SMITH CREEK ASP

Steep Creek Hazard and Risk Assessment

FINAL Rev. 1
December 15, 2020

Project No.: 1531006

Prepared by BGC Engineering Inc. for:
Three Sisters Mountain Village Properties Ltd.
c/o QuantumPlace Development Ltd.

TABLE OF REVISIONS

ISSUE	DATE	REMARKS
DRAFT Rev. A	October 27, 2020	For QPD comments
DRAFT Rev. B	October 28, 2020	For Town of Canmore comments
FINAL Rev. 0	December 10, 2020	Updated with Town of Canmore comments and to include Pigeon Creek assessment
FINAL Rev. 1	December 15, 2020	Correction of minor typographical errors

LIMITATIONS

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EXECUTIVE SUMMARY

Three Sisters Mountain Village Properties Ltd. (TSMV) wishes to develop an area located between Stewart Creek and Pigeon Creek in Canmore, Alberta. This area is collectively referred to as the Smith Creek Area Structure Plan (ASP). Some of the areas to be developed are located on, or in the vicinity of, the fans of Stewart Creek, Fall Creek, Smith Creek, Marsh Creek, Cairnes Creek and Pigeon Creek (Drawing 01). These creeks are prone to steep creek hazards, and parts of the proposed development area are potentially at risk from these hazards.

The objective of this report is to estimate the risk to life for potential building occupants in the Smith Creek ASP from steep creek hazards and evaluate if those risks are considered tolerable according to the Town of Canmore Municipal Development Plan (2016). The results have also informed the conceptual design of steep creek hazard mitigation design for the Smith Creek ASP, which is presented under a separate cover (BGC, December 15, 2020). BGC Engineering Inc. (BGC) notes this work does not include a steep creek risk assessment (SCRA) considering hazards from Fall or Pigeon Creeks, because these creeks are unlikely to result in life loss risk to people within buildings in the proposed development. However, a simplified hazard assessment update and numerical modelling were completed for Pigeon Creek, in order to inform re-grading of Smith Creek ASP development parcels that may be subject to flows from Pigeon Creek.

BGC has previously assessed hazards on Stewart, Smith, Marsh, and Cairnes Creeks; however, the previous assessments did not account for climate change effects. Therefore, BGC completed hydrologic analyses and numerical modelling for those creeks accounting for peak flow or sediment volume increases that may occur due to climate change. The geohazards scenarios considered, cover a range of return periods from 10 to 3000 years, including avulsions.

Using the combined geohazard scenario inundation area from numerical modelling, BGC determined areas potentially exposed to steep creek hazards. No existing buildings were identified as being within modeled inundation areas. Areas within the Smith Creek ASP where building occupants could be exposed to steep creek hazards, includes land designated for residential use and the proposed school parcel area.

A quantitative risk assessment (QRA) was carried out that considered the modelled geohazard scenarios and parcel areas that could be exposed to steep creek hazards. The assessment focused on proposed development within the Smith Creek ASP. The assessment included estimating the risk to individuals, or Probability of Death of an Individual (PDI), and groups and comparing those against the Town of Canmore's risk tolerance criteria. The results of the assessment demonstrated that:

- Pigeon Creek could affect two areas within the proposed development, given current topography. The affected areas will be excluded from development or re-graded as part of the development construction; therefore, life loss risk tolerance threshold will not be exceeded.
- Areas exposed to hazard from Stewart, Smith and Cairnes Creeks contain estimated PDI that exceeds the individual tolerance standard for new developments of 1:100,000 (10

micromorts or $1x10^{-5}$) risk of fatality per year. This includes areas where flows may channelize, such as within topographic depressions or along historic flow channels.

- Steep creek hazards from Marsh Creek do not result in PDI values exceeding the individual risk tolerance standard for new developments.
- The number of potential fatalities from all steep creek hazard scenarios considered in the assessment was less than 1. This implies that group risk tolerance criteria for each creek are met.
- Areas where estimated PDI from Smith Creek hazards exceeds the individual risk tolerance standard include local topographic depressions which would be adjusted as part of site construction. This would reduce the PDI values in these locations below the tolerance standard for new development.

