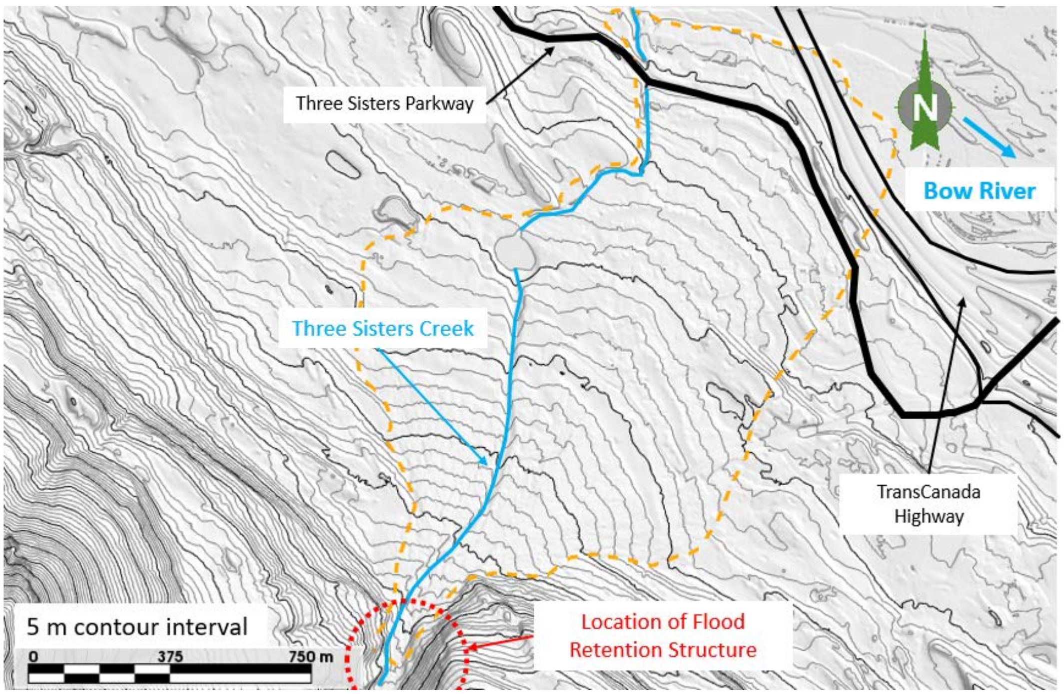

Figure 5-2. Option A-1: Schematic illustration flood retention structure at fan apex. The location of the flood protection structure is shown; it does not represent the size or layout that would be required. Topography is based on lidar flown in September 2015.

5.2.2.2. Option A-2 – Debris Retention Basin at Fan Apex

A large debris retention barrier at the Three Sisters Creek fan apex could be designed with an outlet structure that allows clear-water floods to pass the barrier, while retaining sediment and large woody debris.

This option was **selected for further assessment.** By capturing sediment, the barrier reduces the likelihood of flows overtopping the channel downstream due to the reduction in aggradation that reduces the channel cross-sectional area (and therefore capacity) and increase in downcutting of the channel when starved of sediment. However, the existing channel has insufficient capacity to pass the clear-water flow and therefore some residual risk would remain regardless of the volume of retained sediment. The clear-water flow will also erode banks and exceed the TSP culvert capacity. Therefore, additional erosion protection and increased channel capacity are required downstream of the barrier to meet the risk reduction objectives (Section 3).

Conceptual Design

Sediment from the basin would need to be removed periodically. Inspections and post event maintenance would also be required. The following describes the conceptual design (Figure 5-3, Drawing 02):

- A 9 m high barrier is needed to retain the 100 to 300-year sediment volume (37,000 m^3), and an 11 m high barrier is needed to retain the 1,000 to 3,000-year sediment volume (56,000 m^3), including a minimum of 0.6 m of freeboard.
- A 7 m crest width and 2H:1V side slopes were assumed.
- 15,000 m^3 to 25,000 m^3 of fill is needed to construct the barrier, depending on the design event selected.
- A 6% sediment deposition slope upstream of the barrier was assumed, which is one-half of the typical fan slope (12%) (Piton, 2016). If this option were to be chosen for preliminary design, the sediment deposition angle would need to be specified with additional analysis.
- A vertical slot outlet from creek level to barrier crest (not shown in figure) was assumed including steel grillage across the opening to restrict passage of woody debris. The vertical slot allows typical creek flows to pass the barrier during and after the debris flood.
- Riprap erosion protection covers the upstream face of the barrier.
- Grouted stone pitching defines the channel through the barrier and is placed on the barrier faces that are parallel to the channel, to prevent erosion in areas of high velocity flow.

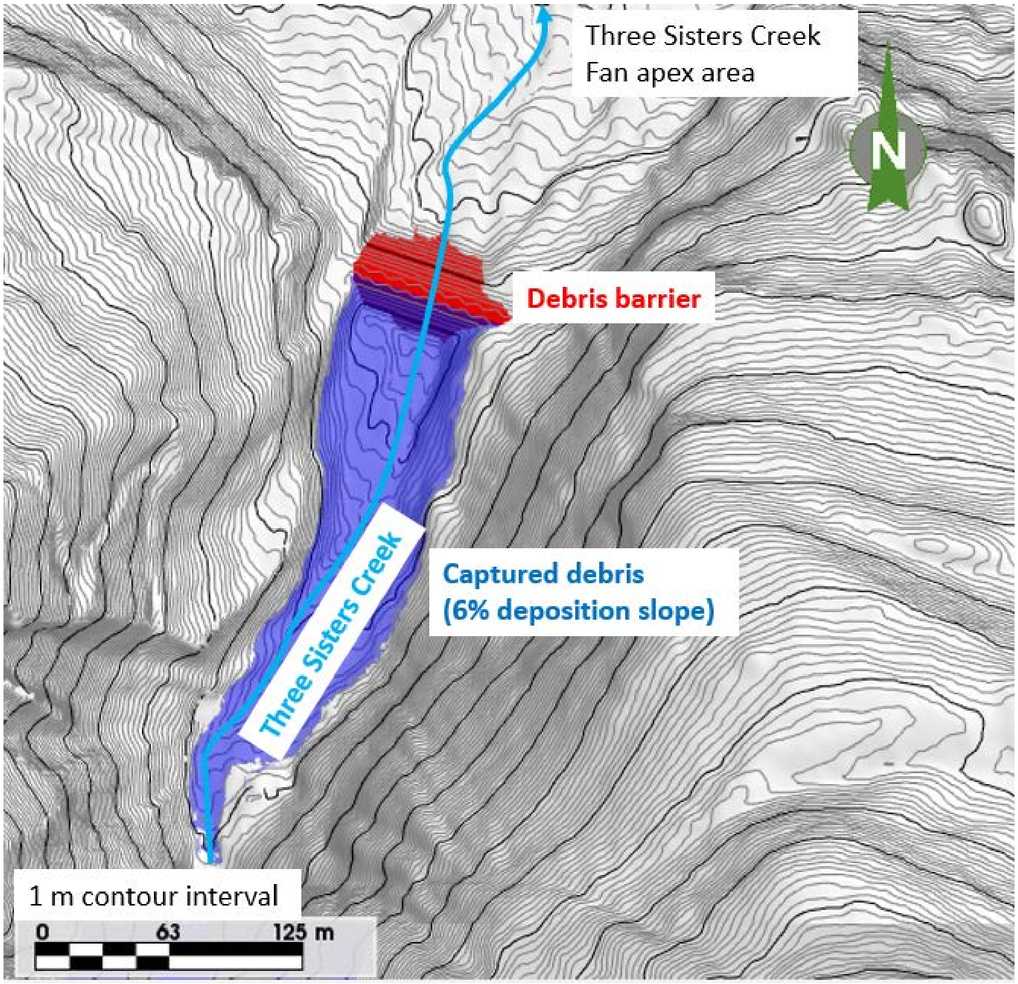

Figure 5-3. Option A-2: Schematic illustration of debris retention barrier at fan apex. Barrier shape and location may change during preliminary design. Topography based on lidar flown in September 2015.

Cost Estimate

The estimated capital cost of the debris basin is $4.9 Million for a 100 to 300-year return period design event, and $6.1 Million for a 1,000 to 3,000-year return period design event. The operation and maintenance costs (NPV) over the 50-year project lifecycle of the structure are estimated to be $800,000 for either return period (Appendix B). Combined, the total mitigation lifecycle cost ranges from $5.7 Million to $6.9 Million (50-year NPV for the 100 to 300-year and 1,000 to 3,0000-year return period design events, respectively).

Risk-Reduction Benefit

BGC estimates the risk-reduction benefit of a debris retention basin at the fan apex ranges from $3.6 Million (100 to 300-year) to $4.2 Million (1,000 to 3,000-year). This estimate assumes that the debris retention basin reduces building risk and life loss risk to existing development by 25 to 50% for the return periods considered (Section 4.1.1) because it removes sediment that originates from the watershed but the water that passes through the basin would still cause damage downstream. It is assumed that it does not reduce risk to TSP.

Cost-Benefit Ratio

The cost-benefit ratio for the debris basin is 0.62 for the 100 to 300-year return period design event and 0.61 for the 1,000 to 3,000-year return period design event.

Advantages and Disadvantages

The primary advantage of this option is that it retains sediment while allowing the clear-water portion of the debris flood to pass and continue downstream. For this reason, the size of the basin required is significantly reduced compared to the flood attenuation basin option.

The primary disadvantages of this option are the high initial capital cost to design and construct the basin, and the ongoing need for maintenance and sediment removal so that the basin has sufficient sediment storage capacity. As the basin is located at the fan apex, it would be constructed inside the Bow Valley Wildland Provincial Park (BVWPP) (Drawing 02) leading to significant permitting and approval requirements. The location would also necessitate construction and maintenance of access roads to enable operations and maintenance works over the lifecycle of the structure through a wildlife corridor. Further, as the basin does not reduce the clear-water flow volume or velocity, additional mitigation measures are still required downstream.

5.2.3. Summary Comparison

Two mitigation options were considered at the fan apex. Of these options, the flood attenuation basin (Option A-1) was rejected without further assessment as it is expected that the design objectives can be achieved at much lower capital and maintenance cost through a combination of the other options considered in this assessment. Further, this option would be very operationally intensive and likely require an in-depth and lengthy approval process.

A debris retention basin (Option A-2) was selected for further assessment. This option achieves the first mitigation objective to provide capacity for all or some sediment deposition; however, it does not reduce the peak discharge entering the fan during a debris flood and therefore additional downstream mitigation works would still be recommended.

BGC recommends that the basin be included in the detailed options analysis and compared with other options in the upper channel to determine which mitigation option(s) achieve the highest risk reduction while optimizing the available funding and other stakeholder priorities.

5.3. Upper Channel Options

5.3.1. Mitigation Objectives

In the upper channel, Three Sisters Creek has multiple avulsion points on the east bank. These avulsion paths extend downstream into the existing residential development with shallow overland flow extending downstream to TSP, along Three Sisters Boulevard, and to the TransCanada Highway (BGC, October 9, 2020). Upstream of the GCP, localized overland flow west of Three Sisters Creek channel that intersects the proposed TSMV is possible in the 100 to 300-year and greater return period debris floods. This section of Three Sisters Creek between the fan apex and the GCP is also susceptible to bank erosion due to the non-cohesive, granular material that comprises the banks. BGC (October 9, 2020) shows the extent of likely bank erosion corridors for different return periods and as witnessed in the 2013 event.

In the upper channel, the mitigation objectives are to:

i. Reduce the potential for avulsion and overland flow east of the main Three Sisters Creek to impact the existing residential development and proposed SCC development
ii. Reduce potential for avulsion and overland flow west of the main Three Sisters Creek to impact the proposed TSMV development

5.3.2. Mitigation Options

Six mitigation options were considered to improve channel conveyance and limit avulsion potential in the upper channel (Table 5-2). The options are described further in the following sections.

Table 5-2. Upper channel mitigation options and options analysis status.

Option	Description	Option Analysis Status
Option B-1	Overflow Channel through Existing Development	Rejected without further assessment
Option B-2	Flood Relief Channel Parallel to Three Sisters Creek	Rejected without further assessment
Option B-3	Revegetation of Channel Banks	Rejected without further assessment
Option B-4	East Apex Deflection Berm	Selected for further assessment
Option B-5	Wide Channel and Floodplain	Selected for further assessment
Option B-6	In-Channel Sedimentation Traps	Rejected following BGC review

5.3.2.1. Option B-1 – Overflow Channel Through Existing Development

An overflow channel could be constructed to convey flow from Three Sisters Creek along the most likely avulsion path to the east through existing residential development. The overflow channel could direct flow and sediment from the creek through the existing residential development, under TSP and TransCanada Highway to Bow River (Figure 5-4).

This option was **rejected without further assessment** because it is unlikely to be feasible to permit and construct due to conflicts with landowners and utilities, and it is likely to be more expensive (many tens of millions of dollars) than other options that were considered by BGC. Moreover, it is very difficult to select a pre-determined proportion of water and debris for design of the bypass channel, and there is the possibility that it becomes the new channel with 100% of the flow.

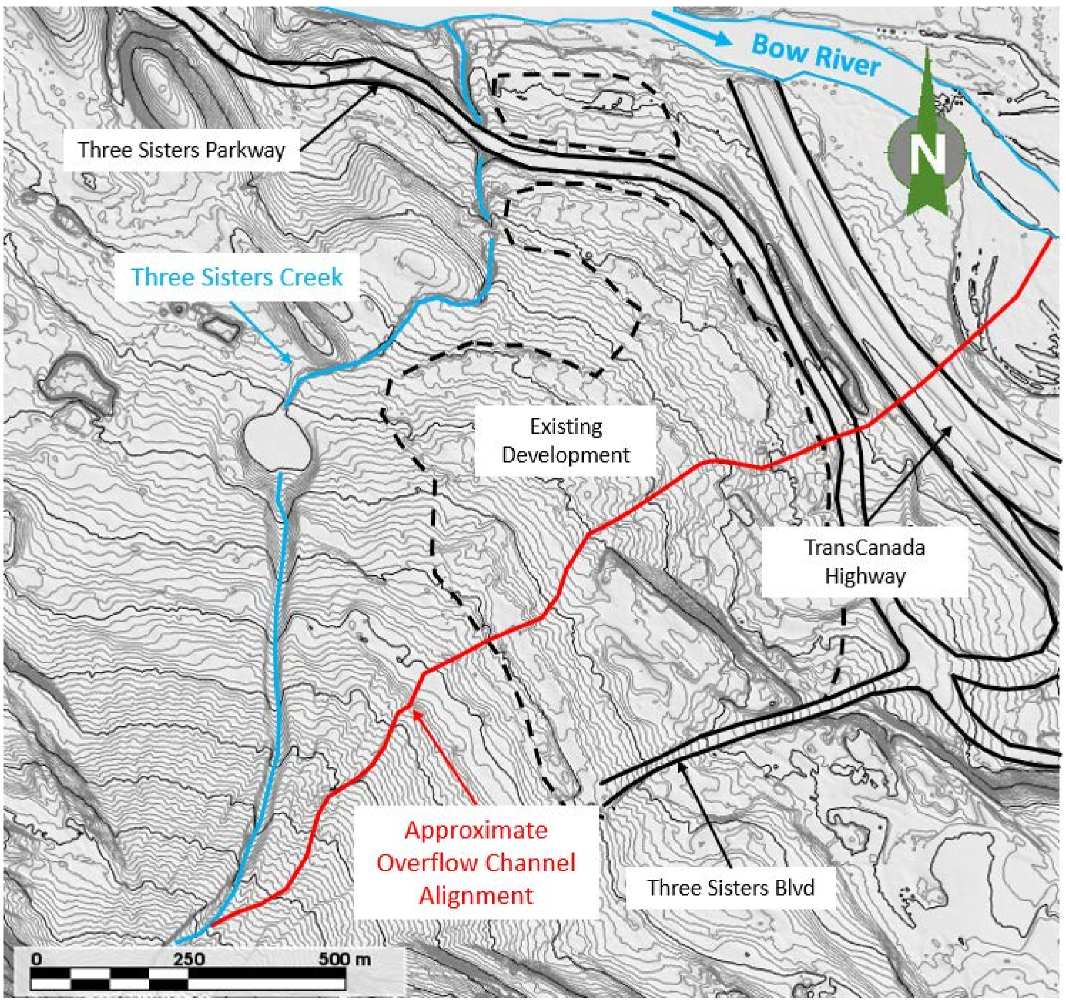

Figure 5-4. Option B-1: Schematic illustration of overflow channel through existing development. The approximate alignment is shown in red. This option was rejected without further assessment. Topography based on lidar flown in September 2015, contour interval is 1 m.

5.3.2.2. Option B-2 – Flood Relief Channel Parallel to Three Sisters Creek

A flood relief channel could be constructed parallel to and offset from Three Sisters Creek to convey water and sediment that overtops the existing channel. The flood relief channel would have multiple entry points that are separated by a low sill that is overtopped during a flood (Figure 5-5). The relief channel could be east or west of the main channel, with the east side being preferred due to the higher avulsion potential and available space on this side of the channel.

This option was **rejected without further assessment** because it is expected to be expensive compared to other options, and in BGC's opinion is unlikely to be effective. Narrow, straight channels have performed poorly during previous debris floods in Bow River Valley, because they lead to deep flow depth, excessive bank erosion, lateral channel migration and increased avulsion potential. Moreover, they may require new bridges or culverts. Similar to Option B-1, it is also very challenging to assign a specific discharge to descend in the bypass channel versus the main channel.

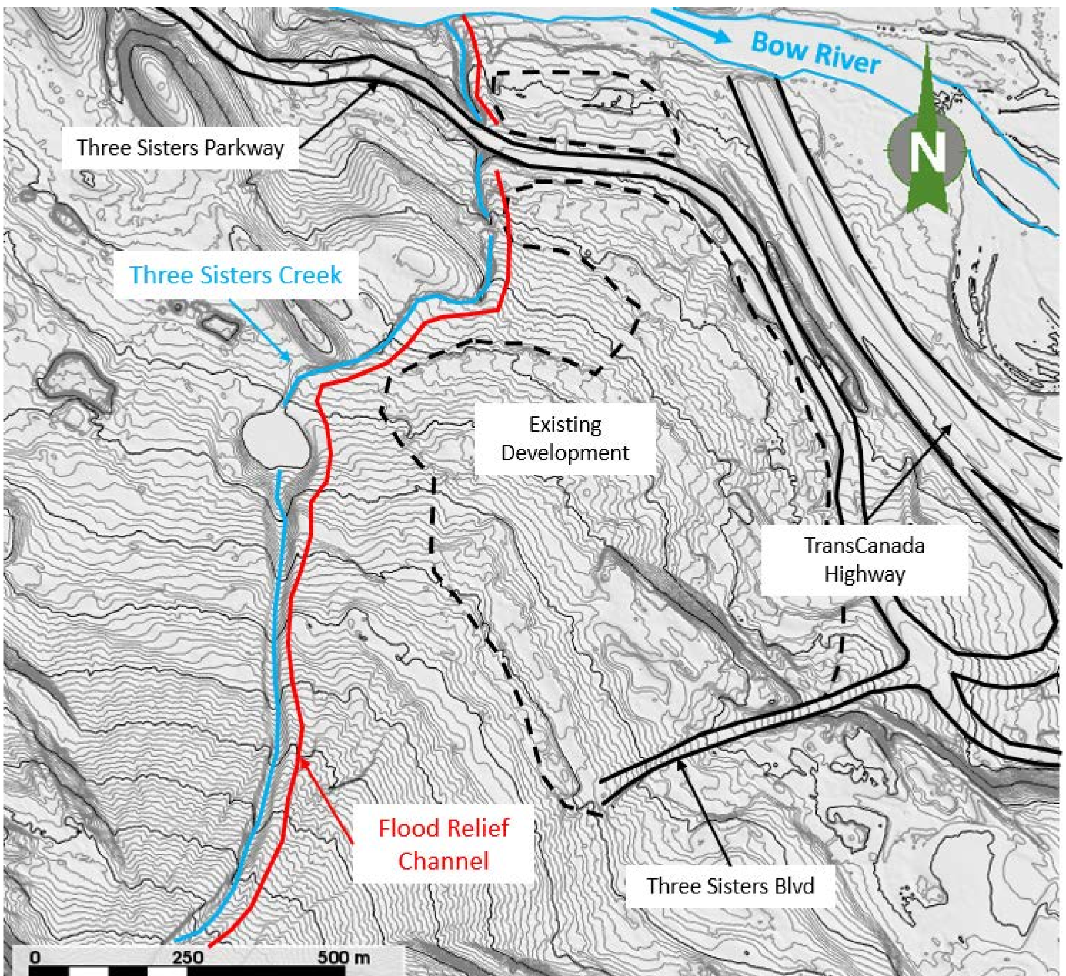

Figure 5-5. Option B-2: Schematic illustration of flood relief channel parallel to Three Sisters Creek. The approximate alignment is shown in red. This option was rejected without further assessment. Topography based on lidar flown in September 2015, contour interval is 1 m.

5.3.2.3. Option B-3 – Revegetation of Channel Banks

Shrubs and grasses could be planted along the channel banks between the fan apex and the GCP as a bioengineering approach to bank erosion protection (Figure 5-6).

This option was **rejected without further assessment** because this type of vegetation is not effective at preventing bank erosion during a debris flood and is likely to suffer considerable damage during the next flood or debris flood. It may be desirable for aesthetic or environmental reasons, and it may be included in the final design for this purpose but is insufficient bank erosion protection without additional mitigation works.

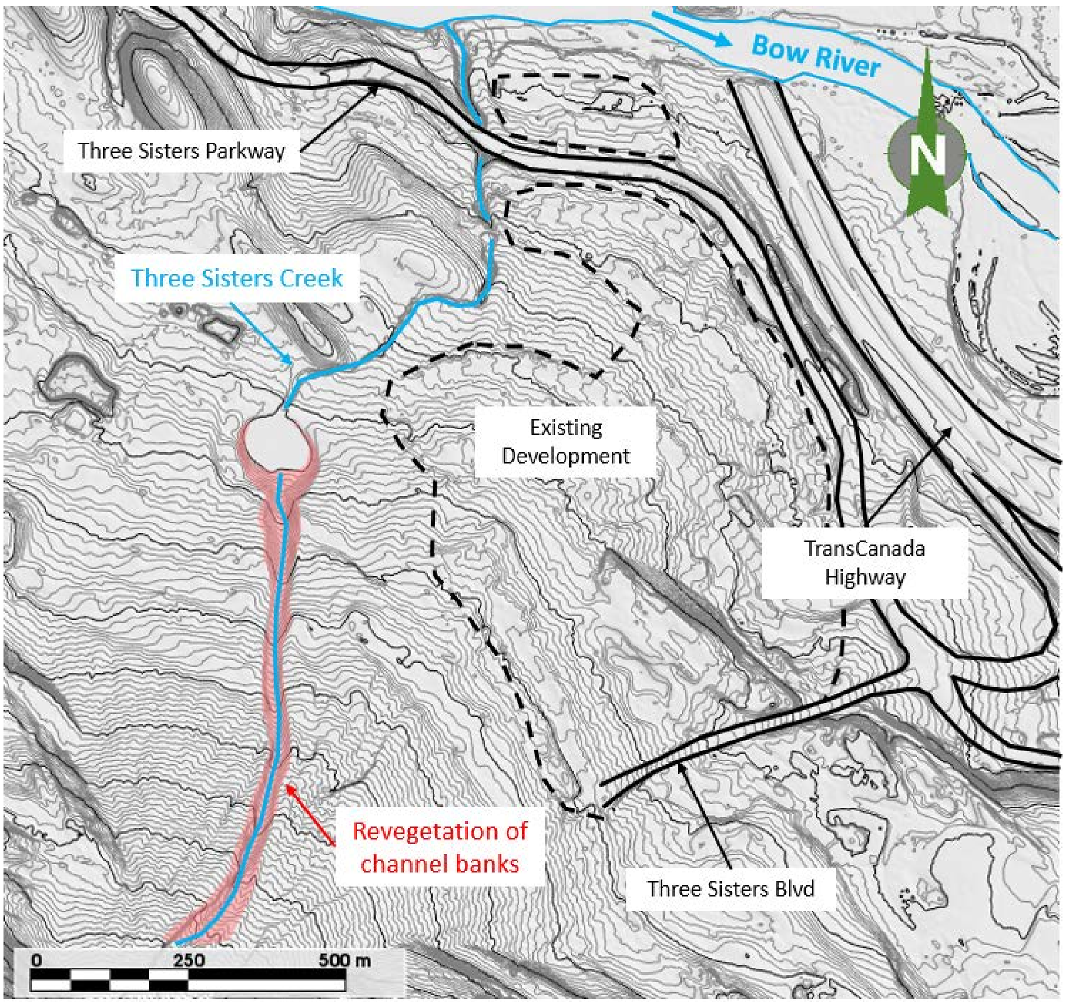

Figure 5-6. Option B-3: Schematic illustration of revegetation of channel banks. Topography based on lidar flown in September 2015, contour interval is 1 m.

5.3.2.4. Option B-4 – East Apex Deflection Berm

A deflection berm could be constructed across the most likely avulsion path from the upper channel on the east bank of Three Sisters Creek. This berm, if functioning as designed, would protect approximately the southeastern portion of the existing development from debris-flood impacts. SweetCroft (April, 2015) described two potential alignments for the deflection berm: one that extends within the BVWPP boundary and wildlife corridor (combined with east-west setback berms in Option B-5 (Section 5.3.2.4)), and one that is located outside of the park boundary and wildlife corridor (Option B-4).

The east apex deflection berm (Option B-4) was **selected for further assessment.** Two locations are presented as sub-options; one outside of the wildlife corridor and one within the wildlife corridor. The conceptual design, cost estimate, risk-reduction benefit and cost-benefit ratio are equal for each location. Figure 5-7 and Drawing 02 show the location outside the wildlife corridor.