The results of this risk assessment will inform the conceptual design of steep creek mitigation measures for the Smith Creek ASP.

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1. INTRODUCTION

Three Sisters Mountain Village Properties Ltd. (TSMV) wishes to develop an area located between Stewart Creek and Pigeon Creek in Canmore, Alberta. This area is collectively referred to as the Smith Creek Area Structure Plan (ASP).

Some of the areas to be developed are located on, or in the vicinity of, the fans of Stewart, Fall Smith, Marsh, Cairnes and Pigeon Creeks (Drawing 01 and Drawing 02). These creeks are prone to steep creek hazards, and parts of the proposed development area are potentially at risk from these hazards.

QuantumPlace Developments Ltd. (QPD), as agent for TSMV, retained BGC Engineering Inc. (BGC) to carry out a quantitative steep creek risk assessment (SCRA) for subdivisions in the ASP. The objectives are to estimate the risk to life for potential building occupants from steep creek hazards and evaluate if those risks are considered tolerable according to the Town of Canmore Municipal Development Plan (Town of Canmore, 2016).

1.1. Scope

The scope of work includes the following tasks:

- Review previous hazard assessments on Stewart, Smith, Marsh and Cairnes Creeks to confirm that methods are consistent across all creeks and carry out a hazard assessment update. A high-level review and simplified update was also completed for Pigeon Creek, as described in Section 1.2 below.
- Determine the areas within existing development and the Smith Creek ASP that could be exposed to steep creek hazards and estimate the associated population in those areas.
- Estimate the risk to life for potential building occupants in exposed areas and compare those to risk tolerance thresholds adopted by the Town of Canmore.

1.2. Pigeon Creek

The report contains a simplified update of the hazard assessment for Pigeon Creek, but does not include a full suite of model updates or a SCRA. A SCRA was not completed because steep creek hazards from Pigeon Creek are unlikely to result in life loss risk to people within buildings in the proposed development. The Smith Creek ASP development is located on higher ground west of Pigeon Creek, and does not intersect the area affected by steep creek hazards, with three exceptions:

1. Two proposed roads which cross Pigeon Creek and provide access to the development. These access points can be managed by installing multiple large capacity box culverts or clearspan bridges. The bridge or culvert capacity would be determined in consultation with the Town of Canmore and other stakeholders.
2. At the western edge of the Pigeon Creek fan near Cairnes Creek, where a small portion of the proposed development is on low ground that could flood if Pigeon Creek avulses west along the TransCanada Highway (parcel area SM 04, Drawing 01).
3. At the eastern edge of Smith Creek ASP, where a small portion of parcels TL 01 and TL 02 are located on the Pigeon Creek floodplain.

Item 1 does not pose a life loss risk to people within buildings. QPD on behalf of TSMV has advised that Items 2 and 3 will be addressed as part of development construction, by sterilizing or re-grading and elevating the affected areas by a suitable height to reduce the risk. Therefore, an SCRA was not completed for these areas because an assessment based on the current topography would not reflect the post-development conditions.

The purpose of the Pigeon Creek hazard assessment update and modelling within this report is to estimate the maximum probable inundation depth that could occur within the Smith Creek ASP, in order to prescribe a suitable minimum depth for the development re-grading.

1.3. Fall Creek

BGC notes this work does not include an SCRA of Fall Creek. Fall Creek was not assessed because tributary debris flows from Fall Creek are likely to deposit on the Fall Creek fan which is outside the Smith Creek ASP boundary (BGC, July 4, 2017). Afterflows from Fall Creek debris flows were also not assessed as they would flow into Stewart Creek and are unlikely to substantially increase its peak discharge.

2. BACKGROUND

The regional and local watershed geology, geomorphology, and hydrology are described in BGC's previous hazard assessment (BGC, August 31, 2015).

This section provides a brief summary of the Smith Creek ASP development, an overview of the Stewart, Smith, Marsh, and Cairnes Creeks and associated fans, and a summary of the previous work relevant to the risk assessment.