Conceptual Design

The following describes the conceptual design:

- The berm location, layout, and dimensions are based on the design proposed by SweetCroft (April, 2015).
- The berm is 200 m long and typically 4 m high, with a 2H:1V slope on the creek side face, and 4H:1V slope of the downstream face.
- The creek side face is protected from erosion with grouted stone pitching, and downstream face is vegetated with grass.
- The berm height ties in above the top of the paleochannel and can divert 100 to 300-year and 1,000 to 3,000-year return period flows.
- Repair of erosion protection may be needed after the berm is impacted.

Cost Estimate

The estimated capital cost of the east apex deflection berm is $2.1 Million. The operation and maintenance costs (NPV) over the 50-year project lifecycle of the structure are estimated to be $100,000 for either return period (Appendix B). Combined, the total mitigation lifecycle cost of this option is $2.2 Million (50-year NPV).

Risk-Reduction Benefit

BGC estimates the risk-reduction benefit of a deflection berm at this location is $2.7 Million. This estimate assumes that the deflection berm reduces building risk and life loss risk to existing development by approximately 33% for the return periods considered (Section 4.1.1) because it deflects flows that could impact the southern half of the existing development but there is the potential for it to be outflanked. It further assumes that risk to TSP is increased by 25% compared to baseline conditions due to the increase in peak discharge that reaches the culvert.

Cost-Benefit Ratio

The cost-benefit ratio for the deflection berm is 1.2.

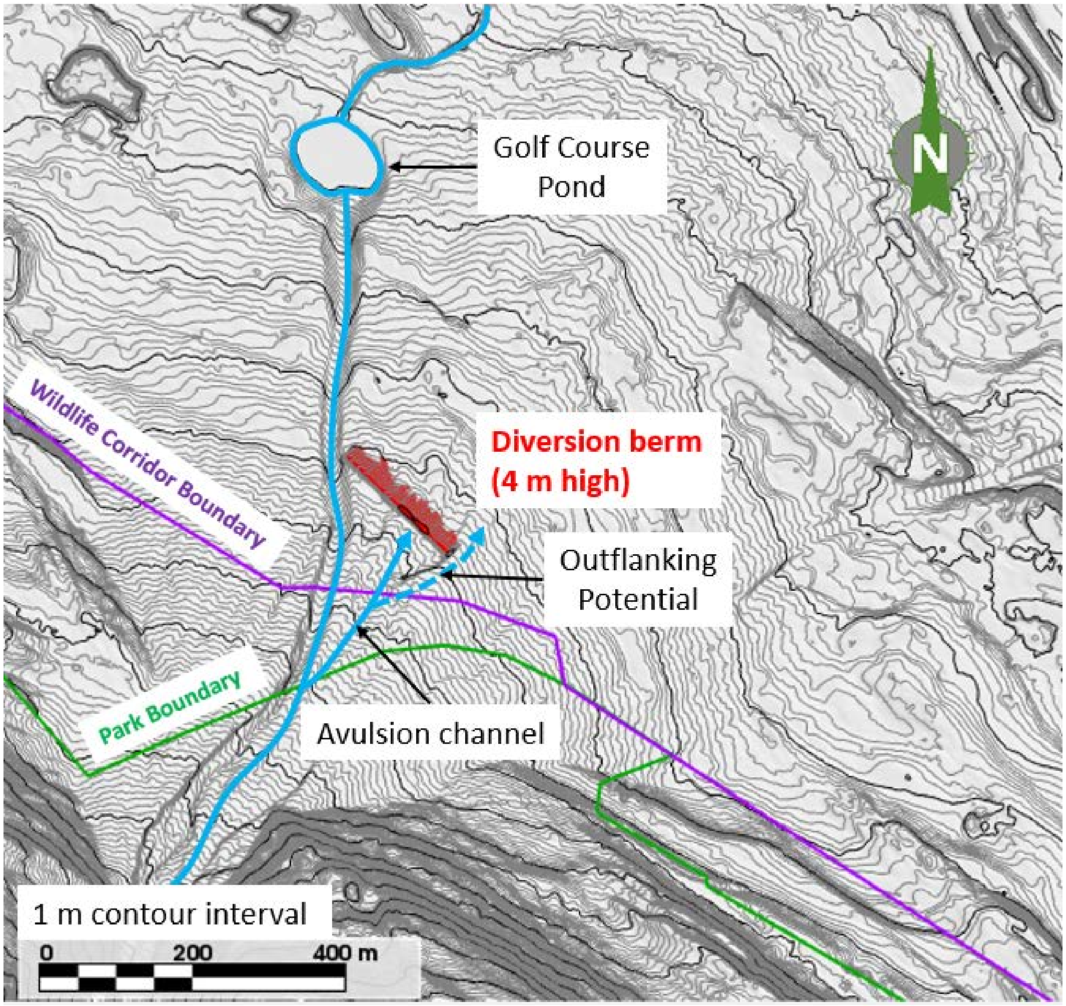

Figure 5-7. Option B-4: Schematic illustration of east apex deflection berm. Berm alignment is approximate, not for design; shape and location may change during preliminary design. Topography based on lidar flown in September 2015.

Advantages and Disadvantages

The primary advantage of this option compared to Option B-5 is that, given the location outside of the wildlife boundary and BVWPP (Drawing 02), it can avoid land tenure conflicts and may be relatively easier to acquire permits and approvals.

The primary disadvantage of this option is that it would increase the discharge in the main channel downstream because the flow that would have been lost through an avulsion would now remain in the main channel. This is a common disadvantage of all mitigation measures that protect against avulsions. Although the location outside of the wildlife corridor is favourable from a permitting perspective, the location within the wildlife corridor is favourable from a technical perspective because sediment may aggrade in the avulsion-channel transected by the berm, which could lead to outflanking at the south end of the berm. Finally, it is anticipated that sediment removal from the upstream side of the deflection berm, and repairs would be required over the operational lifecycle of the structure.

5.3.2.5. Option B-5 –Wide Channel and Floodplain

Low berms parallel to, and setback from, the main channel between the fan apex and GCP could be constructed 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. This option integrates the east apex deflection berm that extends into the BVWPP boundary proposed by SweetCroft (April, 2015). This option was **selected for further assessment.**

Conceptual Design

The following describes the conceptual design (Figure 5-8, Drawing 02):

- The berms are 1.5 m high and were estimated from numerical model results (100 to 300-year and 1,000 to 3,000-year debris floods) from BGC (October 9, 2020) plus a minimum of 0.6 m of freeboard. Depending on the final channel configuration chosen, the berm height may be lowered.
- The berms crest widths are 4 m with inside and outside slopes at 2H:1V. Erosion protection in the form of stone pitching, rip rap and, on the east berm, a launching apron in select locations is required as the channel would be expected to migrate towards the berms in places.
- The floodplain width between the two berms is approximately 100 m to 135 m, which is based on a minimum setback from the east bank crest of 75 m and correlates with the 95th percentile bank erosion assessed as part of the 2020 hazard assessment (BGC, October 9, 2020) The west berm is near the existing channel position to preserve more space for future development. Alternative alignments for the berms could be considered but may require additional erosion protection if within the assessed bank erosion corridor. The option presented herein maximizes the space for development while optimizing the erosion protection costs. The setback location of the east berm does not increase the hazard to existing development east of the creek.
- The east berm extends from the steep slope near the fan apex to the GCP and is partially within the BVWPP and wildlife corridor boundary.
- The west berm extends from near the wildlife corridor boundary, where the bank height decreases, to the GCP.

Cost Estimate

The estimated capital cost of the setback berms and wide floodplain is $4.8 Million. The operation and maintenance costs (NPV) over the 50-year project lifecycle of the structures are estimated to be $100,000 for either return period (Appendix B). Combined, the total mitigation lifecycle cost of this option is $4.9 Million (50-year NPV).

Risk-Reduction Benefit

BGC estimates the risk-reduction benefit of this option is $7.9 Million. This estimate assumes that the setback berms and wide floodplain reduce building risk and life loss risk to existing development by approximately 95% for the return periods considered (Section 4.1.1). It further assumes that risk to TSP is increased by 50% compared to baseline conditions due to the increase in peak discharge that reaches the culvert.

Cost-Benefit Ratio

The cost-benefit ratio for the deflection berm is 1.6.

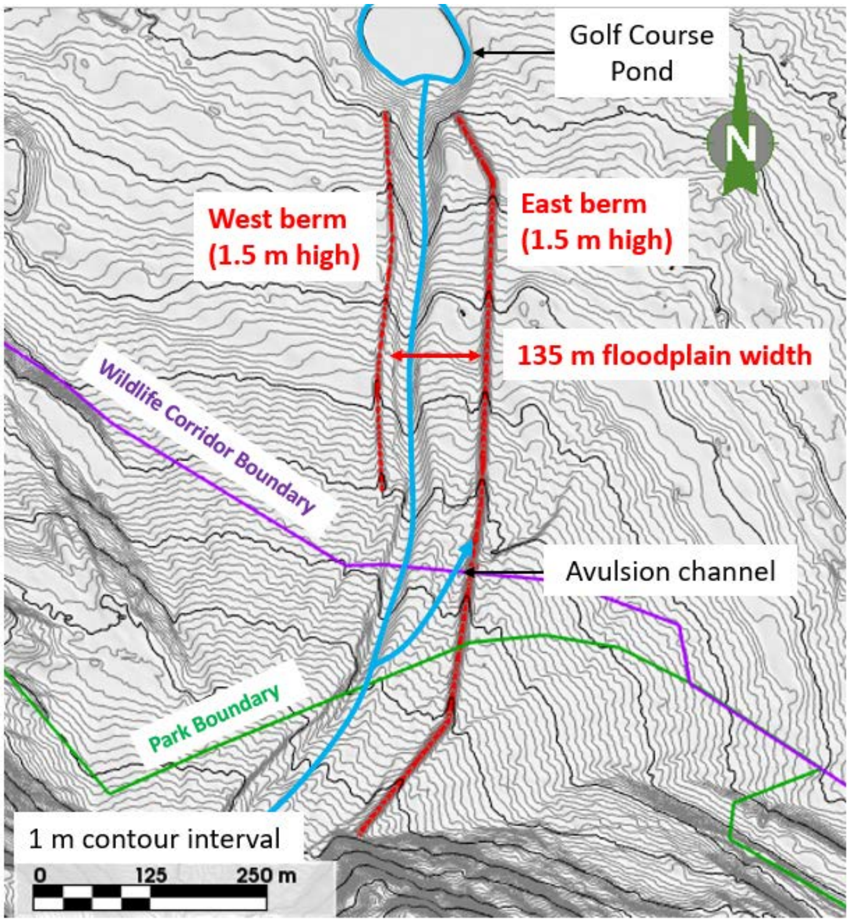

Figure 5-8. Option B-5: Schematic illustration of east and west setback berms to create a wide floodplain. The west berm does not extend upstream as far as the east berm as it ties into the higher banks on the west side. Berm alignments are approximate; shapes and locations may change during preliminary design. Topography based on lidar flown in September 2015.

Advantages and Disadvantages

The primary advantages of the setback berms and wide floodplain are that this option protects existing and proposed development on each side of the creek, requires less maintenance effort and cost than other sediment retention and bank erosion protection options because sediment removal is not required, and the berms are rarely impacted directly by flows. The area between the berms could be developed into recreational land with trails and vegetation and be equipped with purposefully integrated tree islands (dead wood buried into the channel stratum) and boulder islands that reduce flow velocities simulating a natural stream environment.

The primary disadvantage of the setback berms and wide floodplain is that the berms protect against avulsion in the reach upstream of the GCP but increase the discharge that continues downstream relative to an unprotected scenario in which upstream avulsions decrease discharge downstream.

5.3.2.6. Option B-6 – In-Channel Sedimentation Traps

SweetCroft (April, 2015) proposed rock sedimentation traps installed in the Three Sisters Creek upper channel to capture sediment during a debris flood to reduce the sediment volume that is transported downstream and BGC also considered sedimentation traps constructed with materials other than rock, such as concrete or wood (Figure 5-9, Drawing 02).

This option was **rejected following BGC review** due to the following considerations:

- Traps will not have sufficient storage capacity for the anticipated sediment volumes.
- Traps infill during annual flows and require annual sediment removal in order to be open and available to capture sediment during a debris flood. Regular sediment removal requires environmental permits and constitute an on-going expense.
- Trap performance is governed by construction type: if constructed with class 2 riprap, it is very likely that the sedimentation trap itself would be entrained by a debris floods; if constructed of a stable material (e.g., class 4 riprap or concrete), it will tend to force flows against the channel banks, leading to bank erosion and outflanking.
- Erosion protection is required on the downstream side of sedimentation traps to prevent fluvial erosion from developing a plunge pool and undermining the structure over time.
- Water captured in sediment traps may infiltrate into the ground and could potentially increase groundwater levels in adjacent areas.

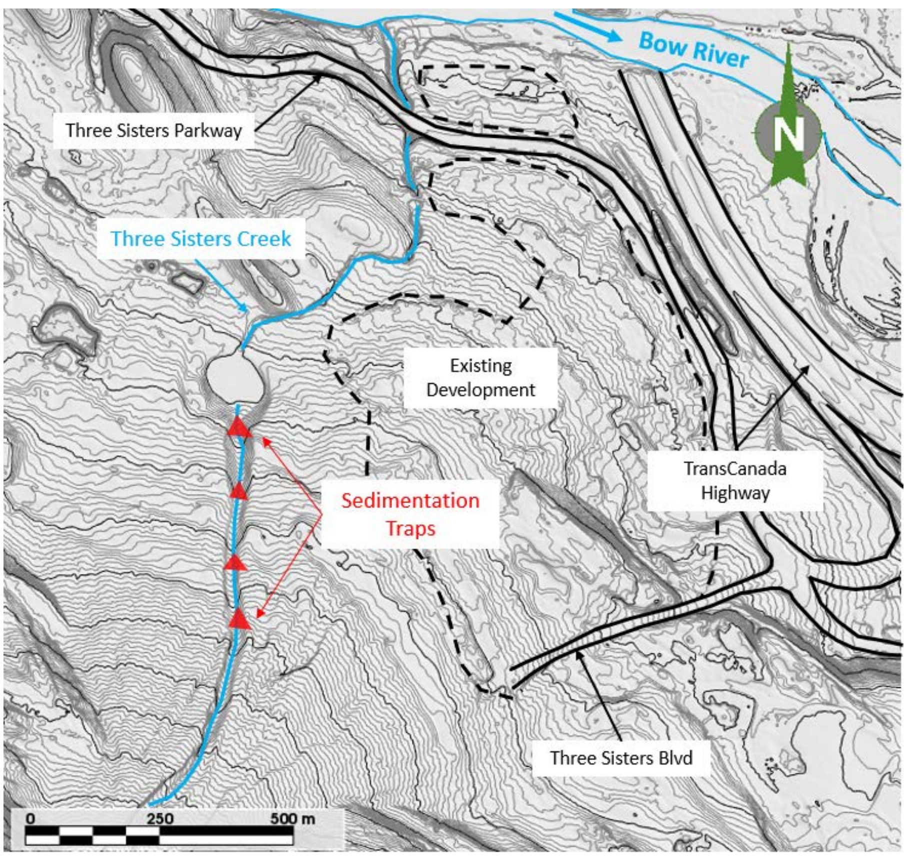

Figure 5-9. Option B-6: Schematic illustration of in-channel sedimentation trap locations. Topography based on lidar flown in September 2015, contour interval is 1 m.

5.3.3. Summary Comparison

Six mitigation options were considered in the upper channel (Table 5-2). Of these, the east apex deflection berm (Option B-4) and setback berms with a wide floodplain (Option B-5) were selected for further assessment. The lifecycle cost, risk reduction and cost-benefit ratio for these two options are outlined in Table 5-3.

Table 5-3. Comparison of cost-benefit for upper channel mitigation options selected for further assessment.

Option	Description	Lifecycle Cost (50-year NPV)	Risk-Reduction Benefit	Cost-Benefit Ratio
Option B-4	East Apex Deflection Berm	$2.2 Million	$2.7 Million	1.2
Option B-5	Wide Channel and Floodplain	$4.9 Million	$7.9 Million	1.6

As shown, the cost-benefit ratio is more favourable for the setback berms and wide floodplain (Option B-5). Although there is a higher capital cost, the setback berms require less maintenance in the long-term and achieve a higher risk reduction benefit as the setback berms protect development on both sides of Three Sisters.

Both options are included in the detailed options analysis and compared with the debris retention basin proposed at the fan apex; however, BGC recommends the wide channel and floodplain as the preferred option for the reasons listed above and advantages outlined in Section 5.3.2.5.

5.4. Golf Course Pond Options

5.4.1. Mitigation Objectives

Three Sisters Creek enters the GCP at approximately mid-fan. The GCP acts as a sedimentation basin during debris floods. Approximately 10 m downstream of the pond outlet, Three Sisters Creek passes under the AltaLink Bridge (Drawing 02). The AltaLink Bridge conveys power transmission lines (AltaLink 76L/113L) that provide power to Calgary and areas west of the city. The transmission line is buried on either side of the creek. 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 (email from Chris Ollenberger, QPD, personal communication, May 25, 2020). This depth is an estimated average and will be refined during preliminary design and with AltaLink's involvement.

The AltaLink 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 approximately the 100 to 300-year return period discharge.

Directly upstream and downstream of the AltaLink bridge the channel is lined by articulated concrete mats to protect from erosion. The articulated concrete matting is designed to withstand flows of up to 6 m/s (email from representative at Armortec Erosion Control Solutions[5], personal communication, October 5, 2020) and extends approximately 20 m upstream and 15 m downstream from the bridge over an 18 m wide area.

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 topography of the area is anticipated to direct flow back into the channel on both sides of the creek. For the 1,000 to 3,000-year return period, flow overtops the downstream side of the GCP for both current (2015 topography) and aggraded conditions (2013 topography). As with the 100 to 300-year return period, the local topography redirects flow into the channel; however the volume of water at this higher return period exceeds the channel capacity and there is overland flooding downstream of the GCP on both sides of the creek when the modelling considers aggraded conditions, and on the west side when the modelling uses the 2015 topography. The impact of the GCP overtopping in comparison with upstream and downstream avulsions is difficult to determine from the numerical modelling results at this higher return period as it is challenging to discern the proportion of flow from each location as flows merge together on the fan. Flows that exceed the capacity of the outlet during a 1,000 to 3,000-year event could damage the bridge or erode the bridge approaches, and potentially damage the transmission line.

The newest Alberta Dam and Canal Safety Directive (2018) does not provide specific direction on the size or storage volume that classifies a structure or retention pond as a dam. With this

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

directive, the GCP may be classified as a dam. The consequence and safety of the GCP, if classified as a dam, was not assessed for this options analysis.

At the GCP, the objective of mitigation is to:

i. Protect the power transmission lines from debris-flood impact to prevent power service interruption.
ii. Manage uncontrolled flows that, in combination with flows that exceed the channel capacity during a 1,000 to 3,000-year debris flood, could impact existing development and the proposed TSMV development.

5.4.2. Mitigation Options

Five mitigation options were considered to prevent overland flow downstream of the GCP and increase capacity at the GCP outlet as well as an option that doesn't introduce any new measures ("no new measures") (Table 5-4.). The options are described further in the following sections.

Table 5-4. Golf Course Pond mitigation options and options analysis status.

Option	Description	Option Analysis Status
Option C-0	No New Measures	Selected for further assessment
Option C-1	Golf Course Pond Enlargement	Rejected following BGC review
Option C-2	Bypass Channel at Pond Outlet	Selected for further assessment
Option C-3	Replace AltaLink Bridge	Selected for further assessment
Option C-4	Golf Course Pond Deflection Berm	Rejected following BGC review
Option C-5	Woody Debris Management	Selected for further assessment

5.4.2.1. Option C-0 – No New Measures

An option at the GCP is to do no additional work, given that the AltaLink bridge has capacity to pass the 100 to 300-year return period debris flood event and is protected from erosion with articulated concrete matting. This option was **selected for further assessment.**

Cost Estimate

There are no additional associated capital costs or operation and management costs with this option compared to current management costs.

Risk-Reduction Benefit

There is no additional risk reduction from this option.

Cost-Benefit Ratio

As there is no cost or risk-reduction associated with this option, a cost-benefit ratio cannot be calculated. For the purposes of comparison to other options a cost-benefit ratio of 1.0 has been assigned to this option (i.e. costs and risk reduction are equal).

Advantages and Disadvantages

The primary advantage of the no new measures option is the cost savings, especially as the existing measures meet the project's objectives.

5.4.2.2. Option C-1 – Golf Course Pond Enlargement

In theory, an expanded basin could be created around the GCP to serve as a detention basin with approximate extents as shown in Figure 5-10, Drawing 02.

This option was **rejected following BGC review**. The option was originally rejected as SweetCroft had identified the potential for the berms needed to retain more water than presently stored in the GCP to lead to the GCP being classified as a dam by the CDA (SweetCroft, April, 2015). Given the new dam safety directive, an increase in pond volume may not influence the dam classification; however, the pond already has approximately 40,000 m^3 of storage, effectively storing up to the 100 to 300-year return period debris-flood sediment volume (BGC, October 9, 2020). Due to its relatively small size compared to the flow and as the GCP is lined and hence always flooded, it would not function as an effective flow attenuator. For all these reasons, the option was rejected.

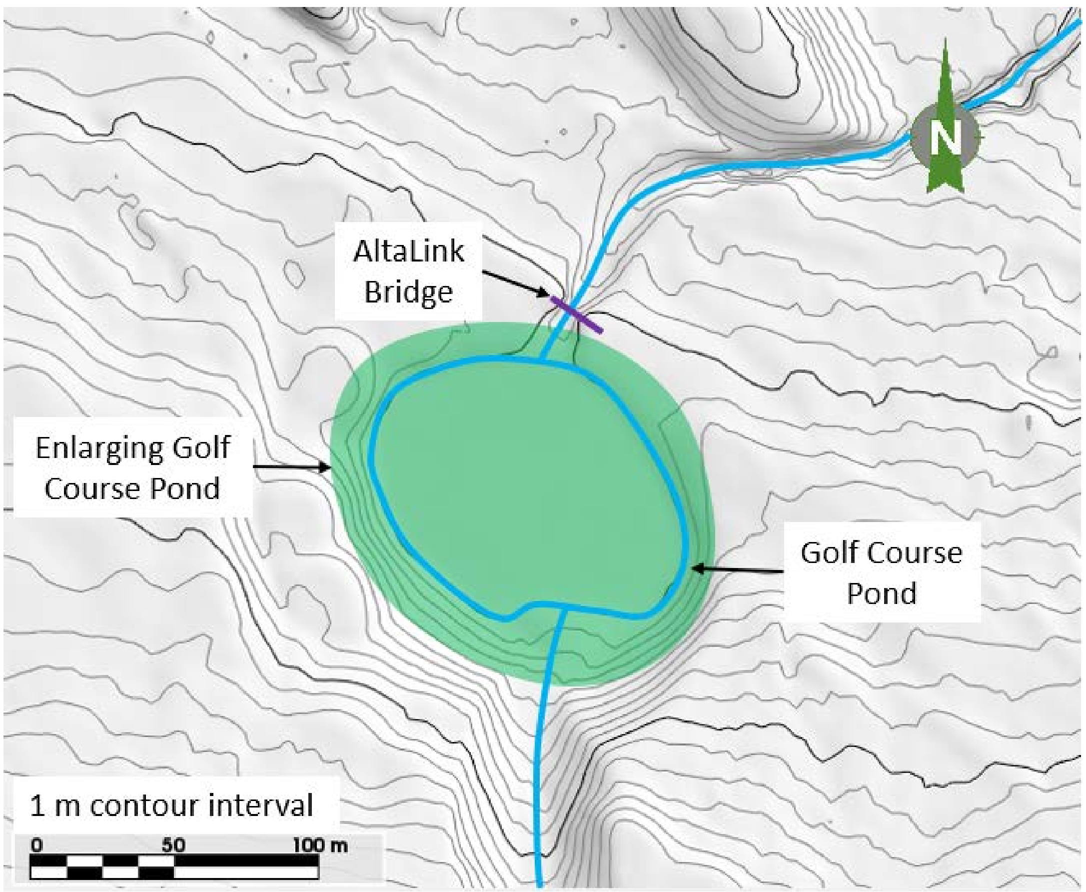

Figure 5-10. Option C-1: Schematic illustration of GCP enlargement. Green shaded area shows potential area of enlarging golf course extent. Topography based on lidar flown in September 2015.

5.4.2.3. Option C-2 – Bypass Channel at Pond Outlet

An overflow channel could be constructed to direct flow that overtops the GCP through an erosion protected channel back into the main Three Sisters Creek channel. This option was **selected for further assessment**.

Conceptual Design

The following points describe the conceptual design (Figure 5-11, Drawing 02):

- Overflow channel crosses the pathway east of the bridge. The aim of the design is to allow for that pathway to function normally at all other times.
- The overflow channel depth would be constrained by the depth of the buried transmission line. For this assessment it has been assumed that depth is approximately 1 m in the vicinity of Three Sisters Creek as it is brought closer to the surface to cross through the AltaLink bridge, allowing the channel to be 0.7 m deep at the transmission line crossing while still maintaining 0.3 m of burial with concrete erosion protection[6]. During preliminary design, and subject to consultation with AltaLink, re-routing of the transmission line deeper in the vicinity of the overflow channel could be explored.
- The channel is 100 m long, 0.7 m deep, and 60 m wide with 2H:1V side slopes to convey the additional flow required for the GCP outlet system to pass the 1,000 to 3,000-year return period peak discharge. For this options analysis, BGC has assumed a constant depth of 0.7 m for the entire spillway length.
- The upper portion of the overflow channel, directly downstream of the GCP, where the transmission line crosses the channel, could be armoured using articulated concrete mats that would transition to riprap approximately 20 m down the channel. 20 m of articulated concrete matting is assumed for this assessment as the exact location of the transmission line downstream of the GCP is not known and it would tie into the extent of the existing mats. It is assumed that articulated concrete mats would be required to protect the buried transmission line as the cover depth would be too shallow to allow for riprap protection, alternatively a monolithic concrete slab could also be installed to provide erosion protection.