2.1. Smith Creek ASP Proposed Development

The Smith Creek ASP has previously been summarized by QPD (2020). The proposed development boundary is located within the southern portion of the Town of Canmore, is adjacent to the Stewart Creek Golf and Country Club and lies immediately south of Highway 1 (Drawing 01). The Smith Creek ASP area spans approximately 154 hectares (Figure 2-1).

Land within the Smith Creek ASP is planned for residential and flexible commercial – industrial use, with some land being designated for open space or other infrastructure (e.g., road networks, utilities). Residential areas encompass the largest portion of the proposed development area and are planned to include single- and semi-detached homes, townhomes, stacked townhomes, apartments, seniors housing and a school zone. Flexible commercial-industrial district is planned for commercial, light industrial and institutional uses.

Smith Creek Area Structure Plan			
Plan Area **Estimated Unit Range**	**154 (ha)** **830-1730**		
	Min. (ha)	**Max. (ha)**	**% of GDA**
Residential	65 ha	70 ha	**40-45%**
	Min. Unit	Max. Unit	Min Max
Low Density	600	1250	60% 75%
Medium Density	200	500	25% 40%
Flex Commercial - Industrial	15 ha	25 ha	**10-15%**
Open Space	30 ha	35 ha	**20-25%**
Other (Roads, Infrastructure, etc.)	30 ha	35 ha	**20-25%**
Density - UPH	**10**	**25**	

Figure 2-1. Smith Creek Unit and Area Projections (QPD, 2020).

2.2. Stewart Creek

2.2.1. Site Description

Stewart Creek and its tributaries descend a drainage basin located immediately east of Three Sisters peak, from a max elevation of 2890 m to the top of the Stewart Creek fan apex at 1465 m. From this point, the creek flows to the north through undeveloped, forested terrain for about 600 m before reaching the Stewart Creek Golf and Country Club fairway (Drawing 02). The creek flows generally northwest through the fairway for about 825 m. It then turns east and flows through

1.3 km of forested terrain before reaching Highway 1 and eventually discharging into the Bow River. The current channel configuration is not natural and was adopted as part of construction of the golf course in the 1990s. Previous BGC observations (August 31, 2015) indicate that the creek has historically flowed further east, as indicated by several abandoned drainages on the central and east portion of the alluvial fan.

The alluvial fan of Stewart Creek has an area of 1.0 km^2 and is mostly undeveloped. The average fan gradient is 8.5%; however, the Stewart Creek channel dips at approximately 3% due to re-routing. The fan extends for approximately 1.7 km (NE/SW direction) from its apex. The fan is crossed by Highway 1 and a buried pipeline operated by ATCO Gas (just upstream of Highway 1) near the fan distal edge.

2.2.2. Previous Steep Creek Assessments

BGC has previously assessed hazards on Stewart Creek for Town of Canmore (BGC, January 3, 2014). Further hazard and risk assessments have been completed for TSMV (or QPD on TSMV's behalf) by BGC for various stages of Stewart Creek development (BGC, August 31, 2015; BGC, July 4, 2017). Table 2-1 presents the frequency-magnitude relationship that was developed for Stewart Creek during these assessments.

Table 2-1. Peak discharge and sediment volume estimates for Stewart Creek (BGC, July 4, 2017).

Return period (years)	Peak discharge (m^3/s)	Sediment volume (m^3)
10 to 30	29	16,000
30 to 100	41	21,000
100 to 300	57	26,000
300 to 1000	68	31,000
1000 to 3000	82	35,000

The previous assessments did not account for peak flow increases that may occur due to climate change. Therefore, Section 3 presents an updated hazard assessment for Stewart Creek that supersedes the previous work.

2.3. Smith, Marsh and Cairnes Creek

2.3.1. Site Description

The Smith, Marsh, and Cairnes Creeks watersheds, fans, and channel have previously been summarized by BGC (August 31, 2015).