Cost Estimate

The estimated capital cost of the bypass channel at the pond outlet is $1.7 million. The operation and maintenance costs (NPV) over the 50-year project lifecycle of the structure is estimated to be $100,000 (Appendix B). Combined, the total mitigation lifecycle cost of this option is $1.8 million.

Risk-Reduction Benefit

BGC estimates the risk-reduction benefit of a bypass channel at this location is $130,000. This estimate assumes that the bypass channel reduces building risk and life loss risk to existing development by approximately 5% for return periods greater than the 100 to 300-year (Section 4.1.1).

[6] The exact burial depth of the transmission line in the vicinity of this bypass channel option is not known and will need to be located for preliminary design. Minimum depth of cover required by AltaLink is not known at the time of this option analysis and will need to be specified by AltaLink during preliminary design.

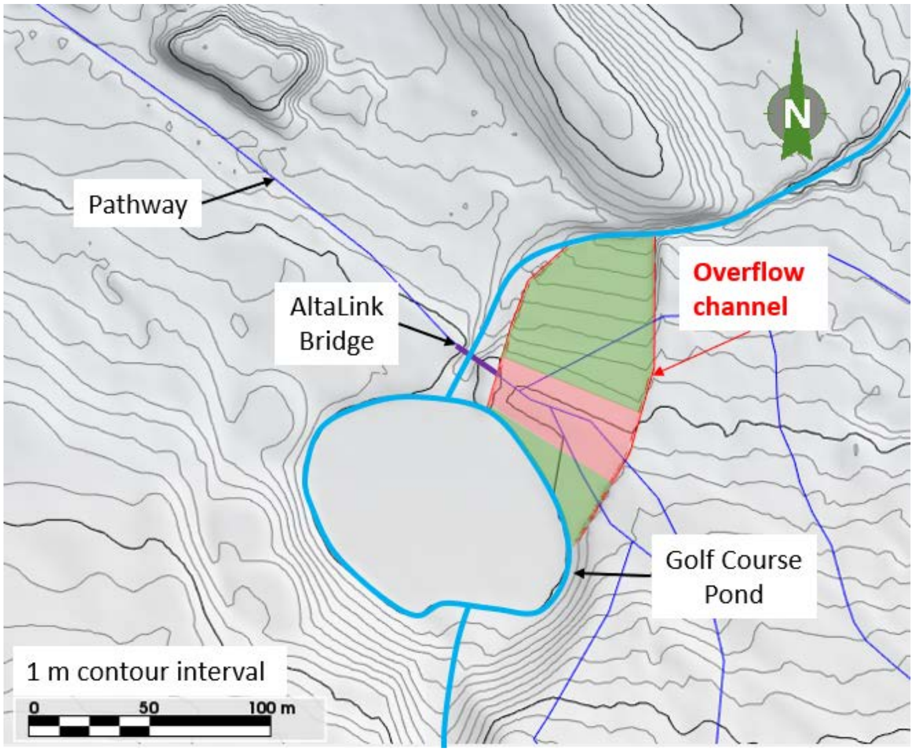

Figure 5-11. Option C-2: Schematic illustration of overflow channel at pond outlet. The invert of the overflow channel would be higher than the invert of the channel at the bridge so routine flows would stay in the existing channel. Red shaded area indicates where concrete erosion protection would be used, and the green shading indicates riprap. Channel alignment is approximate, not for design; shape and location may change during preliminary design. Topography based on lidar flown in September 2015.

Cost-Benefit Ratio

The cost-benefit ratio for the bypass channel is 0.07.

Advantages and Disadvantages

The primary advantage of this option compared to Option C-3 is reduced capital cost and therefore increased cost-benefit ratio.

The primary disadvantage of this option is that it is not required to meet the project objectives of mitigating for the 100 to 300-year debris flood event. An additional disadvantage is the breadth of the bypass channel required to convey the additional flow that the current outlet cannot accommodate. This option could be made more efficient if the channel were able to be deeper (i.e., re-routing of the transmission line) but this is unlikely to be practical. Another disadvantage common to all options that prevent avulsions is increasing the discharge in the main channel downstream because the flow that would have been lost through an avulsion would now remain in the channel. Finally, installing this option may reduce recreation capacity in this area as trails may need to be destroyed to install the bypass channel, or the channel would need to be constructed in such a way that allows for traversing when the bypass channel is not in use.

5.4.2.4. Option C-3 – Replace AltaLink Bridge

The AltaLink bridge could be replaced with a larger capacity structure. This option was **selected for further assessment**.

Conceptual Design

The current AltaLink Bridge has a span of 8.8 m and capacity to pass the 100 to 300-year return period debris flood. Replacing the bridge, with a structure with sufficient capacity to pass the 1,000- to 3,000-year return period debris flood would require a higher span between the channel and bridge deck; either by elevating the bridge deck or excavating the channel under the bridge; a wider span across the creek, or a combination of both. Excavation of the channel at this location would reduce the storage volume of the GCP which could also increase the flow velocity exiting the pond and potentially amplify bank erosion downstream. For this reason, only replacement of the bridge with a wider span but same height above the channel was considered.

To pass the 1,000- to 3,000-year return period debris flood the span would need to be increased to approximately 16 m (Figure 5-12). This option analysis has used the same side slope geometry as the current AltaLink Bridge. The location is shown on Drawing 02.

Cost Estimate

The estimated capital cost of replacing the AltaLink Bridge is $8.1 million. The capital cost does not include the cost for AltaLink line alterations, either temporary or permanent. The operation and maintenance costs (NPV) over the 50-year project lifecycle of the structure is estimated to be $300,000 (Appendix B). Combined, the total mitigation lifecycle cost of this option is $8.4 million.

Risk-Reduction Benefit

BGC estimates the risk-reduction benefit of replacing the bridge is $130,000. This estimate assumes that the bridge replacement reduces building risk and life loss risk to existing development by approximately 5% for the return periods greater than the 100 to 300-year (Section 4.1.1).

Cost-Benefit Ratio

The cost-benefit ratio for the AltaLink Bridge replacement is 0.02.

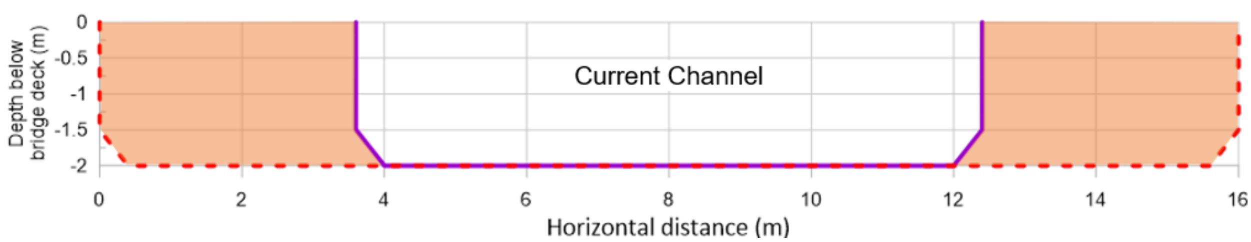

Figure 5-12. Option C-3: Schematic illustration of AltaLink bridge replacement. Comparison between current channel size under the AltaLink Bridge (purple line) and proposed replacement span to pass the 1,000- to 3,000-year return period debris flood (red dashed line). Orange shaded area shows area that would be excavated to expand the outlet capacity.

Advantages and Disadvantages

The primary advantage of this option compared to Option C-2 is having one outlet location and channel for all return periods versus constructing another channel. This simplifies operation and maintenance requirements.

The primary disadvantage of this option is that is not required to meet the project objectives of mitigating the 100 to 300-year debris flood event. Another disadvantage is its capital cost. The current bridge is designed to carry AltaLink transmission lines through it and design and manufacture of another specialized bridge is likely to be expensive, especially as this bridge was recently installed in 2005, along with the challenge of temporary re-route of the lines during installation.

5.4.2.5. Option C-4 – Golf Course Pond Deflection Berm

A deflection berm downstream, to the northeast of the GCP, could be installed to direct flows that exceed the pond outlet capacity back to the main channel, away from existing development, as suggested by SweetCroft (April, 2015). The potential location is shown in Figure 5-13 and on Drawing 02.

This option was **rejected following BGC review** as it transfers risk potential to the AltaLink bridge at the GCP outlet, which contains the AltaLink transmission line, as well as buried sections of the transmission line that are not protected from erosion west of the channel.

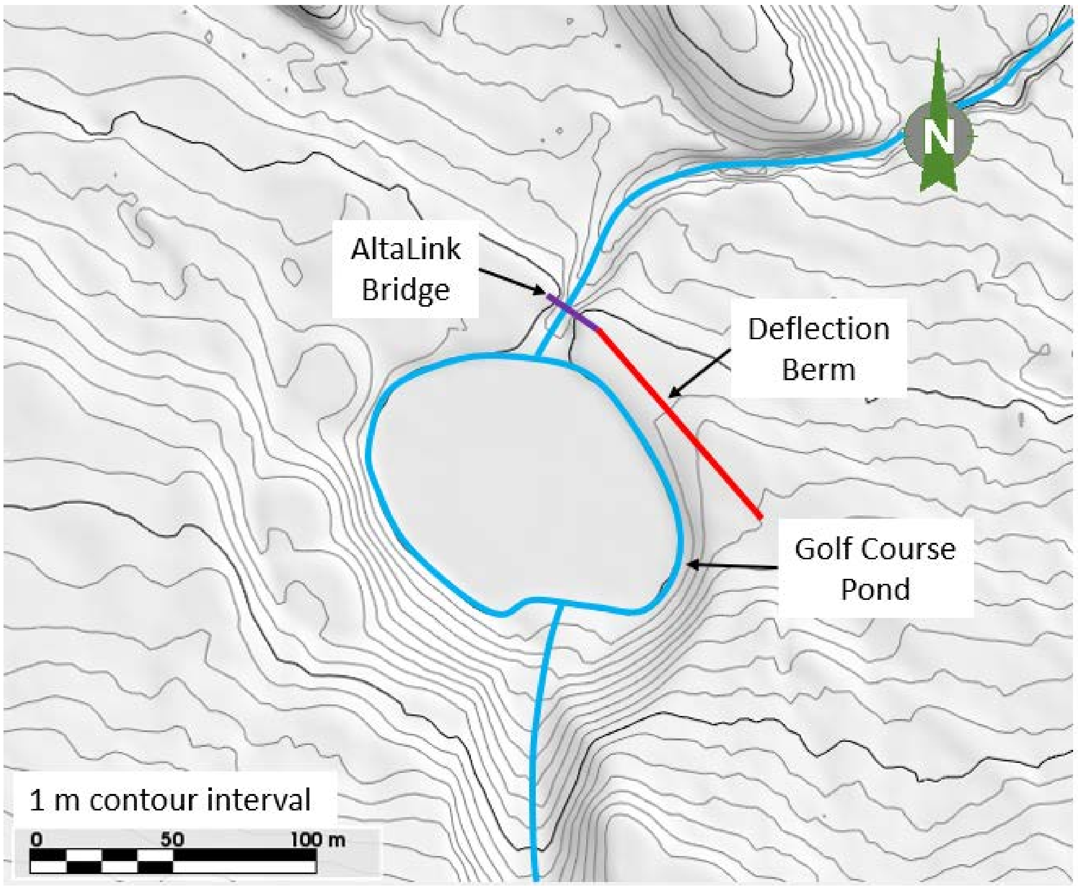

Figure 5-13. Option C-4: Schematic illustration of GCP deflection berm alignment. Red line shows approximate deflection berm location suggested by SweetCroft (April 2015). Topography is based on lidar flown in September 2015, contour interval is 1 m.

5.4.2.6. Option C-5 – Woody Debris Management

A woody debris management system could be installed upstream of the GCP inlet or in the pond to capture woody debris that might otherwise block the GCP outlet or AltaLink Bridge. This option was **selected for further assessment**.

Conceptual Design

A woody debris management system could include in-channel debris management upstream of the GCP inlet or a floating boom system in the GCP. The cost-estimate, risk reduction benefit, cost-benefit ratio and advantages and disadvantages presented are for a floating boom system as is commonly used on dams and reservoirs. The boom would be anchored on either sides of the pond and is estimated to be approximately 150 m long to allow for it to be anchored outside the banks of the GCP (Figure 5-14).

Cost Estimate

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

Risk-Reduction Benefit

The risk-reduction benefit of installing a floating boom woody debris management at GCP is estimated to be $270,000. This estimate assumes that woody debris management reduces building risk to existing development by approximately 5% for debris floods with return periods up to the design event (100 to 300-years). For return periods in excess of 100 to 300-years, the likelihood of the floating boom system functioning as intended is not well known and thus is not included in the risk-reduction benefit.

Cost-Benefit Ratio

The cost-benefit ratio for woody debris management is 0.34.

Advantages and Disadvantages

The advantages of such a system are that it has the potential to prevent large woody debris from reaching and potentially clogging the pond outlet at the AltaLink bridge. In so doing, the potential for flows to overtop and potentially erode the pond embankments is reduced.

The disadvantage of such a system is that it introduces more operations and maintenance costs. Moreover, the efficacy of these systems during extreme debris flood events is not well understood as they are typically installed in locations with little flow velocity.

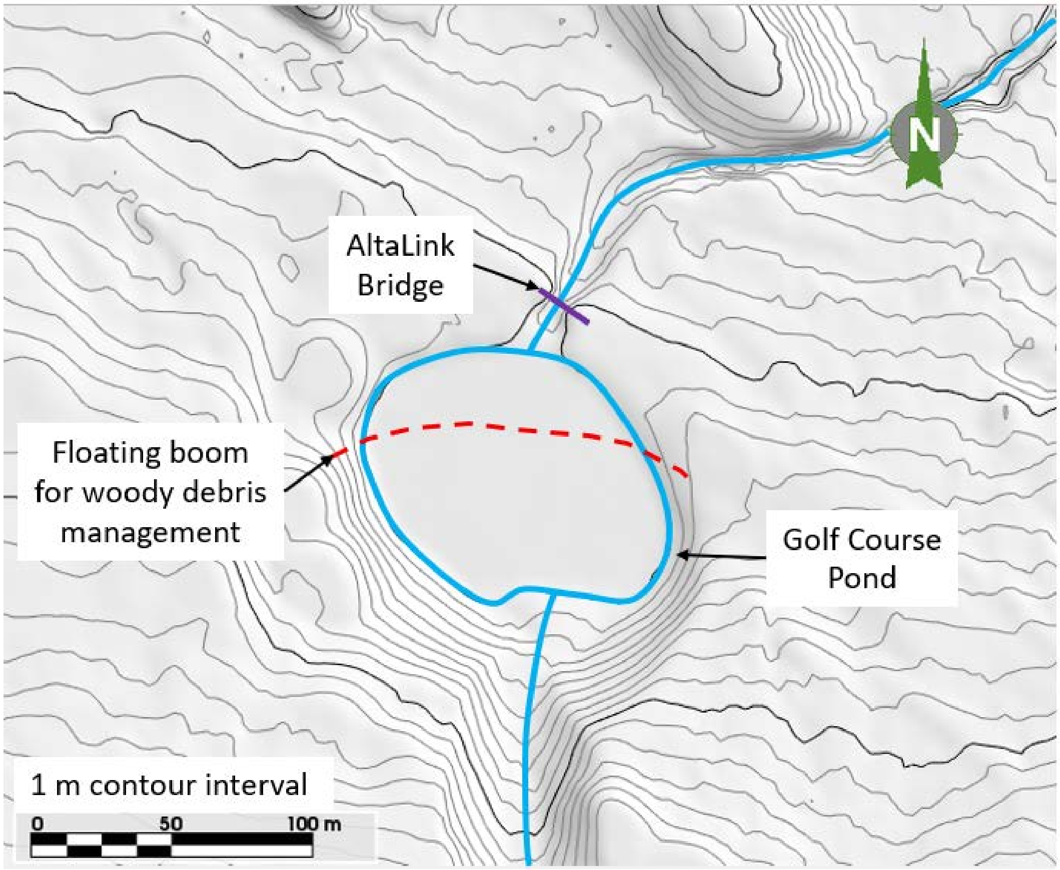

Figure 5-14. Option C-5: Schematic illustration of woody debris management at GCP. Red dashed line shows approximate location of floating boom. Topography is based on lidar flown in September 2015, contour interval is 1 m.

5.4.3. Summary Comparison

Five mitigation options were considered at the GCP as well as an option that doesn't introduce any new measures ("no new measures") (Table 5-4). Of these, no new measures (Option C-0), the bypass channel at the pond outlet (Option C-2), replacement of the AltaLink Bridge (Option C-3) and woody debris management (Option C-5) were selected for further assessment. The AltaLink Bridge replacement (Option C-3) is only required for the 1,000 to 3,000-year debris flood as the existing bridge has sufficient capacity to pass the 100 to 300-year debris flood. The lifecycle cost, risk reduction and cost-benefit ratio for these four options are outlined in Table 5-5.

Table 5-5. Comparison of cost-benefit for Golf Course Pond mitigation options selected for further assessment.

Option	Description	Lifecycle Cost (50-year NPV)	Risk-Reduction Benefit	Cost-Benefit Ratio
Option C-0	No New Measures	-	-	1.0
Option C-2	Bypass Channel at Pond Outlet	$1.8 Million	$130,000	0.07
Option C-3	Replace AltaLink Bridge	$8.4 Million	$130,000	0.02
Option C-5	Woody Debris Management	$790,000	$290,000	0.34

As shown, the cost-benefit ratio is significantly more favourable for the no new measures option (Option C-0). The option meets the project objectives as the AltaLink Bridge has sufficient capacity to convey the peak discharge of a 100 to 300-year debris flow and the articulated concrete mats are designed to withstand the peak velocities anticipated during an event of this magnitude. Woody debris management at the GCP would both support the capacity of the AltaLink Bridge at the outlet and decrease the risk of woody debris reaching the lower channel downstream of the pond. BGC understands that for these reasons, the preferred option for the ToC is to install woody debris management at the GCP.

All four options are included in the detailed options analysis; however, BGC recommends that woody debris management be integrated.

5.5. Lower Channel Options

5.5.1. Mitigation Objectives

Three Sisters Creek leaves the GCP and enters a partially bedrock confined reach upstream of TSP. In this lower reach, modelling shows that flow avulses out of the channel to the west, into the proposed TSMV development at the 100 to 300-year and 1,000 to 3,000-year return periods (BGC, October 9, 2020).

Along the lower channel, the objective of mitigation is to protect the proposed TSMV development from impact.

5.5.2. Mitigation Options

To achieve this objective, BGC considered 5 options to protect against avulsions as well as an option that doesn't introduce any new measures ("no new measures") (Table 5-6.). The options are described further in the following sections.

Table 5-6. Lower channel mitigation options and options analysis status.

Option	Description	Option Analysis Status
Option D-0	No New Measures	Selected for further assessment
Option D-1	Lower Channel Rehabilitation	Rejected following BGC review
Option D-2	Lower Channel Grade Control Structures	Rejected following BGC review
Option D-3	West Setback Berms	Selected for further assessment
Option D-4	North Relief Channel	Rejected following BGC review
Option D-5	Woody Debris Management	Selected for further assessment

5.5.2.1. Option D-0 – No New Measures

An option at the lower channel is to install no additional mitigation and allow flow to avulse west to the proposed development. Based on the work completed to date, mitigation in the lower channel on the east side of the creek to protect existing development is not required. In future phases of work, the need for mitigation on the east side of the creek that may result from risk transfer due to upstream mitigation can be evaluated. The option to install no additional mitigation measures was **selected for further assessment.**

Cost Estimate

There are no additional associated capital costs or operation and management costs with this option compared to current management costs.

Risk-Reduction Benefit

There is no risk reduction from this option.

Cost-Benefit Ratio

As there is no cost or risk-reduction associated with this option, a cost-benefit ratio cannot be calculated. For the purposes of comparison to other options a cost-benefit ratio of 1.0 has been assigned to this option (i.e. the costs and risk reduction are equal).

Advantages and Disadvantages

The primary advantage of not implementing any new measures is the cost savings. Another advantage is the lack of environmental impact compared to other proposed options for the lower channel.

The disadvantage of this option is the lack of risk-reduction to the proposed development as flow would still be able to avulse to the west into the proposed development. BGC acknowledges that given the shallow flow depths, generally <0.1 m for the 100 to 300-year, and generally <0.5 m for the 1,000 to 3,000-year return period debris floods, risk reduction could be achieved through the design of grades and building elevations in the proposed development west of Three Sisters Creek downstream of the GCP.

5.5.2.2. Option D-1 – Lower Channel Rehabilitation

Bioengineering (e.g., vegetation) and hard armour (riprap or articulated concrete mats) could be installed to protect outside bends of the channel from erosion as suggested by SweetCroft (April, 2015) (Figure 5-14, Drawing 02).

This option was **rejected following BGC review** for debris-flood protection because bank erosion that occurs in the lower channel reach (i.e., downstream of the GCP) is unlikely to impact critical elements at risk (homes and infrastructure). Also, some rehabilitation has been completed in 2014 and 2018 (Section 2.1.3), particularly between the pedestrian bridge and downstream of TSP. Bioengineering measures on their own are unlikely to be effective at preventing erosion during a debris flood though there may be aesthetic or environmental reasons to rehabilitate the lower channel.

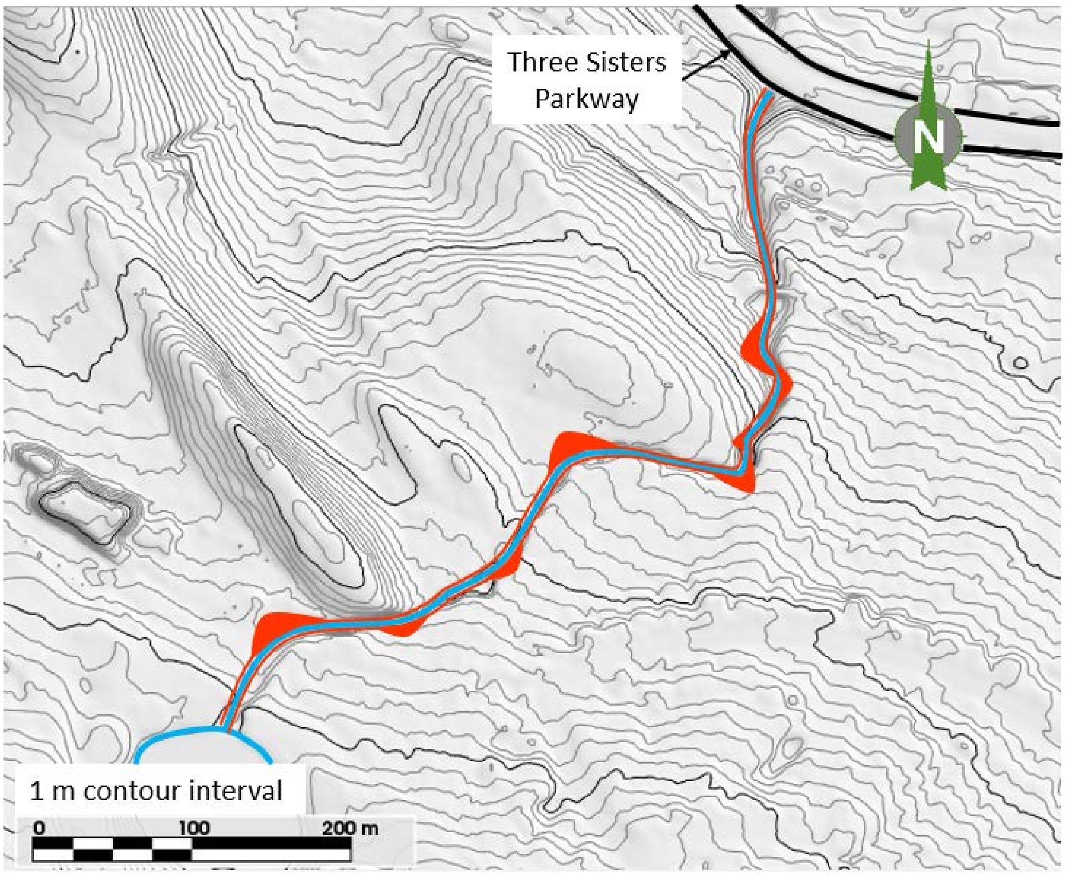

Figure 5-15. Option D-1: Schematic illustration of lower channel rehabilitation between the GCP and TSP. Red lines show areas where bioengineering could be installed on banks and red shading shows areas where hard armour could be implemented. Topography based on lidar flown in September 2015.

5.5.2.3. Option D-2 – Lower Channel Grade Control Structures

Grade control structures within the creek channel could be installed to protect the channel bed from downcutting as suggested by SweetCroft (April, 2015) (Figure 5-15).

This option was **rejected after BGC review** because BGC understands from field work in 2018 that bedrock and till outcrops flank portions of the lower channel reach (BGC, October 9, 2020), and, thus provide some grade control although BGC has not mapped all these locations. Downcutting and bank erosion that occurs in areas that are not bedrock controlled is unlikely to impact elements at risk. Large woody debris that falls into the channel due to bank erosion has the potential to be entrained in the debris floods and block the TSP culvert. To address this potential, Option D-5 considers large woody debris management.

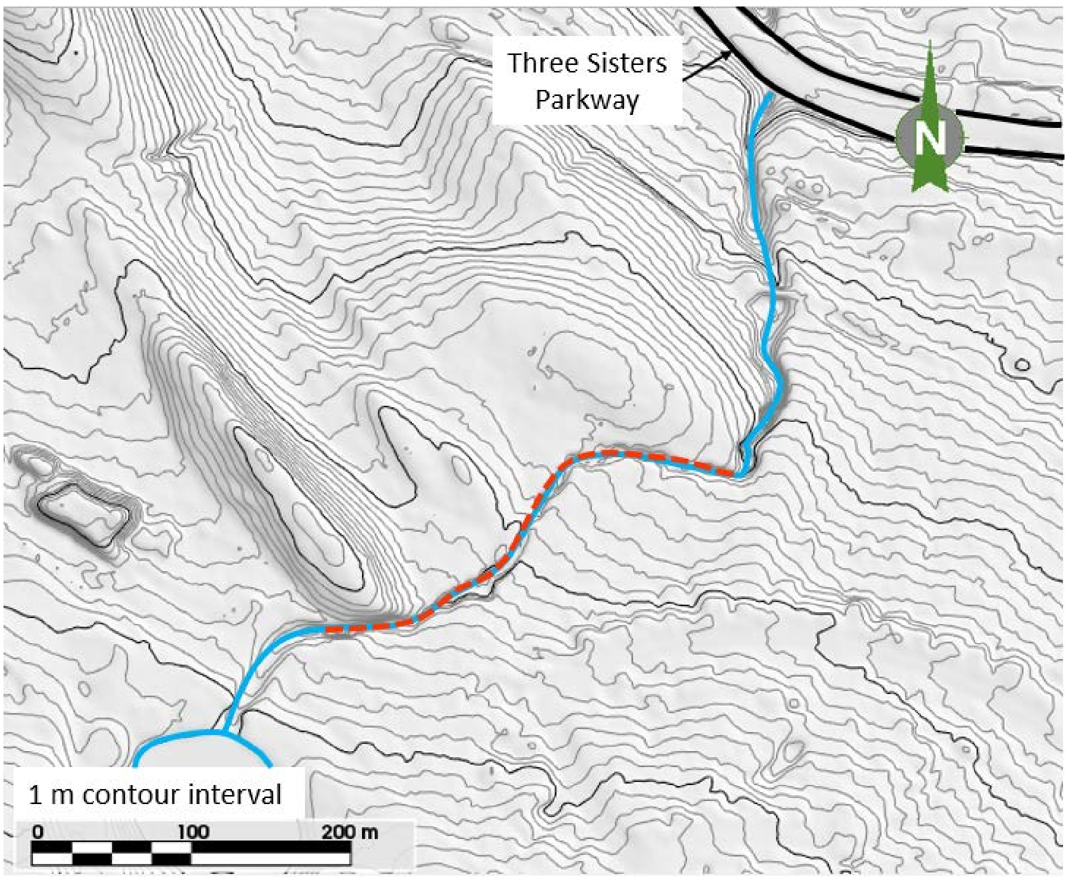

Figure 5-16. Option D-2: Schematic illustration of grade control structures between the GCP and TSP. Dashed red line shows the extent that SweetCroft (April 2015) suggests for grade control structures. Topography based on lidar flown in September 2015.

5.5.2.4. Option D-3 – West Setback Berms

Setback berms on the west side[7] of the channel between the GCP and TSP could be installed to mitigate local avulsions that would affect the proposed TSMV (Figure 5-16, Drawing 02). This option was **selected for further assessment**.

Conceptual Design

The berms protect against avulsions in the reach between the GCP and TSP. The following points describe the conceptual design (Figure 5-16):

- Heights of the berms are estimated using the maximum flow depth at each avulsion location from numerical model results from BGC (October 9, 2020) plus a minimum of 0.6 m of freeboard.
- Lengths of the berms are also estimated using numerical model results from BGC (October 9, 2020) and extend the full length of the avulsing flow.
- The upper setback berm (west setback berm A) is 1.5 m high and 130 m long, while the lower setback berm (west setback berm B) is 1.5 m high and 200 m long.
- Both berms have side slopes of 2H:1V, with the side facing the creek armoured with either riprap or stone pitching and the outside face vegetated
- Berms would be keyed into the bedrock ridges to prevent outflanking and reduce the length required, where possible.
- The extent of the upper setback berm is extended to account for the potential additional overflow identified as part of BGC's modelling with the upper setback berms in place (BGC, October 8, 2020).

Cost Estimate

The estimated capital cost of the lower setback berms is $775,000. The operation and maintenance costs (NPV) over the 50-year project lifecycle of the structure is estimated to be $100,000 (Appendix B). Combined, the total mitigation lifecycle cost is $875,000 (50-year NPV).

Risk-Reduction Benefit

Using the same methods to calculate the risk-reduction benefit as at all other options, BGC estimated the risk-reduction benefit of setback berms at this location is ($50,000). The benefit for this option is low as calculated, as it does not benefit the existing development and risk-reduction has not been quantitatively analysed for the proposed development. It is assumed that risk to TSP is increased by 25% compared to baseline conditions due to the increase in peak discharge that reaches the culvert. For inclusion in the detailed options analysis (Section 6), a cost-benefit ratio was qualitatively assessed using relative rankings. This approach was discussed with QPD and the ToC as part of the workshops.

[7] Although all options in this assessment are regarded in isolation, BGC did a preliminary assessment considering upstream mitigation that would increase the discharge in this zone to assess whether berms on the east side of the channel would be necessary. The preliminary assessment found that avulsions to the east were minor and did not impact existing development, therefore, berms on the east side of the channel were not deemed necessary.

Cost-Benefit Ratio

The cost-benefit ratio for the setback berm was qualitatively evaluated as part of the detailed options analysis (Section 6) to capture the high anticipated risk-reduction benefit to the proposed development in comparison with the cost of the berms. This approach was discussed with QPD and the ToC as part of the workshops.

Advantages and Disadvantages

The primary advantage of this option is that it protects the proposed development from avulsions, which meets the mitigation objective for this zone. This option also requires less maintenance effort and cost compared to in-channel mitigation works. Setback berms also require no in-stream works which is easier to permit.

The primary disadvantage is increasing discharge downstream to the TSP crossing.

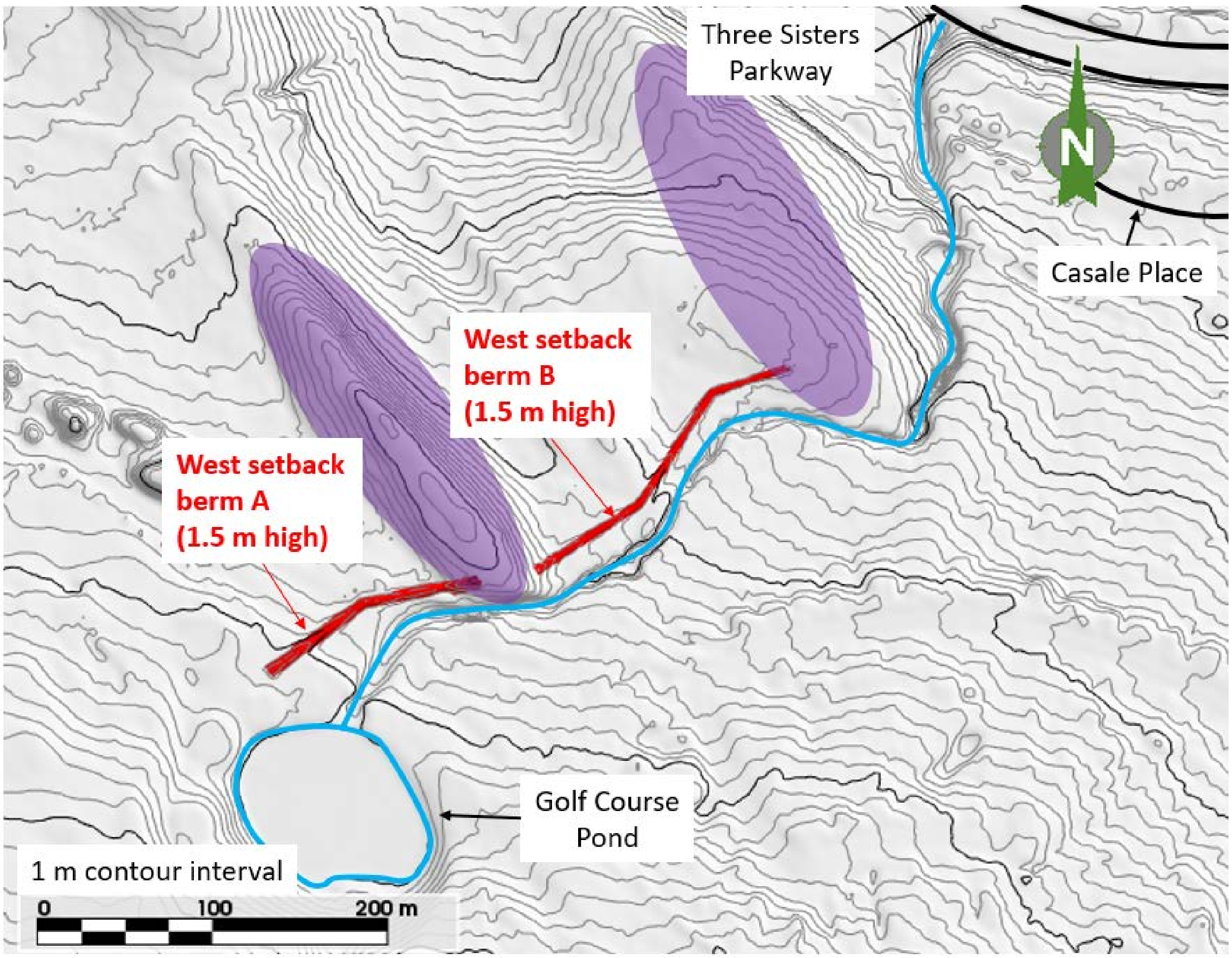

Figure 5-17. Option D-3: Schematic illustration of setback berms between the GCP and TSP. Purple shaded area indicates approximate location of presumed bedrock ridges. Berm alignments are approximate, not for design. Berm shapes and locations may change during preliminary design. Topography based on lidar flown in September 2015.

5.5.2.5. Option D-4 – North Relief Channel

A relief channel could convey flows exceeding the channel capacity west to Bow River and reduce the discharge at the Three Sisters Creek Parkway culvert (Figure 5-17, Drawing 02). This could reduce potential avulsions downstream of the relief channel and erosion and sedimentation at the TSP culvert. The relief channel could be directed towards an existing culvert under TSP and would require review of the culvert capacity to ensure appropriate sizing.

This option was **rejected following BGC review** because of potential for risk transfer to infrastructure located along the relief channel path, including infrastructure downstream of TSP. This option would also require removing some developable land from the proposed TSMV development to designated mitigation land, which is not desirable for TSMV.

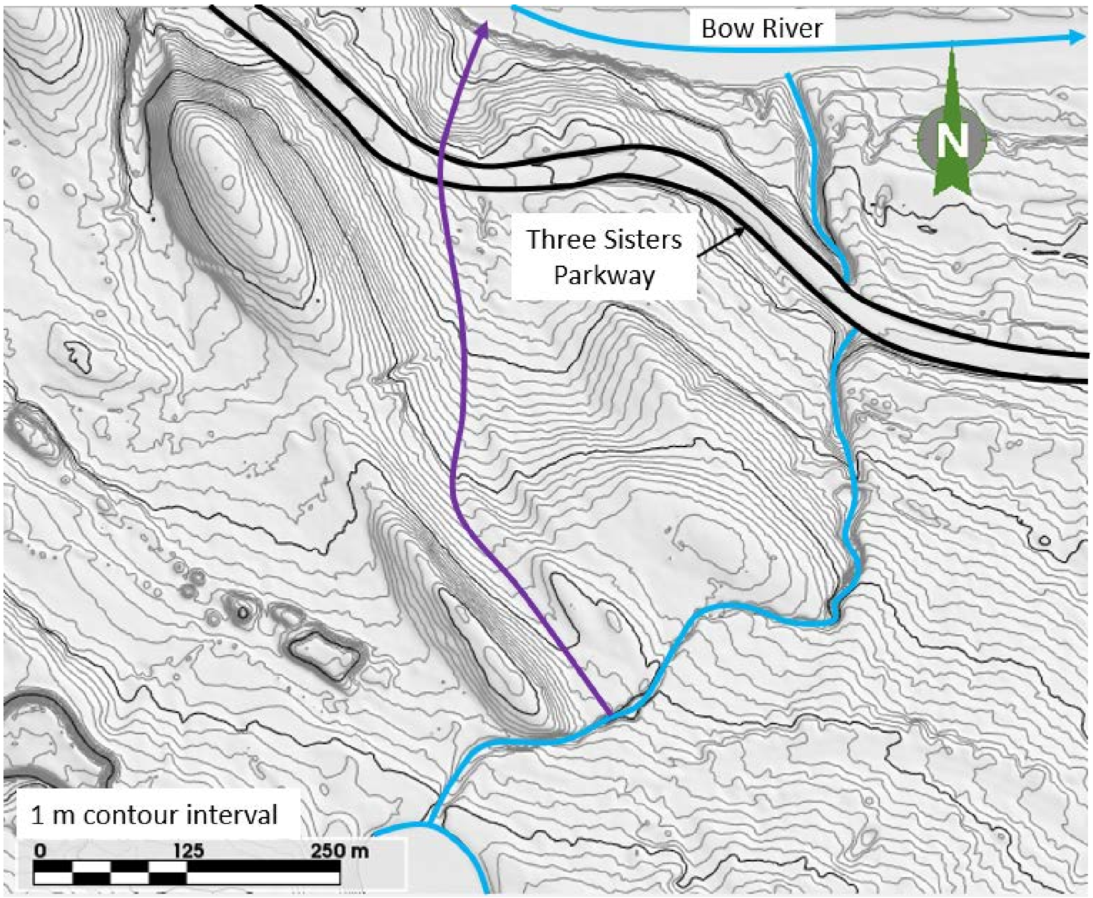

Figure 5-18. Option D-4: Schematic illustration of north relief channel between the GCP and TSP. Purple line shows an approximate location of a relief channel. Topography based on lidar flown in September 2015.

5.5.2.6. Option D-5 – Woody Debris Management

Woody debris could be recruited from bank erosion and tree toppling along the lower channel between the GCP and TSP. Woody debris management in the lower channel upstream of TSP was **selected for further assessment**.

Conceptual Design

BGC assessed several different woody debris management approaches that could be used in isolation or in conjunction with each other. The options with the associated advantages and disadvantages for consideration are outlined in Table 5-7, and the approximate locations of the options are shown on Figure 5-19 and Drawing 02.

Table 5-7. Woody debris management approaches considered.

Approach	Description	Advantages	Disadvantages
Tree removal	Assessment and removal of trees with marginal root support near banks	• Reduces woody debris sources • Cost effective	• Impacts environment and aesthetics • Does not prevent other debris from entering channel
Debris Capture: Woody debris grillage (grizzly)	Steel rack installed at or directly upstream of the culvert inlet of the TSP culvert, up to ten times the surface area of the culvert inlet, to catch debris before it blocks the culvert	• Reduces debris that blocks the culvert • Avoids tree removal	• Requires regular maintenance • If partially or fully blocked prior to, or during a debris flood, reduces channel capacity directly upstream of culvert and increases chance of avulsion due to channel blockage • Creates a backwater effect that can lead to avulsions (risk transfer) • Capital expense
Debris Capture: In-channel posts	A line of posts installed across the channel upstream of the TSP culvert to capture debris before blocking the culvert	• Reduces debris that enters or impacts the culvert	• Requires regular maintenance • If partially or fully blocked prior to, or during a debris flood, reduces the channel capacity and increases chance of avulsion • Creates a backwater effect that can lead to avulsions (risk transfer) • Capital expense

Approach	Description	Advantages	Disadvantages
Debris Capture: Flexible debris net	Flexible debris net installed upstream of the TSP culvert	• Active only during high flow times, leading to lower blockage potential and maintenance requirements • More cost effective than grizzly or channel posts based on estimate received from Trumer Schutzbauten (email from Ahren Bichler, personal communication, June 2, 2020)	• Impacts aesthetics and prone to vandalism • Introduces public safety hazard if used as a climbing structure • Requires maintenance • Low history of use in Canada.

Cost Estimate

The estimated capital cost of the woody debris management that includes installing either the flexible debris net or in-channel posts is $100,000 (both approaches have similar estimated costs). The operation and maintenance costs (NPV) over the 50-year project lifecycle of the structures and considering the tree removal approach as well is estimated to be $200,000 (Appendix B). Combined, the total mitigation lifecycle cost of this option is $300,000.

Risk-Reduction Benefit

BGC estimates the risk-reduction benefit of woody debris management along the lower channel is $600,000. This estimate assumes that woody debris management reduces building risk and life loss risk to existing development by approximately 5% for the return periods considered (Section 4.1.1) It further assumes that risk to TSP is decreased by 70% compared to baseline conditions due to the protection provided to the crossing, if functioning as intended.

Cost-Benefit Ratio

The cost-benefit ratio for woody debris management is 1.9.

Advantages and Disadvantages:

The primary advantage for this option compared to Option D-3 is the protection and risk reduction it provides to the TSP crossing. Considering even the most expensive approaches still results in a high cost-benefit ratio.

The primary disadvantage of the woody debris management option is the potential risk transfer if regular maintenance is not completed. If in-channel structures are not regularly cleaned out, blockages may contribute to avulsions (shown as avulsion potential in Figure 5-19). In-channel mitigation work could also pose a permitting challenge compared to options setback from the creek.

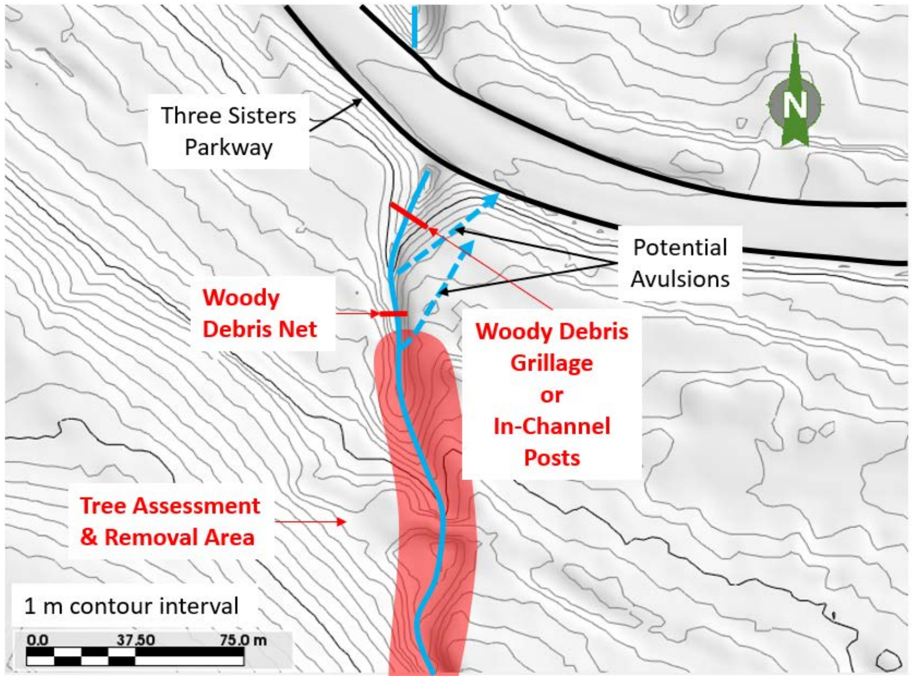

Figure 5-19. Option D-5: Schematic illustration of woody debris management between the GCP and TSP. Tree assessment/removal area shown would extend upstream to the GCP. Mitigation alignment is approximate, not for design; shape and location may change during preliminary design. Topography based on lidar flown in September 2015.

5.5.3. Summary Comparison

Five mitigation options were considered in the lower channel as well as an option that doesn't introduce any new measures ("no new measures") (Table 5-5). Of these, no new measures (Option D-0), the setback berms (Option D-3) and woody debris management (Option D-5) were selected for further assessment. The lifecycle cost, risk reduction and cost-benefit ratio for these two options are outlined in Table 5-8.

Table 5-8. Comparison of cost-benefit for lower channel mitigation options selected for further assessment.

Option	Description	Lifecycle Cost (50-year NPV)	Risk-Reduction Benefit	Cost-Benefit Ratio
Option D-0	No New Measures	-	-	1.0
Option D-3	West Setback Berms	$875,000	($50,000)	N/A
Option D-5	Woody Debris Management	$300,000	$600,000	1.9

As shown, the cost-benefit ratio is significantly more favourable for woody debris management (Option D-5), but it does not entirely meet the objective in this zone of protecting the proposed development. The west setback berms option meets the objective for this zone.

All three options are included in the detailed options analysis; however, BGC recommends the west setback berms as the preferred option for the reasons listed above and advantages outlined in Section 5.5.2.4. BGC recommends woody debris management as an additional method to protect the TSP crossing if the mitigation budget allows.

5.6. Three Sisters Parkway Crossing

5.6.1. Mitigation Objectives

Three Sisters Creek passes beneath TSP in a concrete box culvert. 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. BGC completed a preliminary assessment of the culvert capacity using HY-8 and standard culvert sizing nomographs (USDOT, 2012) in consideration of the topography at the culvert inlet. BGC's estimated capacity was 21 m^3/s which aligns closely with the SweetTech 23 m^3/s estimate; therefore 23 m^3/s was applied for this options analysis. 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 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 event 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 backwater 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 debris flood with a peak discharge of 50 m^3/s that accounts for climate change. As such, the mitigation options presented are to achieve the higher peak discharge of 50 m^3/s at a minimum, with options to mitigate the 1,000 to 3,000-year return period debris flood with peak discharge of 112 m^3/s presented for comparison.

At the crossing, the mitigation objectives are to:

i. Reduce life loss and economic (building damage) risk to the existing Crossbow Landing residential development northeast of the Three Sisters Creek crossing.
ii. Increase the likelihood that TSP remains operational as a transportation corridor into Canmore during debris floods even if the flow exceeds the culvert capacity.
iii. Reduce economic losses associated with damage to TSP and the culvert as well as closure of TSP.

5.6.2. Mitigation Options

Four mitigation options were considered to improve conveyance and reduce risk at the TSP crossing as well as an option that doesn't introduce any new measures ("no new measures")

[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.

(Table 5-9). The following sections describe these mitigation options, four of the options were selected for further assessment.

Table 5-9. Three Sisters Parkway mitigation options and options analysis status.

Option	Description	Option Analysis Status
Option E-0	No New Measures	Selected for further assessment
Option E-1	Bypass Channel and Culvert	Selected for further assessment but rejected following workshop 1
Option E-2	Overflow with Channel	Selected for further assessment
	2a: Riprap channel	Selected for further assessment
	2b: Natural swale	Rejected following BGC review
Option E-3	Replace the TSP Culvert	Selected for further assessment
Option E-4	Northeast Deflection Berm	Selected for further assessment

5.6.2.1. Option E-0 – No New Measures

An option at the TSP crossing is not to implement any new measures at the crossing with the understanding that the current culvert can pass the 100-year debris flood peak discharge and approximately half of the 100 to 300-year debris flood peak discharge and mitigation at this zone may be re-visited when the current culvert meets the end of its intended design life. BGC understands that the TSP culvert has approximately 30 years remaining in its design life based on input from the ToC. Moreover, there are existing erosion works on the downstream side of TSP installed in 2018 (Table 2-2). This option was **selected for further assessment.**

Cost Estimate

There are no additional associated capital costs or operation and management costs with this option compared to current management costs.

Risk-Reduction Benefit

There is no risk reduction from this option.

Cost-Benefit Ratio

As there is no cost or risk-reduction associated with this option, a cost-benefit ratio cannot be calculated. For the purposes of comparison to other options a cost-benefit ratio of 1.0 has been assigned to this option.

Advantages and Disadvantages

The primary advantage of not implementing any new measures is the cost savings. Another advantage is the lack of environmental impact compared to other proposed options for the TSP crossing.

The disadvantage of this option is the lack of risk-reduction to the existing development near TSP that may experience flooding due the crossing overtopping as well as potential damage suffered to TSP during an event.

5.6.2.2. Option E-1 – Bypass Channel and Culvert

To the west of the main TSP crossing, an approximately 900 mm diameter corrugated metal pipe culvert passes beneath the parkway. A bypass channel could be constructed to the west of the existing Three Sister Creek channel to convey overflow from Three Sisters Creek to this culvert when storm events exceed the main culvert capacity. This would require replacement of the existing 900 mm culvert to have sufficient capacity to convey the overflow and installation of erosion protection downstream of TSP to convey flows safely towards Three Sisters Creek and into Bow River (Figure 5-20).

This option was **rejected following BGC review** and input from QPD and the ToC during the workshops due to the high capital and operations and maintenance costs associated with installation of another culvert or bridge to pass the overflow. Given the current TSP culvert capacity (23 m^3/s) and the 100 to 300-year design event (peak discharge of 50 m^3/s), the bypass culvert would need to be larger than the existing TSP culvert (27 m^3/s).

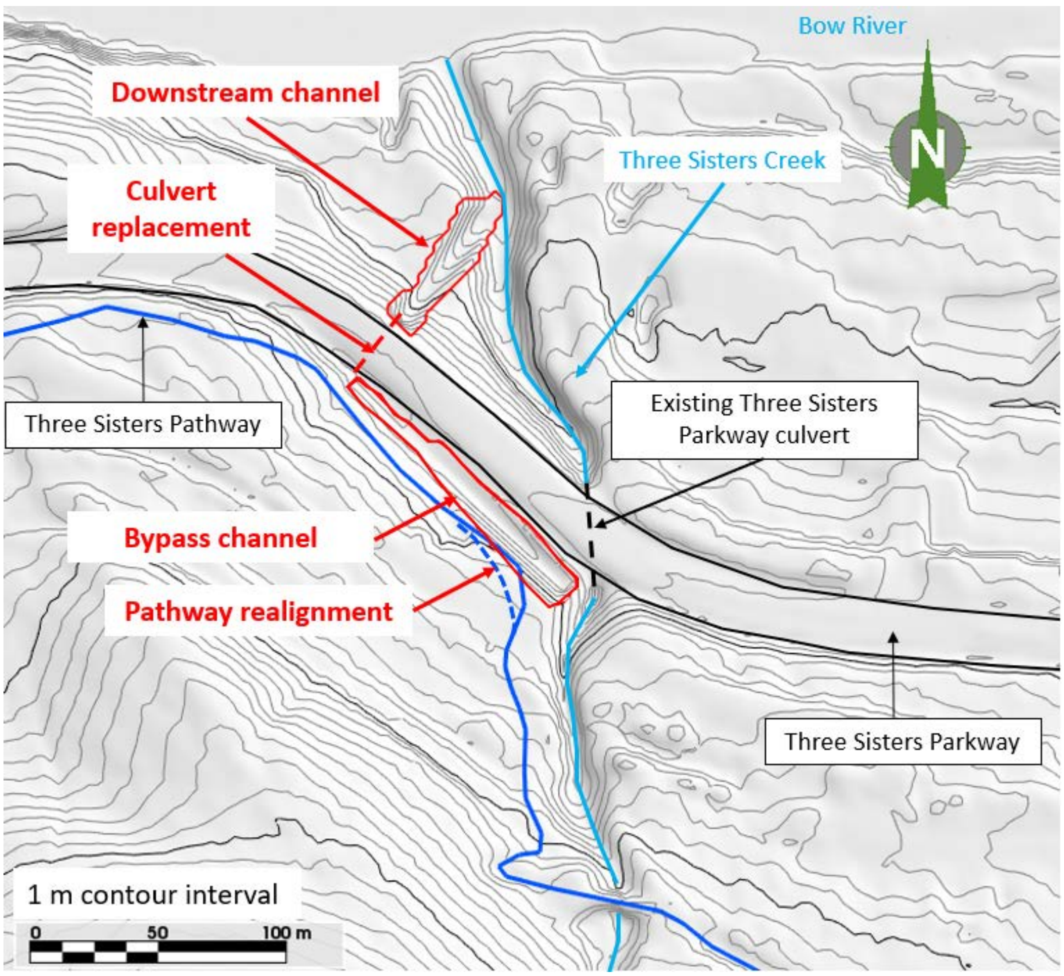

Figure 5-20. Option E-1: Schematic illustration of bypass channel, culvert replacement and downstream channel to redirect overflow from the TSP culvert to main channel. Channel alignments are approximate and based on the 100 to 300-year event; the shapes and locations may change during preliminary design. Topography based on lidar flown in 2015.

5.6.2.3. Option E-2 – Overflow with Channel

At the Three Sisters Creek crossing, TSP slopes towards the northwest. Flow overtopping the channel will follow this grade with the exception of the component of flow that impacts Crossbow Landing. In Option E-2 water would be allowed to flood and overflow TSP which is distinct from option E-1 where water would not be allowed to discharge over TSP. An overflow channel could be constructed on the north side of TSP to the west of the culvert to tie into the existing channel downstream. This option was proposed by SweetCroft (April, 2015), and modified by BGC to include a channel instead of an erosion apron. The proposed location is shown on Drawing 02.

BGC considered two overflow channel options:

- Option E-2a – Riprap channel
- Option E-2b – Natural swale.

Both options would convey overflow from the main TSP culvert during 30 to 100-year and greater return period events. Given the estimated overflow peak discharges for the higher return periods considered and the gradient of the channel required to convey flows from TSP to the existing channel, a natural swale would have insufficient erosion resistance associated with debris flood events.

For this reason, Option E-2a was **selected for further assessment** and Option E-2b was **rejected following BGC review**.

In 2018, the ToC and Alberta Transportation completed erosion mitigation works along the Three Sisters Creek channel between the footbridge along the hiking trail and the Bow River (Drawing 02) (SweetTech, October, 2018). The riprap overflow channel could be designed to complement the existing erosion protection works completed in 2018.

Conceptual Design

The following describes the conceptual design for the riprap channel (Option E-2a) (Figure 5-21):

- The channel location, layout, and dimensions are selected to tie into the existing topographic low on TSP and outlet downstream of the stone pitching installed in 2018 to minimize impacts to the existing mitigation works (Figure 5-21).
- Regrading of TSP would be required to direct flow into the overflow channel, as although there is a natural low in the road, it currently continues to slope to the west allowing flow to continue down TSP rather than back into the Three Sisters Creek channel. The extent of regrading has not been assessed for this options analysis and would need to be determined during preliminary design.
- The channel is designed to accommodate the estimated peak overflow for an 1,000- to 3,000-year event (Table 2-1, BGC, October 9, 2020) assuming the existing TSP culvert capacity is 23 m^3/s (BGC, October 14, 2016).

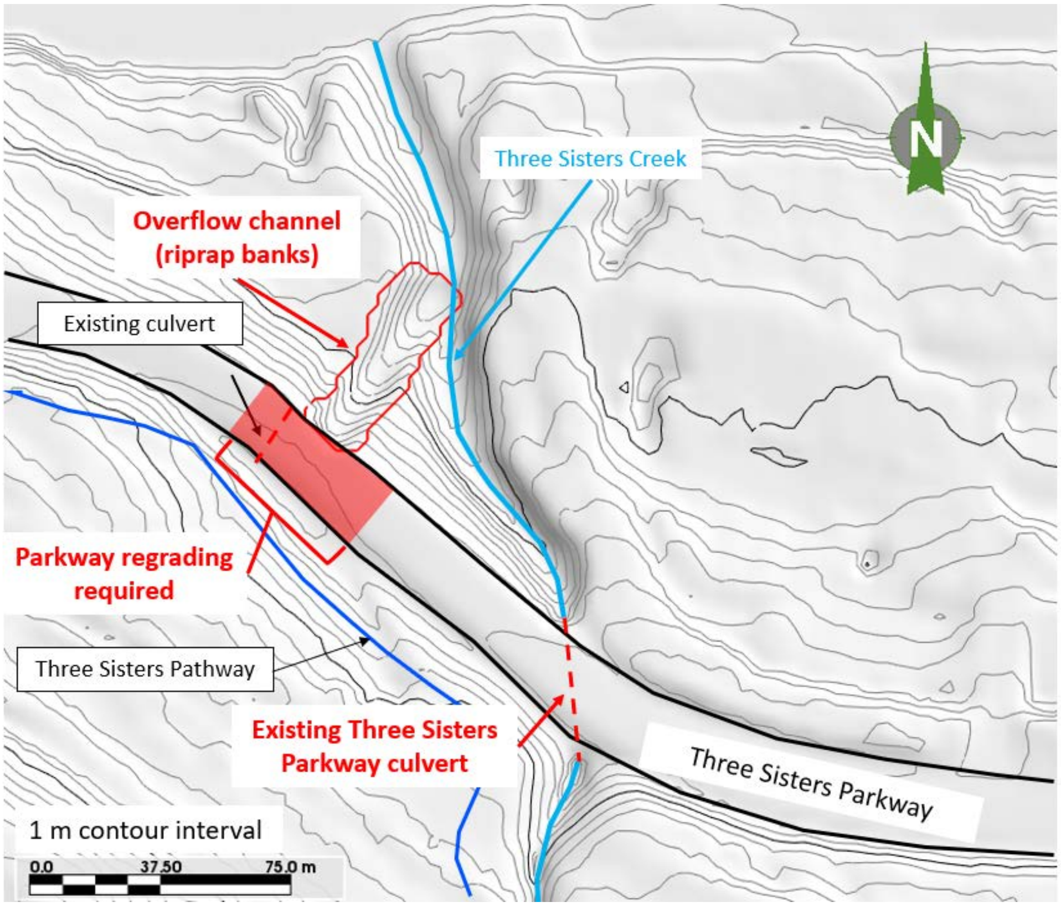

Figure 5-21. Option E-2a: Schematic illustration of overflow channel to redirect overflow from TSP culvert to main channel. Red shaded area indicates approximate section of TSP that may require regrading. Channel alignment is approximate; the shape and location may change during preliminary design. Topography based on lidar flown in September 2015.

- The channel is 54 m long, 2.8 m deep, with 1.8H:1V (55%) slopes.
- The channel banks are protected from erosion with riprap and stone pitching.
- It is assumed that repairs to erosion protection will be required over the projected 50-year design life of the channel.

Cost Estimate

The estimated capital cost of the overflow channel and TSP regrading is $500,000. The operation and maintenance costs (NPV) over the 50-year project lifecycle of the channel is estimated to be $60,000 for either return period (Appendix B). Combined, the total mitigation lifecycle cost of this option is $560,000 (50-year NPV).

Risk-Reduction Benefit

BGC estimates the risk-reduction benefit of this option is $100,000. The only infrastructure downstream of TSP is Crossbow Landing on the northeast side of the crossing. The channel does not prevent flow from reaching Crossbow Landing and therefore does not reduce building risk and life loss risk to existing development for any of the return periods considered (Section 4.1.1). It is estimated that this option reduces risk to TSP by 50% for all return periods considered.

Cost-Benefit Ratio

The cost-benefit ratio for the overflow channel is 0.18.

Advantages and Disadvantages

The primary advantages of the overflow channel are the low lifecycle costs relative to other options.

The primary disadvantages of the overflow channel are the low risk reduction, the need to regrade TSP and the potential for erosion associated with uncontrolled overland flow when the existing TSP culvert overtops. The overflow channel does not protect the existing TSP box culvert from blockage or damage, nor does it prevent overland flooding into the existing Crossbow Landing residential development.

5.6.2.4. Option E-3 – Replace Three Sisters Parkway Culvert

The TSP culvert could be replaced to increase the capacity at the crossing (Drawing 02). To accommodate the 100 to 300-year return period debris flood, the culvert could be replaced with a larger span or two smaller span culverts. In order to accommodate the 1,000 to 3,000-year return period debris flood, the culvert would likely need to be replaced with a larger bridge or a very large culver. A bridge was assumed for the purposes of this assessment. This option was **selected for further assessment.**

Conceptual Design

Table 5-11 provides conceptual level options to replace the TSP culvert. The information presented is only for the purpose of describing the available options at a conceptual level and dimensions of the structure(s) would need to be refined during preliminary design. The estimated dimensions are based on the following assumptions:

- Replacement culvert(s) would be concrete box culverts with angled wingwalls at the inlet and no headwall above the thickness of the precast slab (see Figure 5-22 for parts of a culvert).
- Culvert capacity was estimated assuming no surcharge[10] at the inlet.

Table 5-10. Conceptual culvert replacement dimensions. The dimensions would need to be refined in preliminary design.

Return Period	Peak Discharge (m^3/s)	Design Needed	Approximate Opening Dimensions	
100 to 300-year	50	Box Culvert	Single	7 m wide by 2.6 m high
			Double	4 m wide by 2.5 m high
1,000 to 3,000-year	112	Bridge (Figure 5-23)	Option A	10 m wide base by 3 m high with channel banks at 1H:1V
			Option B	12 m wide base by 2.5 m high with channel banks at 1H:1V

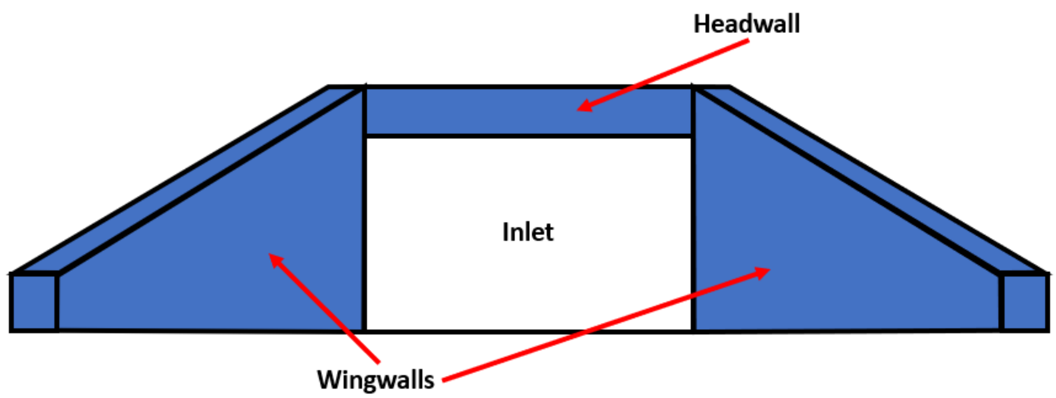

Figure 5-22. Sketch of the main parts of a box culvert inlet.

[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.

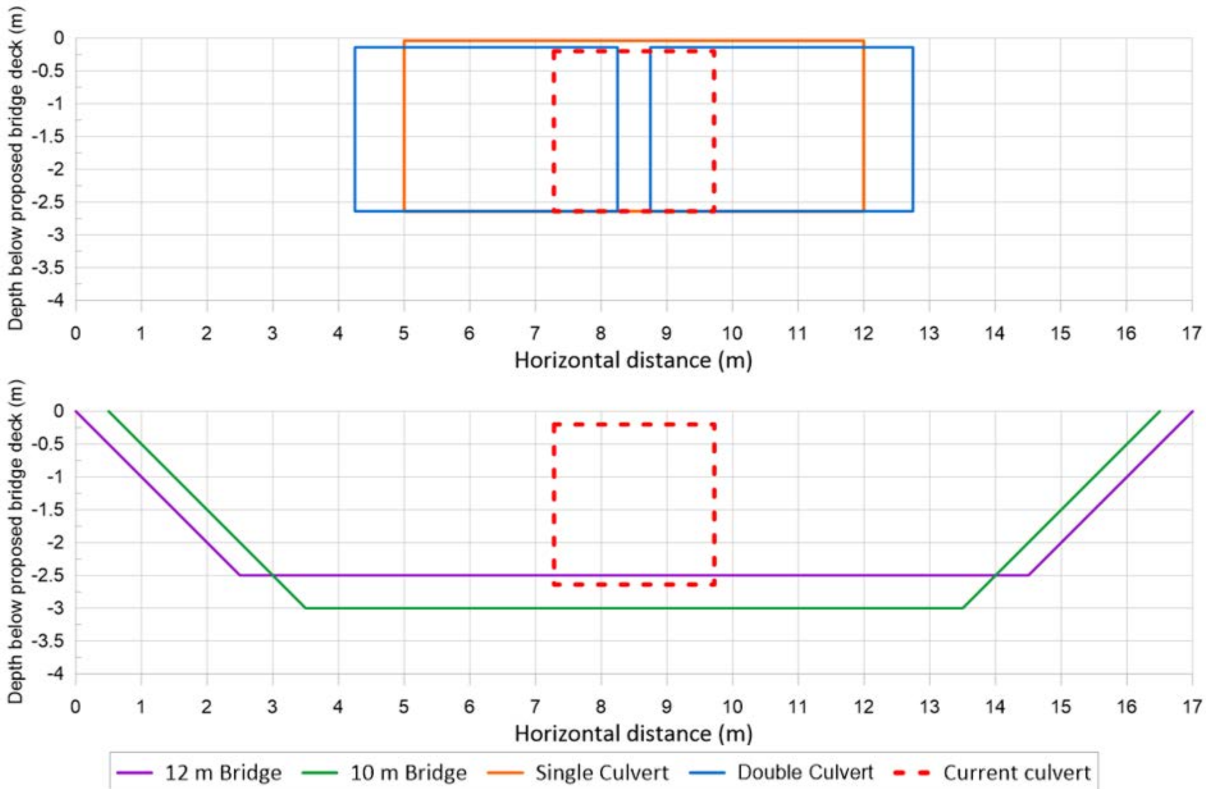

Figure 5-23. Comparison between current culvert size (red dashed line) at TSP and proposed replacement options for the 100 to 300-year return period (top graph) and the 1,000- to 3,000-year return period (bottom graph). For the purposes of this analysis, a replacement bridge deck was assumed to be 1 m deep to compare to the current inlet elevation of the culvert.

Cost Estimate

The estimated capital cost of the TSP culvert replacement is $1.3 Million for a 100 to 300-year return period design event (culvert), and $5.6 Million for a 1,000 to 3,000-year return period design event (bridge). The large price difference is mainly due to the increased cost of bridge materials and installation compared to a concrete box culvert. The operation and maintenance costs (NPV) over the 50-year project lifecycle of the structure are estimated to be $180,000 for either return period (Appendix B). Combined, the total mitigation lifecycle cost ranges from $1.5 Million to $5.8 Million (50-year NPV for the 100 to 300-year and 1,000 to 3,000-year return period design events, respectively).

Risk-Reduction Benefit

BGC estimates the risk-reduction benefit of a TSP culvert replacement is $1.8 Million when designed for a 100 to 300-year debris flood event (the design event). The anticipated additional risk reduction if designed for the 1,000 to 3,000-year debris flood would be small and has not been quantified. The risk reduction benefit assumes that the TSP replacement reduces building and life loss risk at Crossbow Landing. Economic risk to TSP is fully (100%) reduced when designed for the appropriate return period event (100 to 300-year or 1,000 to 3,000-year). The total estimated economic risk of damage and to repair TSP is $1.3 Million (see Appendix A). BGC assumed for this options analysis that the economic risk to TSP would be the same for both a 100 to 300-year event and a 1,000 to 3,000-year event.

Cost-Benefit Ratio

The cost-benefit ratio for the TSP replacement is 1.2 for the 100 to 300-year return period design event and 0.31 for the 1,000 to 3,000-year return period design event.

Advantages and Disadvantages

The primary advantage of the TSP replacement is that it reduces risk to the TSP culvert and roadway. This corridor provides secondary access into Canmore and notably was the only route in and out Canmore during and immediately after the 2013 debris flood. BGC understands that TSP may not be as essential as an access route when the Cougar Creek structure is completed.

In comparison with other mitigation options at the crossing location, this option does not require construction of auxiliary channels or berms to direct flow back towards the main channel. Construction of a larger culvert or bridge reduces the potential for blockage of the culvert by woody debris or sediment by increasing the size of the opening for the channel to pass at the crossing. Blockages by woody debris or sediment would further reduce the capacity. A larger opening also facilitates easier sediment removal and has the potential to reduce ongoing maintenance costs.

The primary disadvantage of the TSP replacement is the high capital cost and that the 100 to 300-year debris flood design event selected in this analysis exceeds the current Alberta Transportation standards. As Alberta Transportation are the owners of the road infrastructure, selection of the appropriate mitigation design at TSP will need to be selected in consultation with Alberta Transportation.

5.6.2.5. Option E-4 – Northeast Deflection Berm

SweetCroft (April 2015) proposed a deflection berm on the east side of Three Sisters Creek downstream of TSP (Figure 5-24, Drawing 02). The berm would prevent flow from overtopping the channel and avulsing northeast into the adjacent residential development. The berm, in isolation, would not prevent all flows from entering the residential development as upstream avulsions that overtop TSP and flow north along Crossbow Place and into the development were identified during numerical modelling by BGC (October 9, 2020).

This option was **selected for further assessment.** It could be combined with replacing the TSP culvert to convey the 100 to 300-year debris flood. If the culvert is replaced with a bridge with sufficient capacity to convey the 1,000 to 3,000-year debris flood, the deflection berm would not be required.

Conceptual Design

The following describes the conceptual design:

- The berm location, layout, and dimensions are based on the design proposed by SweetCroft (April 2015). BGC decreased the overall length of the berm from 159 m proposed by SweetCroft to 90 m based on the BGC (BGC, October 9, 2020) model results.
- The berm is 1.5 m high, has 1.5 m crest width with 1.5H:1V slopes.
- The creek side face is protected from erosion with riprap, and downstream face is vegetated with grass.
- The berm can divert 100 to 300-year and 1,000 to 3,000-year return period flows.
- It is assumed that repairs to erosion protection will be required over the projected 50-year design life of the structure.

Cost Estimate

The estimated capital cost of the northeast deflection berm is $100,000. The operation and maintenance costs (NPV) over the 50-year project lifecycle of the berm is estimated to be $40,000 for either return period (Appendix B). Combined, the total mitigation lifecycle cost of this option is $140,000 (50-year NPV).

Risk-Reduction Benefit

BGC estimates the risk-reduction benefit of this option is $200,000. This estimate assumes that the deflection berm protects Crossbow Landing from flooding. Life loss risk to existing development is reduced to negligible at Crossbow Landing. There is no risk reduction to TSP.

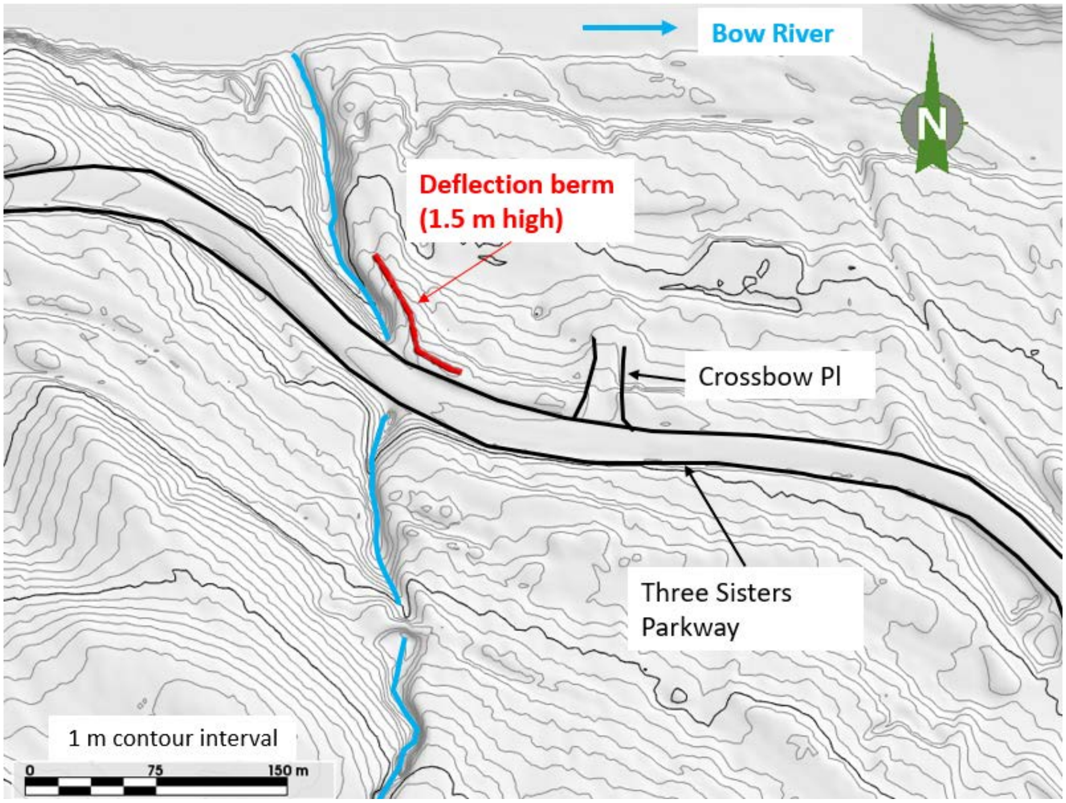

Figure 5-24. Option E-4: Schematic illustration of northeast deflection berm. Berm alignment is approximate; shape and location may change during preliminary design. Base topography from lidar flown in September 2015.

Cost-Benefit Ratio

The cost-benefit ratio for the deflection berm is 1.42.

Advantages and Disadvantages

The primary advantages of the deflection berm are the low lifecycle costs and high cost-benefit ratio and simple construction access due to the location adjacent to TSP.

The primary disadvantage of the deflection berm is that it does not improve conveyance or reduce risk to TSP or the existing culvert. As a result, it only partially achieves the mitigation objectives at this location by protecting the existing development but not TSP. This option would also occupy land that is currently used by residents of Crossbow Landing as recreation space.

5.6.3. Summary Comparison

Four mitigation options were considered at Three Sisters Parkway as well as an option that doesn't introduce any new measures ("no new measures") (Table 5-7). Four of these options were selected for further assessment. The lifecycle cost, risk reduction and cost-benefit ratio for these options are outlined in Table 5-11.

Table 5-11. Comparison of cost-benefit for TSP mitigation options selected for further assessment.

Option	Description	Lifecycle Cost (50-year NPV)	Risk-Reduction Benefit	Cost-Benefit Ratio
Option E-0	No New Measures	-	-	1.0
Option E-2	Overflow with channel	$560,000	$100,000	0.18
Option E-3	Replace TSP culvert (100 to 300-year)	$1.5 Million	$1.8 Million	1.20
	Replace TSP culvert (1,000 to 3,000-year)	$5.8 Million	$1.8 Million	0.31
Option E-4	Northeast deflection berm	$140,000	$200,000	1.42

As outlined in Section 5.6.1, the mitigation objectives at the TSP crossing are to reduce economic and life loss risk at the Crossbow Landing development, reduce economic risk associated with damage and closure of TSP, and increase the likelihood that TSP remains operational as a transportation corridor during debris floods. Of the mitigation options considered at this location, replacing the TSP culvert (Option E-3) is the only option that achieves all objectives.

Option E-2 partially achieves the objectives by reducing risk to TSP. Option E-4 protects the buildings, and consequently reduces life-loss risk to the development but does not reduce risk to TSP.

The remaining four options are included in the detailed options analysis; however, BGC does not recommend the overflow with channel (Option E-2) as it only partially achieves the mitigation objectives and does not protect Crossbow Landing. Table 5-11 demonstrates that greatest cost-benefit ratios are for the northeast deflection berm, replacing the TSP culvert with a culvert sized for the peak discharge of the 100 to 300-year debris flood design event and the option to complete no new measures. With the latter option, BGC expects that at the end of the design life of the existing TSP culvert, selection of a replacement of adequate sizing for the debris flood design event would be considered by AT in consultation with the ToC.

This work demonstrates a substantially lower cost-benefit for the design of a TSP replacement aimed to protect against less frequent debris-flood events.

5.7. Recommendations for Detailed Options analysis

BGC recommended that from the 25 identified mitigation options, the fourteen options that were selected for further assessment be carried forward into the detailed options analysis (Table 5-12). The options that were rejected without further assessment or following BGC review are not included.

Table 5-12. Options selected for further assessment and brought forward for detailed options analysis.

Zone	No.	Mitigation Options	Capital Cost[1]	Operation & Management Cost[1]	Risk Reduction Benefit	Cost-Benefit Ratio
Fan Apex	A-2	Debris Retention Basin (100 to 300-year)	$4.9 Million	$800,000	$3.6 Million	0.61
		Debris Retention Basin (1,000 to 3,000-year)	$6.1 Million	$800,000	$4.2 Million	0.62
Upper Channel	B-4a	East Apex Deflection Berm (outside of wildlife corridor)	$2.1 Million	$100,000	$2.7 Million	1.2
	B-4b	East Apex Deflection Berm (within wildlife corridor)				
	B-5	Wide Channel and Floodplain	$4.8 Million	$100,000	$7.9 Million	1.6
Golf Course Pond	C-0	No New Measures	-	-	-	1.0
	C-2	Bypass Channel at Pond Outlet	$1.7 Million	$100,000	$130,000	0.07
	C-3	Replace AltaLink Bridge	$8.1 Million	$300,000	$130,000	0.02
	C-4	Woody Debris Management	$400,000	$400,000	$290,000	0.34
Lower Channel	D-0	No New Measures	-	-	-	1.0
	D-3	Lower Setback Berms	$800,000	$100,000	$50,000	N/A
	D-5	Woody Debris Management	$100,000	$200,000	$600,000	1.9
Three Sisters Parkway	E-0	No New Measures	-	-	-	1.0
	E-2	Overflow with Culvert	$500,000	$60,000	$100,000	0.18
	E-3	Replace TSP Culvert (100 to 300-year)	$1.3 Million	$200,000	$1.8 Million	1.20
		Replace TSP Culvert (1,000 to 3,000-year)	$5.6 Million	$200,000	$1.8 Million	0.31
	E-4	Northeast Deflection Berm	$100,000	$40,000	$200,000	1.42

Note:

1. Capital cost and operation and management cost combine to the lifecycle cost.

6. DETAILED OPTIONS ANALYSIS

This section outlines the comparison process applied to analyse the mitigation options selected for further assessment. The analysis follows the KT Method (described in Section 4) wherein key factors for consideration (for example economic, life loss, environmental, permitting) and their relative importance (weightings expressed as numbers from 1 to 5) are defined and then assessed. The factors and representative weightings were initially defined by BGC and were then refined by input from stakeholders after the option analysis workshops for transparency and to consider a spectrum of stakeholder priorities.

Numerical values were assigned for each factor and combined with the weighting, to arrive at a total score for each mitigation option. The options are ranked based on the total score. This process was completed for each zone on the Three Sisters Creek fan (Figure 5-1) as the full mitigation system will require elements in more than one zone. The outcome of the KT Method was informed by and complemented with consideration of the lifecycle costs, anticipated performance, feasibility to construct, and environmental, aesthetic and recreational impacts of each mitigation option as described in the coming sections.

Section 6.1 describes the factors while Section 6.2 summarises the weightings applied to each factor. Section 6.3 outlines the comparison of mitigation options and full-fan mitigation systems that integrate options from each mitigation zone.

6.1. Factors

Factors considered in the KT Method describe the priorities that potential options are evaluated against. The following sections discuss the factors that were selected to assess mitigation options at Three Sisters Creek fan. Factors are each rated on a five-point scale, that are shown in Appendix C.

This options analysis did not consider all possible factors that could be evaluated. The analysis focused on factors that differentiated the options. Additional work will be required during future design phases to assess other key factors required for the environmental assessment and permitting process. Notably, ownership of the land where the mitigation options would be located was not considered as a factor in the KT analysis.

6.1.1. Risk Factors

The three risk factors that were considered in the ranking were:

- **Economic and life-loss risk reduction**: reduction relative to the BGC (January 11, 2018) risk assessment baseline that considered risk to existing development on the east side of fan.
- **Infrastructure protection**: the degree mitigation protects existing and proposed infrastructure.
- **Risk transfer avoidance**: the degree to which mitigation avoids transferring risk to downstream elements, for example an option that concentrates flow within the channel

and increases the peak discharge that reaches a downstream location is transferring risk downstream and would receive a low ranking for this factor.

6.1.2. Economic Factors

The three economic factors that were considered in the ranking were:

- **Cost-benefit**: the lifecycle costs (capital and 50-year operation and maintenance costs) for a mitigation option compared to the life loss and economic risk reduction.
- **Capital cost**: the capital costs of installation for a mitigation option.
- **Operation, management and recovery cost**: the operation, maintenance and repair costs after an event that may include sediment removal or erosion protection repair.

6.1.3. Environmental and Social Factors

The two environmental and social factors that were considered in the ranking were:

- **Habitat, wildlife corridor and riparian impacts**: alteration or encroachment on wildlife habitat.
- **Aesthetic and recreation**: creation or change to existing recreation infrastructure as well as the possibility of aesthetic improvement.

6.1.4. Technical Factors

The two technical factors that were considered in the ranking were:

- **Likelihood of functioning as intended**: the likelihood that the mitigation will function as intended when the design event occurs and does not cause unforeseen adverse effect (for example, if the mitigation requires storage capacity, this factor considers the likelihood that the design capacity will be available at the time of the event through regular maintenance).
- **Risk of delay due to permitting**: estimation based on type of permitting that may be required (e.g. Wildlife corridor changes, in stream works).

6.2. Weightings

Each factor was assigned a weighting from one to five to show the importance of the factor to stakeholders (1 being less important, 5 being most important). Table 6-1 shows the weightings assigned for each factor.

Table 6-1. Summary of weightings applied to each factor for ranking of mitigation options.

Factor Category	Factor	Weighting
Risk	Economic and life-loss risk reduction	5
	Infrastructure protection	4
	Risk transfer avoidance	3
Economic	Cost-benefit	4
	Capital cost	3
	Operation, management and recovery cost	2
Environment and social	Habitat, wildlife corridor and riparian impacts	4
	Aesthetics and recreation	2
Technical	Likelihood of functioning as intended	4
	Risk of delay due to permitting	2

6.3. Summary Comparison

Table 6-2 shows the scoring for each mitigation option selected for further assessment from Section 5. The table is arranged to compare mitigation options within each zone.

Table 6-2. Summary comparison of debris-flood mitigation options selected for further assessment from all zones and selected combinations of mitigation options.

Mitigation Option (by zone)	Factor	Economic & Life-loss Risk Reduction	Infrastructure Protection	Risk Transfer Avoidance	Cost-Benefit	Capital Cost	Operation, Maintenance & Recovery Cost	Habitat, Wildlife Corridor and Riparian Impacts	Aesthetics and Recreation	Likelihood of Functioning as Intended	Duration of Regulatory Approval	Total Score	Rank
	Weighting	5	4	3	4	3	2	4	3	4	3		
Fan Apex and Upper Channel													
A-2 Debris retention basin		4	3	5	2	1	2	2	2	3	1	88	4
B-4a East apex deflection berm (outside of wildlife corridor)		3	3	4	3	4	4	3	3	2	4	105	3
B-4b East apex deflection berm (within wildlife corridor)		4	3	4	3	3	4	3	3	3	2	107	2
B-5 Wide channel and floodplain		5	3	2	4	2	4	3	3	4	2	111	1
Golf Course Pond													
C-0 No new measures		1	2	5	3	5	5	3	3	3	5	105	1
C-2 Bypass channel at pond outlet		2	3	3	1	3	4	2	2	4	3	86	3
C-3 Replace AltaLink bridge		2	4	5	1	1	5	3	3	5	2	100	2
C-4 Woody debris management		1	3	5	1	5	5	3	1	2	5	93	4
Lower Channel													
D-0 No new measures		1	2	5	3	5	5	3	3	3	5	105	2
D-3 Lower setback berms		3	2	3	4[2]	4	4	3	3	4	4	110	1
D-5 Woody debris management		2	3	4	4	4	4	2	2	3	3	100	3
Three Sisters Parkway Crossing													
E-0 No new measures		1	2	5	3	5	4	3	3	3	5	103	3
E-2 Overflow with culvert		2	3	4	1	4	3	2	2	3	2	84	4
E-3 Replace Three Sisters Parkway culvert[3]		3	4	5	3	3	5	4	4	5	2	125	1
E-4 Northeast deflection berm		2	2	4	4	5	4	3	2	4	4	109	2

Notes:

1. Factor ranking scale is from one to five, with one being least desirable to five being most desirable. For factor scales see Appendix C.
2. The cost-benefit for the lower setback berms is a qualitative estimate considering that the risk-reduction benefit to the proposed development is high compared with the cost of the berms. It does not follow the factor scales.
3. Considers Three Sisters Culvert is replaced with a culvert designed to pass the peak flow associated with a 100 to 300-year return period event.
4. Do nothing options assigned "3" for cost-benefit ratio

7. CONCLUSIONS AND RECOMMENDATIONS

As requested by QPD on behalf of TSMV and in collaboration with the ToC, BGC completed a debris-flood mitigation options analysis to evaluate mitigation alternatives to reduce debris-flood impact to existing and proposed development on the Three Sisters Creek fan. The analysis started with a comprehensive list of mitigation options developed by SweetCroft (April, 2015). Additional options and option modifications were developed by BGC as part of this options analysis. In total, 25 mitigation options were identified.

BGC reviewed the mitigation options list with respect to design objectives and construction feasibility. Based on this review, ten of the original options were rejected and fourteen options were selected for further assessment. Each of the fourteen options were assessed further to estimate capital cost and risk reduction, and develop conceptual level design sketches.

Using the factors and weightings developed by QPD and the ToC at the option analysis workshops, the results of the detailed options analysis show that a mitigation system consisting of the option combination shown in Table 7-1 optimizes the overall score while meeting the design objectives.

Table 7-1. Summary of BGC recommended mitigation system.

No.	Option	Life Cycle Cost for 100 to 300-year Return Period
B-5	Wide Channel and Floodplain	$4.9 Million
C-4	Woody Debris Management	$0.8 Million
D-3	Lower Setback Berms	$0.9 Million
E-3	Replace Three Sisters Parkway Culvert	$2.4 Million
	Total	**$9.0 Million**

Note:

1. AltaLink Bridge has capacity to pass the 100 to 300-year return period debris flood, no mitigation required to protect bridge.

BGC recommends the above option combination as the preferred mitigation. It protects existing and proposed development efficiently from a cost and technical perspective while reducing operation and management costs. At the 100 to 300-year return period, mitigation is not required at the GCP as the AltaLink Bridge has sufficient capacity to convey the peak discharge, while small avulsions at low points of the GCP banks are likely tolerable; however, woody debris management will support the performance of the bridge by reducing the likelihood of blockage and/or conveyance of woody debris to the downstream reach.

The lower setback berm option could be excluded from the mitigation system or replaced with changes to the grades and elevation in the proposed development depending on budgetary constraints as the residual economic risk from small shallow avulsions is likely tolerable. BGC is outlining a workplan for a residual risk analysis to be completed as part of a separate scope of work. Alberta Transportation may wish to consider delaying the culvert replacement to the end of the existing culvert design life, which BGC understands to be approximately 30 years, as it has sufficient or close to sufficient capacity to convey the peak discharge associated with debris floods with return periods up to 100-years based on historical and current conditions. For return periods in excess of 100-years, flows would be expected to overtop the culvert.

BGC recommends woody debris management as an additional method to protect the TSP crossing if the mitigation budget allows. The estimated life cycle costs for woody debris managements for the 100 to 300-year return period is $300,000.

The combination of options recommended by BGC unites the current understanding of debris-flood physics and mitigation experience with a functional and aesthetically pleasing design.

The mitigation options, as presented in this report, are at a conceptual level of design. It is anticipated that the location, geometry and cost estimates will be refined during preliminary design which will follow upon an agreement of mitigation options.

8. CLOSURE

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

Yours sincerely,

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APPENDIX A
WORKSHOP 2 FOLLOW-UP MEMO

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Project Memorandum

To:	**QuantumPlace Developments, Town of Canmore**	**Doc. No.:**	
Attention:	**Chris Ollenberger, Phil Wareham, Felix Camire, Andy Esarte**	**cc:**	
From:	**Lauren Hutchinson, Beatrice Collier-Pandya**	**Date:**	**October 8, 2020**
Subject:	**Three Sisters Creek Workshop 2 Follow-Up on Requests for Additional Analysis – FINAL REV 1.**		
Project No.:	**1531005**		

1.0 INTRODUCTION

On August 4, 2020, BGC hosted a workshop with QuantumPlace Developments (QPD) and the Town of Canmore (ToC) to advance selection of a preferred debris-flood mitigation system on Three Sisters Creek fan. In the workshop, a series of action items came about from discussion between BGC, QPD, and ToC to support decision making. QPD requested that BGC complete the suggested tasks:

1. Confirm life safety risk at Crossbow Landing.
2. Evaluate the influence of pond water elevation and sediment in the Golf Course Pond (GCP) on the model results.
3. Estimate the cost to repair Three Sisters Parkway (TSP) to be included in the risk reduction benefit of mitigation options at TSP.
4. Add woody debris management as an option at the GCP.
5. Evaluate debris flood impacts to existing development with proposed mitigation in place.
6. Consider reducing the GCP capacity.

This memo summarizes the additional analyses completed by BGC to respond to the tasks outlined above. The purpose of the memo is to communicate the findings and request comments from QPD and the ToC. The comments will inform the selection of the preferred debris-flood mitigation system on Three Sisters Creek fan and will be reflected in the Mitigation Options Analysis Report and Conceptual Design Report, as appropriate.

2.0 TASK 1 –LIFE SAFETY RISK AT CROSSBOW LANDING

The ToC suggested that BGC confirm the life safety risk to properties at Crossbow Landing (Figure 2-1) to inform the selection of appropriate mitigation measures at the TSP crossing, if any. In this task, BGC considered the three parcels closest to TSP and the creek (ID 1965702, 2019134, 199775) given the buildings on these properties are impacted by 100- to 300-year return period debris floods in the 2020 numerical model results.

Figure 2-1. Screen capture from the Town of Canmore Property Information Viewer ArcGIS Online site showing Crossbow Landing and the individual parcel IDs. Screen capture taken on September 2, 2020.

2.1. Previous Assessments

2.1.1. 2015 Risk Assessment

BGC completed a risk assessment for Three Sisters Creek in 2015 (BGC, January 20, 2015). The assessment showed that, based on debris-flood modelling completed in 2014, there were no existing parcels on the Three Sisters Creek fan with a probability of death of an individual (PDI) that exceeds the Town of Canmore threshold for existing development (1:10,000) (Town of Canmore, Municipal Development Plan, 2016). In the 2015 assessment, three parcels exceeded the ToC's PDI threshold for proposed development (1:100,000). One of these parcels is within Crossbow Landing (ID 1965702) and corresponds to the northwest property in the development (Figure 2-1). The other two properties with PDI >1:100,000 are located further east and upstream. The life safety risk at properties outside of Crossbow Landing were not reviewed as part of this task.

2.1.2. 2016 Mitigation Modelling and 2018 Risk Assessment Update

BGC completed additional debris flood modelling in 2016 to support the selection and design of mitigation works at TSP (BGC, October 14, 2016). The 2016 model results did not show any debris-flood impacts to Crossbow Landing for the 30-100-year and 100- to 300-year debris flood return periods. The 2016 model results informed a risk update in 2018 that reflected the risk reduction to Crossbow Landing (BGC, January 11, 2018).

2.1.3. 2020 Hazard Assessment Update

In 2020, a hazard assessment update for the full Three Sisters Creek fan was completed with updated modelling (BGC, August 28, 2020). The hazard assessment includes updates to previous assessments to consider climate change impacts to debris floods on Three Sisters Creek. The 2020 numerical model results show impacts to Crossbow Landing for the 100- to 300-year, 300 to 100-year, and 1000 to 3000-year return periods.

2.1.4. Comparison of Model Results

The model grid sizes, peak discharges, and model initiation locations used for each iteration of modelling are summarized in Table 2-1. Note, the 2020 model results do not include any of the proposed mitigation works in place.

Table 2-1. Differences in 2016 and 2020 numerical models for the 100 to 300-year return period.

Model	Grid size (m)	Peak discharge (m^3/s)	Model Initiation Location	Crossbow Landing Impacted
2014	5	45	Fan apex	Yes
2016	2	45	Three Sisters Pathway bridge	No
2020	4	50	Fan apex	Yes

The differences in the inundation extents between the different model years reflect the differences in the variables summarized in Table 2-1. The initiation location influences the overall inundation extents given the potential for avulsions upstream of the GCP when the creek has aggraded and no mitigation works are in place. The flow depth, velocity, and intensity at the three parcels reviewed in this task (IDs 1965702, 2019134, 1997775) for each model year are summarized in Table 2-2.

As is illustrated from the different model results between 2014 and 2020, the buildings impacted in Crossbow Landing are on the boundary of what might be impacted in a 100 to 300-year debris flood. In the first workshop to support the mitigation options analysis work on July 2, 2020, BGC, QPD and the ToC agreed that the 100 to 300-year event is a reasonable design event starting point for future work. Thus, the Crossbow Landing area should be thought of as within the range of uncertainty of the model results where small changes in the model inputs result in different inundation extents.

Table 2-2. Summary of debris flood model results completed in 2014, 2016, and 2020 (BGC, August 28, 2020).

Parcel ID	Return Period	2014[3]			2016[4]			2020[5]		
		Flow Depth (m)	Velocity (m/s)	Intensity (m^3/s^2)	Flow Depth (m)	Velocity (m/s)	Intensity (m^3/s^2)	Flow Depth (m)	Velocity (m/s)	Intensity (m^3/s^2)
1965702	10-30	-	-	-	-	-	-	0	0	0
	30-100	0.1	0.1	0.0	-	-	-	0	0	0
	100-300	1.3	0.3	0.1	0	0	0	0.4-0.5	0.2	0.01-0.02
	300-1000	1.9	0.4	0.2	-	-	-	2.4-2.5	0.4-0.9	0.3-1.9
	1000-3000	1.9	1	0.3	-	-	-	2.4-2.6	0.8-0.9	1.6-2.0
2019134	10-30	-	-	-	-	-	-	0	0	0
	30-100	0.03	0.2	0.0	-	-	-	0	0	0
	100-300	0.1	0.6	0.02	0	0	0	0.03-0.06	0.2	0.0
	300-1000	0.1	0.6	0.03	-	-	-	0.1-0.3	0.4-0.8	0.03-0.2
	1000-3000	0.1	0.8	0.1	-	-	-	0.2-0.3	0.9-1.6	0.2-0.5
1997775	10-30	-	-	-	-	-	-	0	0	0
	30-100	0	0	0	-	-	-	0	0	0
	100-300	0	0	0	0	0	0	0-0.1	0-0.2	0.0
	300-1000	0.03	0.1	0.2	-	-	-	0-0.9	0-1.9	0-3
	1000-3000	0.1	0.2	0.2	-	-	-	0.04-0.9	1.3-2.1	0-3.9

Notes:

1. "-" indicates no results for that return period.
2. "0" indicates the building on the parcel was not impacted by flow.
3. The 10 to 30-year return period was not included in the 2014 risk assessment.
4. The 2016 modelling was only completed for the 100 to 300-year return period.
5. The 2020 model results show a range that represents the range for the scenarios considered (Table 3-6 in BGC's updated hazard assessment (BGC, August 28, 2020)).

2.2. Calculation of Life Safety Risk

Calculation of life safety risk at the three parcels considered, followed the methodology outlined in BGC's 2015 work (BGC, January 19, 2015) using the 2020 numerical model results. Debris-flood scenarios with return periods ranging from 10 to 3000 years were all considered (scenarios 1a-5c of the 2020 model results as outlined in Table 3-6 in BGC's updated hazard assessment (BGC, August 28, 2020)). None of the scenarios include the proposed upstream mitigation works.

The vulnerability was calculated based on the flow depth and the flow intensity ($velocity^2 x\ flow\ depth$). When the flow depth is less than 0.3 m, the vulnerability is set as zero. When the flow depth exceeds 0.3 m, the intensity of the flow is used to determine the vulnerability. These criteria are based on known events and comparison to results calculated from published mortality functions for large scale river floods and have been applied in Canmore, MD Bighorn, Seton Portage (Squamish-Lillooet Regional District), and the District of North Vancouver (BGC, January 20, 2015).

The results are summarized in Table 2-3. As shown, none of the properties exceed the tolerable threshold for existing development (1:10,000). Two properties exceed the tolerable threshold for proposed development (1:100,000) by a factor of approximately 2 to 3. Parcel ID 1997775 was not previously identified in the 2015 or 2018 assessments. The life safety risk at this property is controlled by scenarios 4b, 4c, 5b, and 5c (Table 3-6 in BGC, August 28, 2020) that correspond to the 300 to 1000-year and 1000 to 3000-year return periods assuming an aggraded channel (2013 topography) (4b, 5b) and on the current (2015) topography with a channel blockage near the fan apex. In these scenarios, avulsions in the upper reach (upstream of the GCP) inundate downstream developed areas on the east side of the creek.

Table 2-3. Life safety risk for three parcels at Crossbow Landing.

Parcel ID (Figure 2-1)	PDI
1965702	2.9E-05
2019134	1.2E-07
1997775	2.2E-05

2.3. Implications for Mitigation Options

The life safety risk at Crossbow Landing is within the Town of Canmore tolerable limits for existing development in all model results (2014, 2016, 2020). Based on the 2020 numerical model results, two parcels (IDs 1965702 and 1997775) experience life safety risk in excess of the tolerable threshold for proposed development. Given that the threshold for existing development is met, BGC anticipates that economic risk will be the primary driver of mitigation option selection at TSP.

If life safety risk in excess of the threshold for proposed development is selected as a criterion for mitigation works at TSP, the selection should consider the source of the debris-flood impacts. For the 100- to 300-year return period debris flood:

- Impacts to parcel ID 1965702 result from possible overland flow on the east bank of Three Sisters Creek when the culvert capacity is exceeded.
- Impacts to parcel ID 1997775 result from possible overland flow associated with avulsions upstream of the GCP that travel north and west down TSP from Fitzgerald Rise.

For this reason, mitigation works at TSP could reduce the life safety risk to parcel ID 1965702, while the proposed setback berms in the upper channel would reduce the life safety risk to parcel ID 1997775. BGC notes that a residual risk assessment to evaluate the life safety risk to existing development is planned as part of a future phase of the work. The residual risk assessment will consider the risk to existing development following installation of the preferred mitigation system and will identify needs for additional mitigation, if any.

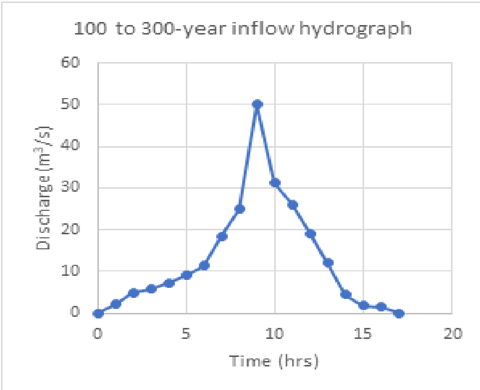
3.0 TASK 2 – INFLUENCE OF POND WATER ELEVATION AND SEDIMENT AT THE GCP

During the workshop, ToC inquired how the pond water elevation and depth of sediment in the pond influence the debris-flood model results. This inquiry related both to the potential for the GCP to overtop and lead to downstream inundation and impacts during a 100 to 300-year return period debris flood as well as the potential for a breach of the GCP. This section summarizes BGC's analysis to evaluate the influence of the pond water elevation and depth of sediment at the GCP on the debris-flood model results, as well as a review of the design specifications of the existing articulated concrete mats (ACMs) at the GCP outlet to determine if they have sufficient erosion resistance. This task focuses only on the 2020 numerical modelling as it provides the most up-to-date assessment, including consideration of climate change impacts.

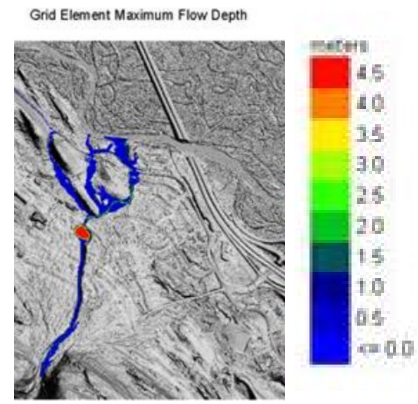
3.1. Pond Water Elevation During Numerical Modelling

The 2020 numerical modelling uses an inflow hydrograph that mimics the peak of the 2013 event. Based on the hydrograph, the peak discharge of 50 m^3/s is reached after approximately 9 hours[1]. Figure 3-1 shows screenshots of the hydrograph and select times during the modelling to determine the water level in the pond as the storm approaches and reaches its peak. When the peak discharge reaches the GCP, the pond will be full and for this reason, no additional modelling of a scenario with the pond pre-filled is required.

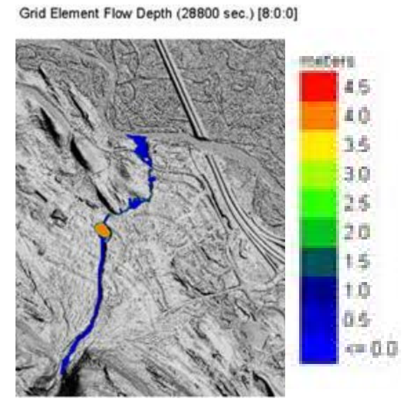
[1] Note that the arrival of the peak discharge could vary widely depending on the type of storm, antecedent moisture conditions and other variables such as temporary impounding of the creek by side slope landslides.



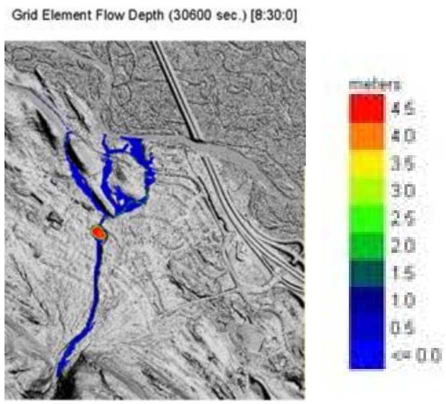
100 to 300-year inflow hydrograph showing peak discharge of 50 m^3/s at approx. 9 hours.



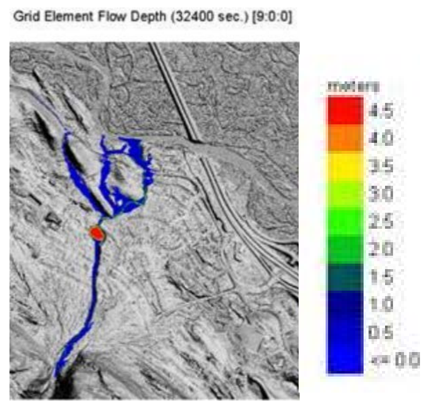
Maximum flow depth for 100 to 300-year model. The flow depth at the GCP is 4.5 m.



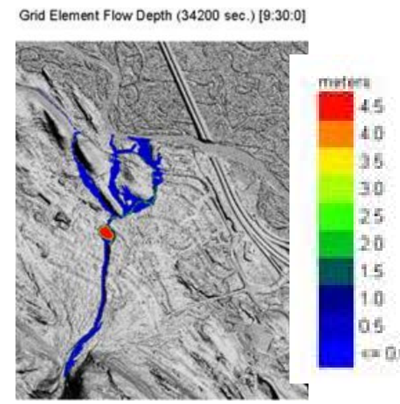
Flow depth at 8 hours into model run. The flow depth at the GCP is 4.0 m.



Flow depth at 8.5 hours into model run. The flow depth at the GCP is 4.5 m.



Flow depth at 9 hours into model run. The flow depth at the GCP is 4.5 m.



Flow depth at 9.5 hours into model run. The flow depth at the GCP is 4.5 m.

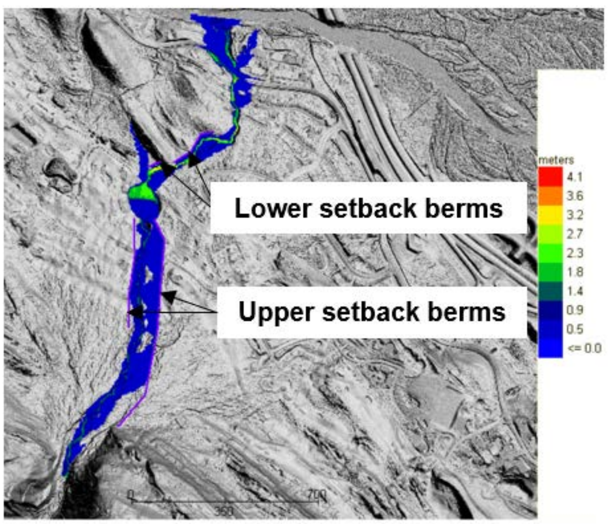
Figure 3-1. Model results showing pond elevation prior to and following the peak of the storm. All results show the current topography[2].

[2] The current topography is represented by the 2015 lidar which shows the pond and upstream channel in a cleaned-out condition. The 2013 lidar is referred to as aggraded topography and represents Three Sisters Creek channel in a natural, aggraded state following the June 2013 event.

3.2. Influence of sediment in GCP

The 2020 numerical modelling did not include sediment transport in the model runs. For this reason, BGC includes results for both an aggraded scenario (equivalent to the post June 21, 2013 topography) and current (2015) topography in the 2020 hazard assessment update (BGC, August 28, 2020). At the GCP, the aggraded topography represents the pond bathymetry where sedimentation has reduced the overall pond storage volume. BGC assigned a probability to these scenarios for the 100 to 300-year return period event of 60% aggraded (2013) and 40% current (2015) as reflected in the hazard mapping (BGC, August 28, 2020). Figure 3-2 shows the model results at the GCP for both scenarios for a 100 to 300-year return period debris flood.

Aggraded (2013 Topography) (Upper and Lower Setback Berms in Place)	**Current (2015 Topography) (Upper and Lower Setback Berms in Place)**



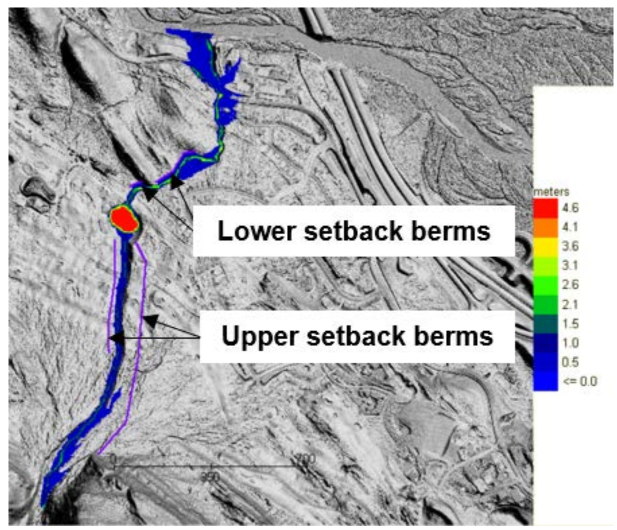


Figure 3-2. 2020 numerical model results for a 100- to 300-year return period debris flood with proposed setback berms in place.

Given the potential for overtopping on the east and west sides of the GCP outlet during a 100 to 300-year return period debris flood assuming an aggraded channel (Figure 3-2), two potential options can be considered:

1. Maintain the existing alignment of the southern lower proposed setback berm.
2. Extend the southern lower setback berm on the west side to redirect any potential overflow back to the channel and prevent impacts to the proposed development, in the event there is overtopping on the west side of the outlet.

With either option, regular sediment removal from the GCP to maintain capacity between storm events should form part of regular operations and maintenance activities. In addition, with either option an excavator could be placed on standby at the GCP during storm events to support hazard management. The excavator could remove any sediment or large woody debris that has the potential to reduce the capacity of the AltaLink bridge as well as to monitor for and mitigate any headward erosion associated with overland flow on the east side of the pond, and is practiced in similar situations in Canmore and other municipalities. BGC understands that the ToC prefers not to have operational controls such as this as the primary mitigation strategy.

Figure 3-3 shows the inundation extents for an aggraded channel (black squares), with the proposed setback berms (red solid line) and potential extension of the southern lower setback berm from option 2 above (red dashed line). The alignment of the extension is intended to tie into, but not impact, the function of the road that connects either side of the creek across the AltaLink bridge.

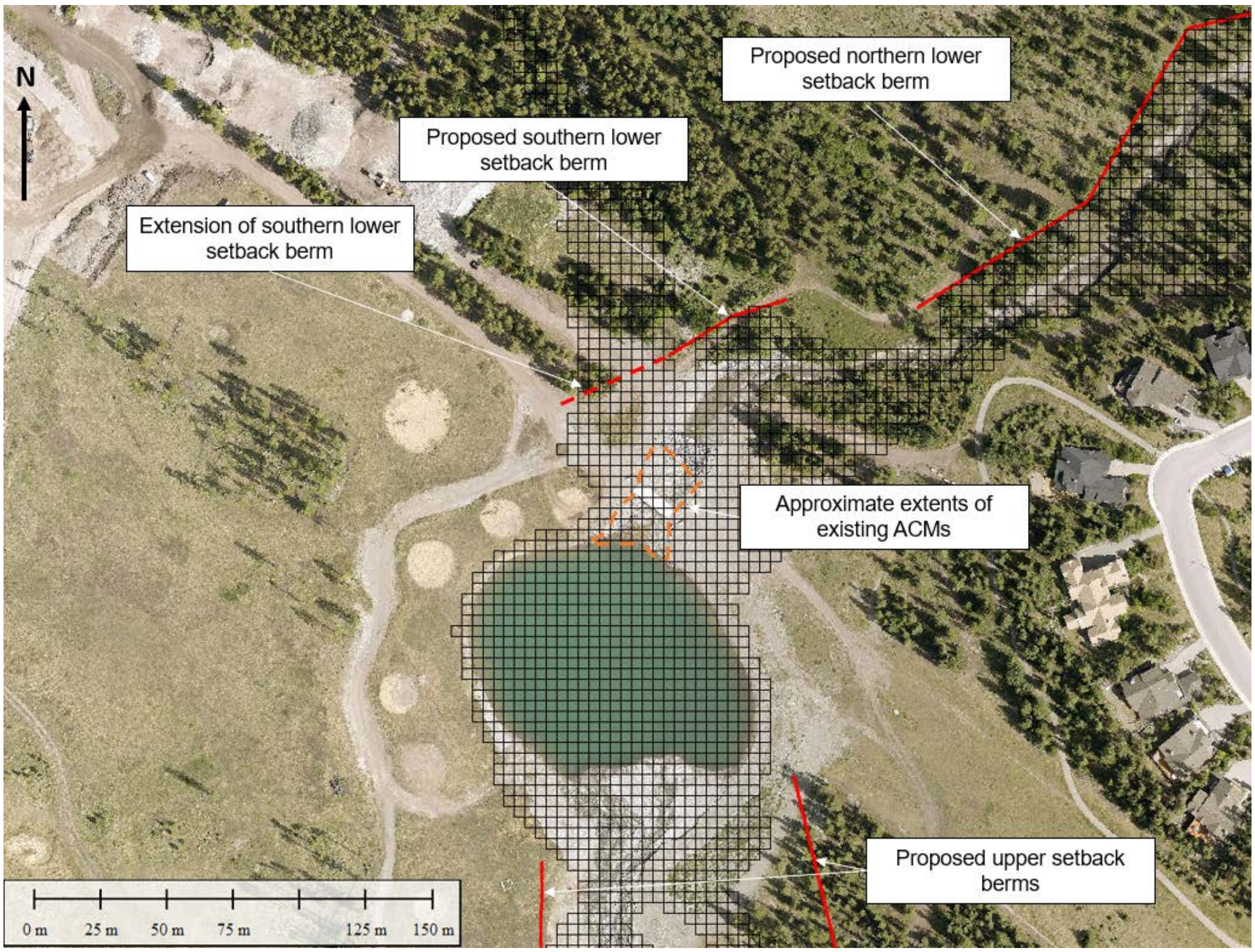


Figure 3-3. Screen capture of 100 to 300-year return period model results for the 2013 topography with proposed setback berms in place (red lines) and an optional extension of the southern lower setback berm (red dashed line). The black squares show the inundation extents and the base imagery is World Imagery from ESRI. The area outlined with a dashed orange line shows the approximate extent of existing ACMs.

3.3. Erosion Resistance of Existing Articulated Concrete Mats

BGC reviewed available specifications for the articulated mats to check if the estimated flow parameters for the 100 to 300-year design event is within the capacity of mats provided by the supplier, Armorflex. The approximate extents of the mats are shown in Figure 3-3.

The ToC provided information on the articulated concrete mats (ACM) installed a Three Sisters Creek. The ACMs are Armorflex 75, manufactured by ArmorTec Erosion Control Solutions (email from Felix Camire, personal communication, September 23, 2020). In an email communication from the manufacturer, BGC learned that a similar mat system is typically rated to 6 m/s (email from Tony, personal communication, October 5, 2020). Based on BGC's model results, the peak velocity of the 100 to 300-year return period design event is immediately downstream of the AltaLink bridge at 5.8 m/s. As such, the ACMs installed are designed to withstand the shear stresses of the 100 to 200-year return period design event[3].

4.0 TASK 3 – COST TO REPAIR THREE SISTERS PARKWAY (TSP)

To support the evaluation and selection of preferred mitigation option(s) at TSP, the ToC inquired what the cost to repair TSP in the event of a debris flood overtopping the culvert would be and to include this cost in the cost-benefit ratio for the options analysis. Significant uncertainty is associated with estimating the degree of damage that TSP would experience during a debris flood due to the stochastic nature of debris flood events as well as uncertainty around the time of day when an event would occur. If a debris flood occurs during the day and leads to damage to the road, it could be anticipated that more equipment would be on site to manage erosion to limit damage to road than if the same event occurred overnight leading to damage on the road at night. For the purposes of generating an estimate of potential damages, BGC used the following assumptions:

- The length of the parkway damaged is 170 m (Figure 3-4). The length of road was estimated by measuring the length of the parkway where the flow velocity exceeded 0.5 m/s in the 100 to 300-year return period model results[4]. The velocity threshold applied (0.5 m/s) is not a definite boundary after which damage to a road is expected and instead was used as a proxy to determine the areas that may be most susceptible for the purposes of generating an estimate.
- A section of the parkway approximately 20 m wide is eroded from the road surface down to the channel bed (a depth of 10 m). The length of road was estimated by measuring the length of the parkway where the flow velocity exceeded 3 m/s adjacent to the culvert. Note that this section could be wider or narrower.
- The water and sewer utilities below the Parkway at the crossing identified on record drawings and potentially additional third-party utilities including a gas pipeline, Telus, and Fortis electricity (Felix Camire, personal communication, August 7, 2020) are impacted.

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[3] The design specifications provide a metric to assess whether the ACMs may fail due to the shear stresses induced by flow but do not consider other failure mechanisms. Other failure mechanisms could include fines being washed away and through retrogression leading to sagging of the ACMs, progressive corrosion, and impact loading by a boulder leading to failure of a mat component. These additional failure mechanisms may be less likely to occur than shear stress failure.

[4] The model results considered were the aggraded topography with the proposed upper and lower setback berms in place.

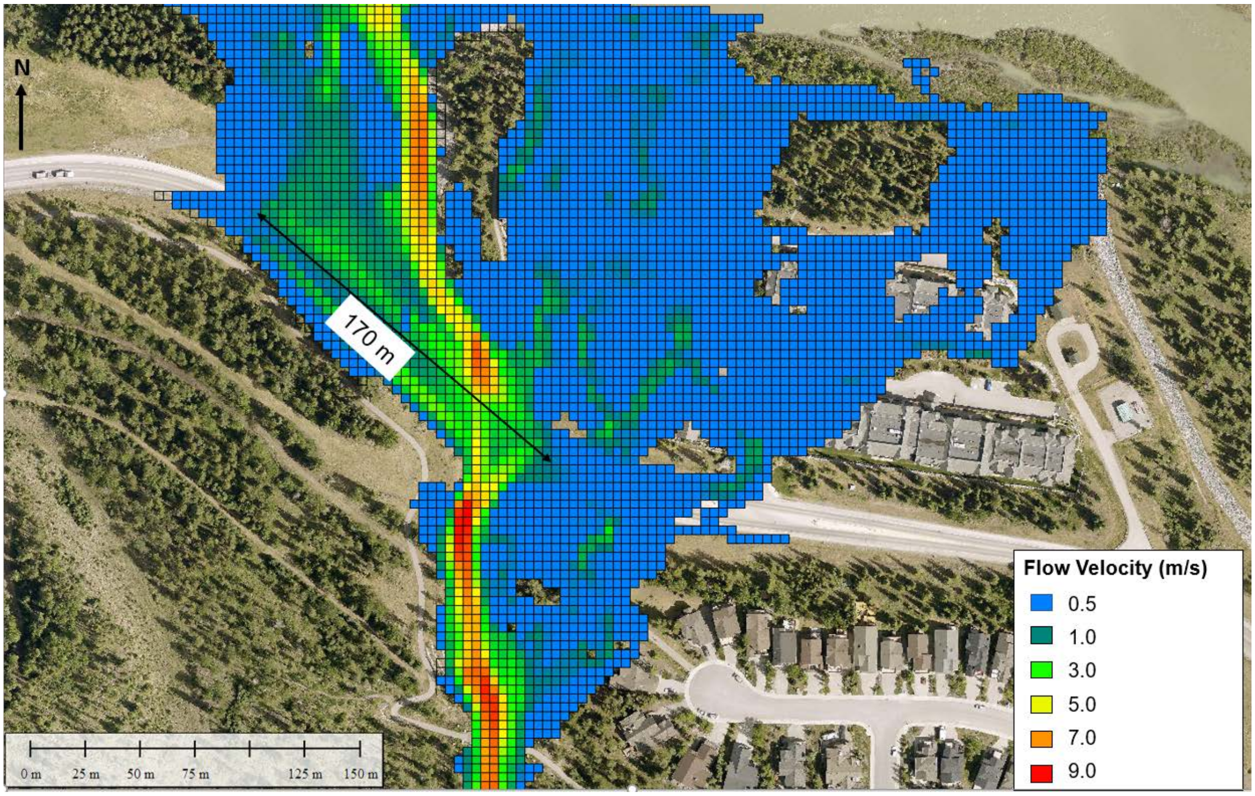


Figure 3-4. Screen capture of 100 to 300-year flow velocity model results for the 2013 topography with proposed upstream (not on image) setback berms in place. Base imagery is World Imagery from ESRI.

For the estimate, BGC assumed that the road would need to be fully regraded along the full 170 m length and that the 20 m section that fully erodes would need to be backfilled and erosion protection installed at surface. Costs were estimated based on approximate volumes and dimensions given the considerations outlined above and unit costs derived primarily from April 2020 contractor bids for debris-flood protection works at Heart Creek in the nearby hamlet of Lac des Arcs and supplemented with other relevant project experience and personal communication with QPD and the ToC.

As outlined in Table 2-1, this results in a cost of approximately $1,300,000 including a lump sum of $250,000 for the costs to repair the utilities based on an estimate provided by the ToC as part of review of this report. This estimate was not confirmed with input from the ToC or third party utility providers and should be considered uncertain. The cost estimate does not include any repair costs for the existing Three Sisters Parkway culvert or existing Three Sisters Creek channel up or downstream of the crossing. It also excludes any possible business losses due to power, communication or gas interruptions.

Table 3-1. Cost estimate for repairs to Three Sisters Parkway during a 100 to 300-year debris flood.

Item		Quantity	Unit	Unit Cost	Item Total Cost
Direct Costs					
1	Excavation (basin or channel)	1600	m^3	$ 6.00	$ 9,600
2	Berm fill supply	6,000	m^3	$ 20.00	$ 120,000
3	Fill placement for berm or barrier	7,500	m^3	$ 14.00	$ 105,000
4	Class 3 or 4 riprap (supply & placement)	1,100	m^2	$ 150.00	$ 165,000
5	Regrade highway	2,550	m^2	$ 9.00	$ 22,950
6	Asphalt paving	2,550	m^2	$ 2.50	$ 6,375
7	Seeding, planting, site restoration	4,250	m^2	$ 7.00	$ 29,750
				Direct Costs Subtotal:	**$ 460,000**
Utilities Repair					
8	Utilities Repair	1	LS	$250,000	$ 250,000
				Direct Costs and Utilities Repair Subtotal	**$ 710,000**
Indirect Costs					
9	Contractor general	1	LS	15%	$ 106,500
10	Contingency (unlisted items)	1	LS	50%	$ 355,000
11	Engineering and permitting	1	LS	15%	$ 106,500
				Indirect Costs Subtotal:	**$ 570,000**
				Item Total:	**$ 1,280,000**

With the cost to repair included in the cost benefit of a Three Sisters Parkway culvert replacement, the cost-benefit ratio increases from 0.34 to 1.20. This value assumes the debris flood occurs in the first year following culvert replacement and does not consider discounting back to the net present value for an event that occurs at a distant time in the future. This indicates that when the costs to repair the parkway are considered, the economic benefit of reducing the risk at this location through replacement of the culvert is higher in relation to the total cost to install and maintain a replacement.

Replacement of the culvert was the top ranked option in the Kepner-Tregoe analysis prior to including the costs to repair (total score of 118 out of 165). With the improvement in the cost-benefit ratio, the ranking stays the same and the total score increases to 125 which further reinforces this as the preferred option.

5.0 TASK 4 – WOODY DEBRIS MANAGEMENT AT THE GCP

To prevent potential blockages of the outlet of the GCP at AltaLink Bridge, ToC suggested inclusion of woody debris management option in the form of a floating buoy system as is commonly used at dams and reservoirs to prevent large woody debris blocking spillways or impacting other dam infrastructure. QPD and BGC agreed that this option merited inclusion in the mitigation options assessment. BGC has included this option in the mitigation options table and will include a section in the mitigation options draft report.

The advantages of such a system are that it has the potential to prevent large woody debris from reaching and potentially clogging the pond outlet at the AltaLink bridge. In so doing, the potential for flows to overtop and potentially erode the pond embankments is reduced. The disadvantage of such a system is that it introduces more operations and maintenance costs. Moreover, the efficacy of these systems during extreme debris flood events is not well understood by BGC as they are typically installed in locations with little flow velocity.

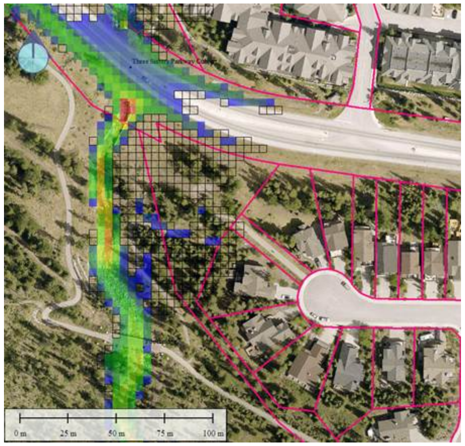
BGC reached out to multiple contractors who design similar systems to determine if a floating system can be designed to withstand debris-flood impacts and estimate cost. BGC has received confirmation from Versatech Products (http://www.versatech.com/) that systems can be designed to withstand the flow velocities anticipated in the GCP during a 100 to 300-year debris flood based on the numerical model results. A system purpose designed and built for the conditions at the GCP is estimated to range from $110,000 to $235,000 excluding taxes and anticipated travel costs (email from Omid Javadi, personal communication, August 28, 2020). BGC received a second design and estimate that proposed installation of a boom system installed at one or two locations upstream of the GCP. The cost for this system ranges from $250,000 to $370,000 excluding taxes and anticipated travel costs (email from Berard Kassis, personal communication, September 28, 2020). Based on BGC’s present understanding, the latter system is not recommended for inclusion in the options analysis.

An alternative mitigation scheme that could be combined with the above is to have an excavator on site during extreme precipitation events as outlined in Section 3.0. This practice is being followed still by several municipalities in BC and Alberta including the MD Bighorn. To avoid endangering the operator, a decision may have to be made on site if excavation during a debris flood can be accomplished safely.

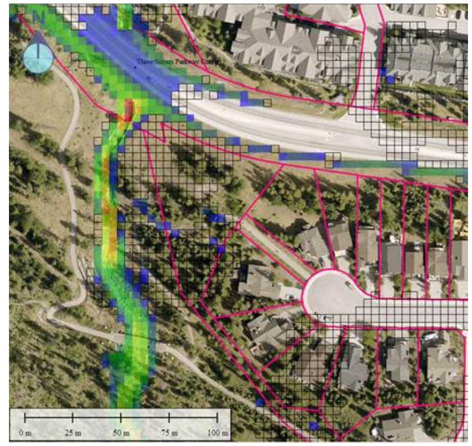
6.0 TASK 5 – DEBRIS-FLOOD IMPACTS TO EXISTING DEVELOPMENT WITH PROPOSED SETBACK BERMS IN PLACE

As discussed in the workshop, BGC reviewed the debris-flood model results with the proposed upper and lower setback berms in place to determine if there are debris-flood impacts to existing development on the east side of Three Sisters Creek downstream of the GCP during the 100 to 300-year design event. Figure 6-2 shows the 100 to 300-year model results on the east side of Three Sisters Creek for both the channel aggradation (2013 topography) and current (2015 topography) conditions with and without the proposed setback berms in place. As shown, the inundation extents do not change significantly, nor is there an increase in flow depth greater than approximately 10 cm. Finally, the debris-flood inundation extents are within the backyard of the property and are unlikely to impact the building. For these reasons, BGC does not anticipate that any additional berm(s) will be required at this location to protect the existing buildings from the

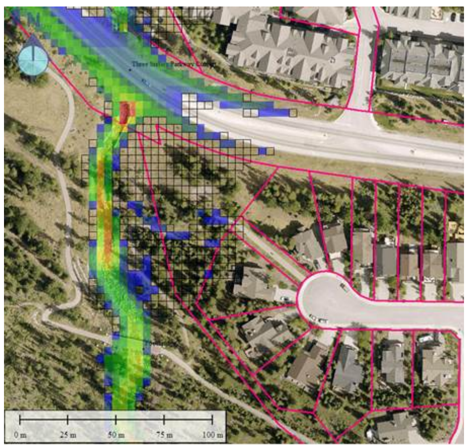
100 to 300-year design event. The residual risk to this property will be considered as part of a separate scope.



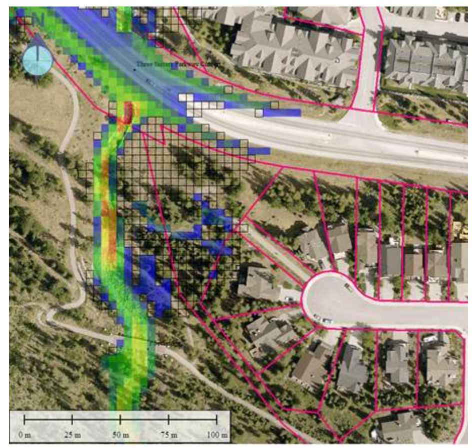
100 to 300-year debris flood, model run on 2015 topography, **no mitigation**.



100 to 300-year debris flood, model run on 2013 topography, **no mitigation**.



100 to 300-year debris flood, model run on 2015 topography, **with mitigation**.



100 to 300-year debris flood, model run on 2013 topography, **with mitigation**.

Legend:

Flow depths (m)

0
0.1
0.25
0.5
1
1.5
2
2.5

*Approximate and interpolated between depth values by GIS software

Figure 6-1. Debris-flood model results for the 100 to 300-year debris flood on aggraded (2013 topography) and current (2015 topography) without mitigation (top row) and with mitigation (bottom row). Base map is ESRI World Imagery.

7.0 TASK 6 – REDUCING GCP CAPACITY

ToC suggested that BGC and QPD could consider reducing the GCP capacity through one or a combination of lowering the outlet elevation or allowing sediment to infill. Based on discussion with QPD and considering the performance of the GCP during the 2013 event as well as the mitigation options under consideration that do not include changes to the GCP geometry, no additional analyses have been completed. QPD has expressed that they may pursue a dam safety assessment separately from the options analysis work to ensure compliancy with current dam regulations in Alberta.

8.0 SUMMARY AND REQUESTS FOR INPUT

This memo summarizes the additional analyses completed by BGC based on recommendations from ToC and requested by QPD following the August 4 options analysis workshop. Table 8-1 summarizes the analyses and proposed updates to the Mitigation Options Analysis Report. BGC requests that QPD and the ToC review the proposed updates and comment if any modifications are required.

Table 8-1. Summary of additional analyses and BGC recommendations

Task	Summary	Proposed Updates to Mitigation Options Assessment
1. Confirm life safety risk at Crossbow Landing	No parcels at Crossbow Landing have a PDI that exceeds $1x10^{-4}$ (threshold for existing development). Two parcels at Crossbow Landing have a PDI that exceeds $1x10^{-5}$ (threshold for proposed development).	As the criteria for existing development is met, BGC anticipates that economic risk will be the primary driver in selecting mitigation options at Three Sisters Parkway. BGC further notes that a residual risk assessment will consider the post-mitigation risk in this and other areas of existing development.
2. Evaluate the influence of pond water elevation in the GCP on the model results	The pond water level does not influence the numerical modelling results. The model on 2013 (aggraded) topography shows the potential for flow to overtop the outlet. BGC outlined two options for consideration: 1. Maintain the existing proposed setback berm alignments. 2. Extend the setback berm on the west side.	BGC will include option 2 in the mitigation options analysis report. With both options, an excavator could be on standby to remove woody debris with the potential to block the outlet and monitor for headward erosion on the east side.
3. Estimate the cost to repair TSP	The estimated cost to repair TSP assumes a 170 m length of the parkway is affected with significant erosion on the downstream side over a 20 m length. The estimated cost to repair is $1,280,000 including a lump sum allotment to repair ToC and third-party utilities.	With the cost to repair the crossing in the event of debris-flood damage included in the cost benefit of a TSP culvert replacement, the cost-benefit ratio increases from 0.34 to 1.20 which further confirms this option as the preferred option at TSP. This update will be reflected in the options assessment report.
4. Add woody debris management at the GCP	A floating debris barrier could be custom designed and built to withstand debris flood impacts and is anticipated to cost $110,000 to $235,000 pre-tax and travel.	BGC will add this option to the options assessment.
5. Evaluate debris flood impacts to existing development with proposed mitigation in place.	BGC reviewed the debris flood inundation extents and flow depths downstream of GCP on the east side of the creek. There was no significant change in debris flood extents or flow depths.	No change to the options analysis at this stage. The residual risk to all existing development will be evaluated as part of a separate scope of work.
6. Consider reducing the GCP capacity.	Based on discussion with QPD, BGC understands that this is not required.	No additional analyses or recommendations.

9.0 CLOSURE

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Yours sincerely,

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LCH/BCP/AS/mj/mm

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BGC Engineering Inc. (2016, October 14). *Three Sisters Creek Debris Flood Mitigation Modelling* [Memorandum]. Prepared for Town of Canmore.

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APPENDIX B
COST ESTIMATE TABLES

B.1. COST ESTIMATE INTRODUCTION

This appendix contains the cost estimates of the eleven options selected for further assessment that required costing out. 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 -50% to +100%. Volumes, areas and lengths are estimated using approximate geometries and layouts and will change if brought to preliminary design.

B.2. COST ESTIMATE TABLES

Table B-1. Option A-2 Debris Retention Basin (100 to 300-year) at Fan Apex cost estimate.

Item	Quantity	Unit	Cost per Unit	Item Total Cost
Access construction	800	m	$100	$80,000
Clearing, grubbing and disposal	4,000	m^2	$6	$24,000
Excavation (basin and channel)	5,000	m^3	$6	$30,000
Off-site sediment disposal	5,000	m^3	$16	$80,000
Barrier fill supply	17,000	m^3	$20	$340,000
Fill placement for barrier	17,000	m^3	$14	$238,000
Class 3 or 4 riprap (supply and placement)	1,200	m^2	$150	$180,000
Grouted stone pitching	1,700	m^2	$320	$544,000
Concrete and steel outlet structure	1	Lump sum	$2,000,000	$2,000,000
Seeding, planting and site restoration	2,000	m^2	$7	$14,000
			Direct costs subtotal	**$3,530,000**
Contractor general	1	Lump sum	15%	$529,500
Contingency (unlisted items)	1	Lump sum	10%	$353,000
Engineering and permitting	1	Lump sum	15%	$529,500
			Indirect costs subtotal	**$1,410,000**
			Option total	**$4,900,000**

Table B-2. Option A-2 Debris Retention Basin (1,000 to 3,000-year) at Fan Apex cost estimate.

Item	Quantity	Unit	Cost per Unit	Item Total Cost
Access construction	800	m	$100	$80,000
Clearing, grubbing and disposal	5,000	m^2	$6	$30,000
Excavation (basin and channel)	8,000	m^3	$6	$48,000
Off-site sediment disposal	8,000	m^3	$16	$128,000
Barrier fill supply	24,000	m^3	$20	$480,000
Fill placement for barrier	24,000	m^3	$14	$336,000
Class 3 or 4 riprap (supply and placement)	1,400	m^2	$150	$210,000
Grouted stone pitching	2,000	m^2	$320	$640,000
Concrete and steel outlet structure	1	Lump sum	$2,400,000	$2,400,000
Seeding, planting and site restoration	2,000	m^2	$7	$14,000
			Direct costs subtotal	**$4,370,000**
Contractor general	1	Lump sum	15%	$655,500
Contingency (unlisted items)	1	Lump sum	10%	$437,000
Engineering and permitting	1	Lump sum	15%	$655,500
			Indirect costs subtotal	**$1,750,000**
			Option total	**$6,100,000**

Table B-3. Option B-4 East Apex Deflection Berm at Upper Channel cost estimate.

Item	Quantity	Unit	Cost per Unit	Item Total Cost
Access construction	300	m	$100	$30,000
Clearing, grubbing and disposal	10,000	m^2	$6	$60,000
Excavation	4,000	m^3	$6	$24,000
Off-site sediment disposal	4,000	m^3	$16	$64,000
Berm fill supply	19,000	m^3	$20	$380,000
Fill placement for berm	19,000	m^3	$14	$266,000
Grouted stone pitching	2,000	m^2	$320	$640,000
Seeding, planting and site restoration	10,000	m^2	$7	$70,000
			Direct costs subtotal	**$1,530,000**
Contractor general	1	Lump sum	15%	$229,500
Contingency (unlisted items)	1	Lump sum	10%	$153,000
Engineering and permitting	1	Lump sum	15%	$229,500
			Indirect costs subtotal	**$610,000**
			Option total	**$2,100,000**

Table B-4. Option B-5 Wide Channel and Floodplain at Upper Channel cost estimate.

Item	Quantity	Unit	Cost per Unit	Item Total Cost
Access construction	1,300	m	$100	$130,000
Clearing, grubbing and disposal	16,100	m^2	$6	$97,000
Excavation	6,000	m^3	$6	$36,000
Off-site sediment disposal	6,000	m^3	$16	$96,000
Berm fill (supply and placement)	11,100	m^3	$34	$377,000
Class 3 riprap (supply and placement)	19,200	m^3	$137	$2,630,000
Seeding, planting and site restoration	16,700	m^2	$5	$84,000
			Direct costs subtotal	**$3,450,000**
Contractor general	1	Lump sum	15%	$518,000
Contingency (unlisted items)	1	Lump sum	10%	$345,000
Engineering and permitting	1	Lump sum	15%	$518,000
			Indirect costs subtotal	**$1,381,000**
			Option total	**$4,800,000**

Notes:

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

Table B-5. Option C-2 Bypass Channel at Pond Outlet at Golf Course Pond cost estimate.

Item	Quantity	Unit	Cost per Unit	Item Total Cost
Access construction	135	m	$100	$13,500
Clearing, grubbing and disposal	5,500	m^2	$6	$33,000
Excavation (channel)	12,600	m^3	$6	$75,600
Off-site sediment disposal	12,600	m^3	$16	$201,600
Articulated concrete mats	1,240	m^2	$290	$359,600
Class 3 or 4 riprap (supply and placement)	4,260	m^2	$150	$639,000
Seeding, planting and site restoration	675	m^2	$7	$4,725
			Direct costs subtotal	**$1,330,000**
Contractor general	1	Lump sum	15%	$199,500
Contingency (unlisted items)	1	Lump sum	10%	$133,000
Engineering and permitting	1	Lump sum	5%	$66,500
			Indirect costs subtotal	**$400,000**
			Option total	**$1,700,000**

Table B-6. Option C-3 Replace AltaLink Bridge at Golf Course Pond cost estimate.

Item	Quantity	Unit	Cost per Unit	Item Total Cost
Excavation (channel)	200	m^3	$6	$1,200
Off-site sediment disposal	200	m^3	$16	$3,200
Bridge construction[1]	1	Lump sum	$4,000,000	$4,000,000
Re-route transmission line[2]	1	Lump sum	$1,500,000	$1,500,000
Articulated concrete mats	1,000	m^2	$290	$290,000
Seeding, planting and site restoration	500	m^2	$7	$3,500
			Direct costs subtotal	**$5,800,000**
Contractor general	1	Lump sum	15%	$870,000
Contingency (unlisted items)	1	Lump sum	10%	$580,000
Engineering and permitting	1	Lump sum	15%	$870,000
			Indirect costs subtotal	**$2,320,000**
			Option total	**$8,100,000**

Notes:

1. Bridge construction cost a placeholder based on small bridge construction that BGC has been a part of. Cost estimate could be refined further with input of cost experiences from Town of Canmore, QPD and Alberta Transport.
2. Cost estimate of re-routing transmission line during and post construction was provided by QPD.

Table B-7. Option C-4 Woody debris management at Golf Course Pond cost estimate.

Item	Quantity	Unit	Cost per Unit	Item Total Cost
Anchoring	1	each	$50,000	$50,000
Boom	150	m	$1,000	$150,000
Design basis & drawing package (external contractor)	1	each	$10,000	$10,000
Installation and commissioning	1	each	$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**

Table B-8. Option D-3 Lower Setback Berms at Lower Channel cost estimate.

Item	Quantity	Unit	Cost per Unit	Item Total Cost
Access construction	290	m	$100	$29,000
Clearing, grubbing and disposal	3,900	m^2	$6	$23,000
Excavation	2,000	m^3	$6	$12,000
Off-site sediment disposal	2,000	m^3	$16	$32,000
Berm fill (supply and placement)	2,400	m^3	$34	$82,000
Class 3 riprap (supply and placement)	2,600	m^3	$137	$356,000
Seeding, planting and site restoration	4,100	m^2	$5	$21,000
			Direct costs subtotal	**$560,000**
Contractor general	1	Lump sum	15%	$83,000
Contingency (unlisted items)	1	Lump sum	10%	$56,000
Engineering and permitting	1	Lump sum	15%	$83,000
			Indirect costs subtotal	**$220,000**
			Option total	**$800,000**

Notes:

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

Table B-9. Option D-5 Woody Debris Management at Lower Channel cost estimate.

Item	Quantity	Unit	Cost per Unit	Item Total Cost
Access construction	50	m	$100	$5,000
Steel grillage	1	Lump sum	$10,000	$10,000
In-channel posts, steel posts on concrete pad	1	Lump sum	$45,000	$45,000
Woody debris net	1	Lump sum	$40,000	$40,000
Seeding, planting and site restoration	500	m^2	$7	$3,500
			Direct costs subtotal	**$100,000**
Contractor general	1	Lump sum	15%	$15,000
Contingency (unlisted items)	1	Lump sum	10%	$10,000
Engineering and permitting	1	Lump sum	15%	$15,000
			Indirect costs subtotal	**$40,000**
			Option total	**$100,000**

Table B-10. Option E-2 Overflow with Culvert at Three Sisters Parkway cost estimate.

Item	Quantity	Unit	Cost per Unit	Item Total Cost
Clearing, grubbing and disposal	1,000	m^2	$6	$6,000
Excavation (channel)	1,700	m^3	$6	$10,200
Off-site sediment disposal	1,700	m^3	$16	$27,200
Geotextile	1,000	m^2	$5	$4,600
Class 3 or 4 riprap (supply and placement)	900	m^2	$150	$135,000
Grouted stone pitching	500	m^2	$320	$160,000
Regrade highway	1,000	m^2	$9	$9,000
Asphalt paving	1,000	m^2	$2.5	$2,500
Seeding, planting and site restoration	1,000	m^2	$7	$7,000
Direct costs subtotal				**$360,000**
Contractor general	1	Lump sum	15%	$54,000
Contingency (unlisted items)	1	Lump sum	10%	$36,000
Engineering and permitting	1	Lump sum	15%	$54,000
Indirect costs subtotal				**$140,000**
Option total				**$500,000**

Table B-11. Option E-3 Replace Three Sisters Parkway Culvert (100 to 300-year) at Three Sisters Parkway cost estimate.

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	$7	$28,000
Direct costs subtotal				**$930,000**
Contractor general	1	Lump sum	15%	$139,500
Contingency (unlisted items)	1	Lump sum	10%	$93,000
Engineering and permitting	1	Lump sum	15%	$139,500
Indirect costs subtotal				**$370,000**
Option total				**$1,300,000**

Note:

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

Table B-12. Option E-3 Replace Three Sisters Parkway Culvert (1,000 to 3,000-year) at Three Sisters Parkway cost estimate.

Item	Quantity	Unit	Cost per Unit	Item Total Cost
Bridge[1]	1	Lump sum	$4,000,000	$4,000,000
Seeding, planting and site restoration	4,000	m^2	$7	$28,000
			Direct costs subtotal	**$4,030,000**
Contractor general	1	Lump sum	15%	$604,500
Contingency (unlisted items)	1	Lump sum	10%	$403,000
Engineering and permitting	1	Lump sum	15%	$604,500
			Indirect costs subtotal	**$1,610,000**
			Option total	**$5,600,000**

Note:
1. Bridge construction cost a placeholder based on small bridge construction that BGC has been a part of. Cost estimate could be refined further with input of cost experiences from Town of Canmore, QPD and Alberta Transport.

Table B-13. Option E-4 Northeast Deflection Berm at Three Sisters Parkway cost estimate.

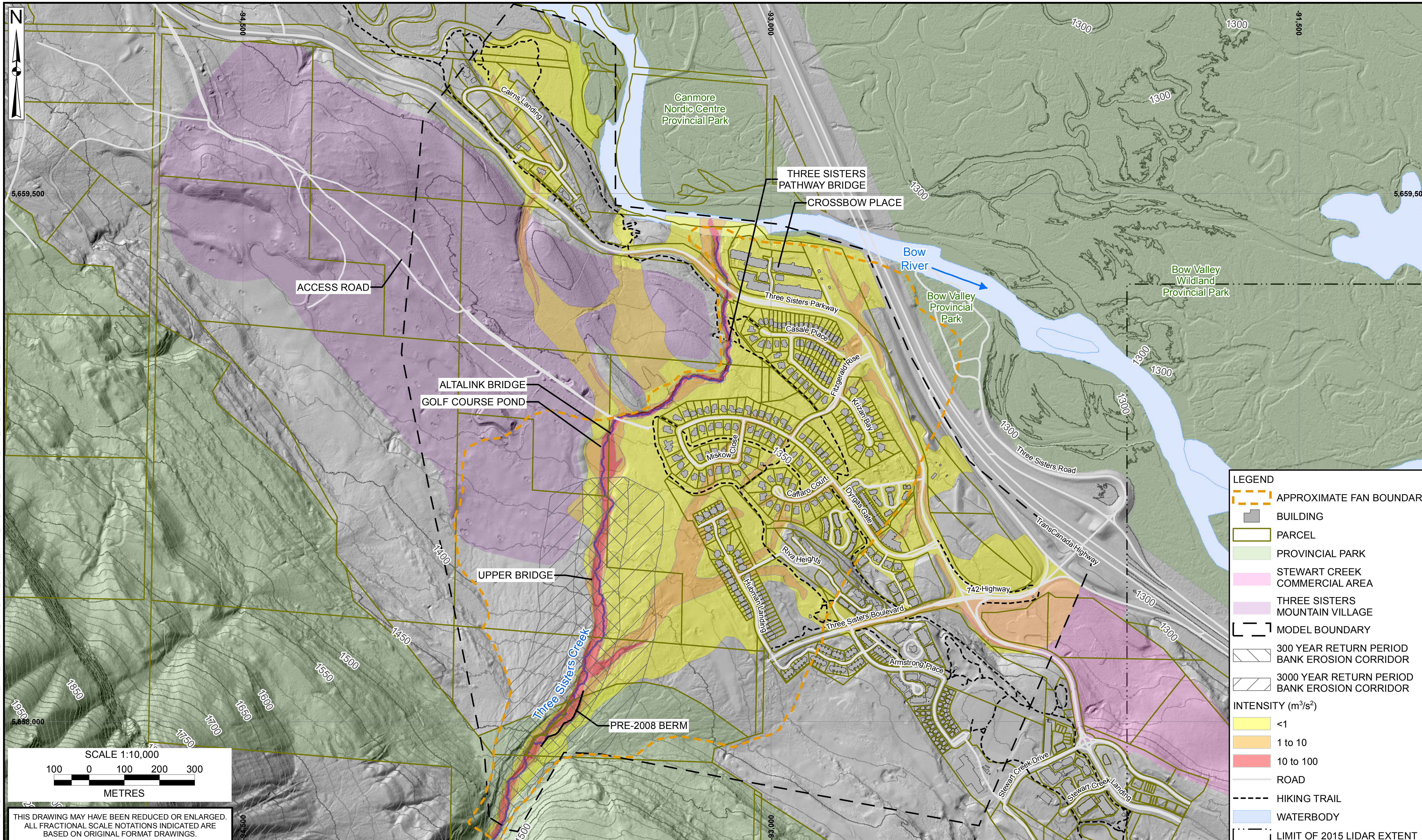
Item	Quantity	Unit	Cost per Unit	Item Total Cost
Access construction	25	m	$100	$2,500
Clearing, grubbing and disposal	600	m^2	$6	$3,600
Excavation	270	m^3	$6	$1,620
Off-site sediment disposal	270	m^3	$16	$4,320
Berm fill supply	500	m^3	$20	$10,000
Fill placement for berm	500	m^3	$14	$7,000
Class 3 or 4 riprap (supply and placement)	210	m^2	$150	$31,500
Seeding, planting and site restoration	600	m^2	$7	$4,200
			Direct costs subtotal	**$60,000**
Contractor general	1	Lump sum	15%	$9,000
Contingency (unlisted items)	1	Lump sum	10%	$6,000
Engineering and permitting	1	Lump sum	15%	$9,000
			Indirect costs subtotal	**$20,000**
			Option total	**$100,000**

APPENDIX C
FACTOR SCALES

Table C-1. Detailed option analysis factors scale criteria.

Scale	Factor Criteria									
	Economic and life-loss risk reduction	Infrastructure protection	Risk transfer avoidance	Cost-benefit	Capital cost	Operation, maintenance and recovery cost	Habitat, wildlife corridor and riparian impacts	Aesthetics and recreation	Likelihood of functioning as intended	Risk of Delay Due to Permitting
5	>75% reduction	Complete protection	No risk transfer	Benefit-cost ratio >2	Lowest cost or >$100,000	Lowest cost or >$100,000	Substantial enhancement	Substantial enhancement	High certainty in performance	No approvals needed
4	>50% reduction	Complete protection of one item or some protection of all	Negligible risk transfer	Benefit-cost ratio >1.5	>$500,000	>$500,000	Enhancement	Enhancement	Likely to perform as intended with regular maintenance	Minor effort for approvals
3	>25% reduction	Some protection of one item or minor protection of all	Some risk transfer	Benefit-cost ratio >1	>$1,000,000	>$1,000,000	Neutral change	Neutral change	Performance contingent on other variables	Normal effort in reaching approval
2	>10% reduction	No change to current condition	Significant risk transfer	Benefit-cost ratio >0.5	>$2,000,000	>$2,000,000	Degradation	Degradation	May not perform as intended	Major delays (years) for approval
1	No life-loss risk reduction	Increased impact	Full risk transfer	Benefit-cost ratio >0	Highest cost or >$5,000,000	Highest cost or >$5,000,000	Substantial degradation	Substantial degradation	Potential for unforeseen adverse effects	May not receive approval

DRAWINGS



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3. HAZARD INTENSITY MAPPING WAS COMPLETED BY BGC (JUNE 12, 2020) AND DISPLAYED HERE TO SHOW THE HAZARD EXTENTS. METHODS AND LIMITATIONS CAN BE FOUND IN BGC (OCTOBER 9, 2020).
4. LIDAR DATA PROVIDED BY AIRBORNE IMAGING, DATED SEPTEMBER 2015, AND BY LIDAR SERVICES INC. (LSI), DATED JUNE 28, 2013. CONTOUR INTERVAL IS 10 m.
5. 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.
6. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM BASED ON LIDAR DATED JUNE 2013. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL FLOODING.
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CLIENT: THREE SISTERS mountain village

PROJECT: THREE SISTERS CREEK DEBRIS-FLOOD MITIGATION OPTIONS ANALYSIS

TITLE: THREE SISTERS CREEK SITE PLAN AND HAZARD RATINGS

PROJECT No.: 1531 005

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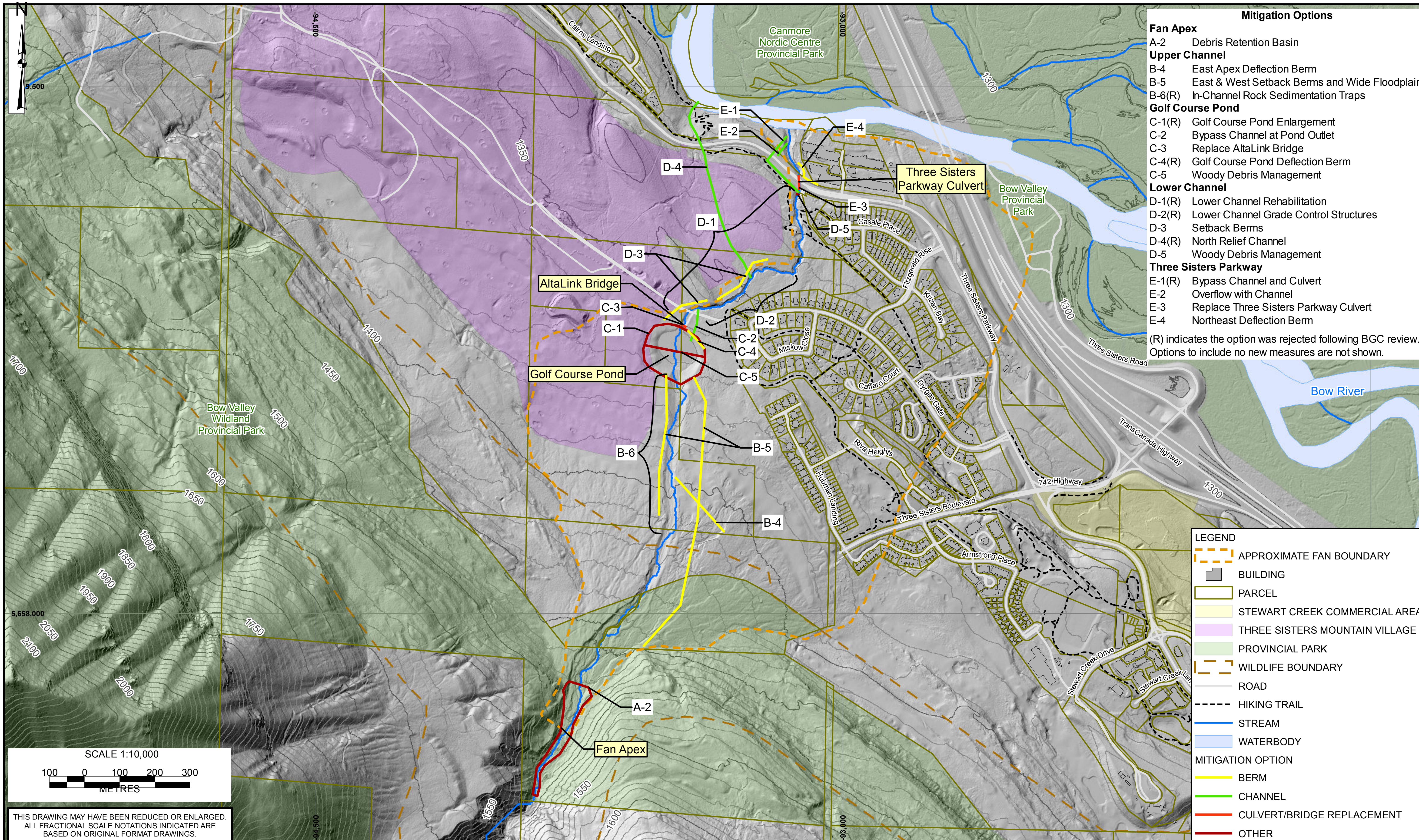

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