The Smith, Marsh, and Cairnes Creeks descend the northeast facing slope of Mount Rimwall, from a maximum elevation of 2180 m to 1440 m near the associated fan apexes. The centerlines of these creeks trend northeast-southwest and are approximately 0.5 km apart. These creeks all have small watersheds (< 0.6 km^2) and fan areas (< 0.1 km^2), and the watersheds are completely forested. Smith, Marsh and Cairns Creek are ephemeral with their primary water source being from spring runoff or storm events. Each creek ultimately drains into the Bow River, and in places below grade as groundwater depending on flow conditions.

The Smith Creek alluvial fan is the smallest of the three creeks (0.046 km^2). From the fan apex, Smith Creek discharges into a well confined channel that extends for approximately 250 m through forested terrain, then becomes increasingly unconfined to a point where there is no obvious channel or drainage (BGC, August 31, 2015).

Alluvial fans of Marsh and Cairnes Creeks are characterized by upper and lower fans (Marsh upper and lower: 0.082 km^2 and 0.014 km^2; Cairnes Creek upper and lower: 0.054 km^2 and 0.1 km^2). The Marsh Creek channel transitions from confined along the upper fan, to unconfined below, and then re-channelizes along the lower fan. Cairnes Creek is relatively confined for most of its alignment but becomes increasingly unconfined along the lower fan (BGC, August 31, 2015).

2.3.2. Previous Steep Creek Assessments

BGC (August 31, 2015) has conducted a preliminary hazard assessment for Smith Creek, Marsh Creek, and Cairnes Creek. BGC concluded that all three creeks were prone to debris flows.

In a follow-up study, BGC (June 18, 2019) delineated portions of the Smith Creek, Marsh Creek, Cairnes Creek and Pigeon Creek fans and adjacent areas that could be affected by steep creek hazards. The purpose of that study was to identify the hydrogeomorphic assessment zone for planning purposes, expressed as the “Study Area Boundary”.

The work included estimation of the debris volumes and peak flows associated with 1000- to 3000- year return period debris flows for Smith, Marsh, and Cairnes Creek considering a regional frequency-magnitude approach. Clearwater or afterflow peak discharges were derived by scaling based on watershed area from previous work on X, Y and Z Creeks located to the west (BGC, December 21, 2018). Numerical modelling was completed using a two-phase approach, which was also consistent with X, Y, Z and Echo Canyon Creeks (BGC, December 21, 2018; June 18, 2019).

While Smith, Marsh, and Cairnes Creeks are debris flow-prone, hazard modelling along these creeks shows that debris-flow runout does not reach the proposed development. Instead, the hazard to the proposed development is shallow overland flows with fine sedimentation (BGC, August 31, 2015), which may include hyper-concentrated after-flows, debris flood, or bedload transport events (BGC, June 18, 2019).

The 2019 report did not include numerical modelling of return periods other than the 1000 to 3000-year[1] event, nor did it account for the potential effects of climate change. Therefore, Section 3 presents an updated hazard assessment for Smith, Marsh and Cairnes Creeks that supersedes the previous work.

[1] For this report, when referring to an event of certain return period (e.g. 1000 to 3000-year return period event), year is used as an abbreviation for ‘year return period’.

2.4. Pigeon Creek

2.4.1. Site Description

Pigeon Creek has a watershed area of 54.7 km^2 and a fan area of 1.3 km^2. The watershed includes numerous sediment sources, including potential for landslide damming.

Pigeon Creek is subject to debris floods. The debris flood that occurred in June 2013 damaged or affected several facilities in the vicinity of Pigeon Creek, including Thunderstone Quarry, the TransCanada Highway, and roads and properties within the hamlet of Dead Man's Flats. A majority of the fan is located within the Municipal District (MD) of Bighorn, and only a small proportion is located with the Town of Canmore's municipal boundary.

2.4.2. Previous Steep Creek Assessments

BGC completed a forensic report on Pigeon Creek following the June 2013 event (BGC, December 2, 2013). The memo provided an overview of the physical setting, a description of the impacts of the 2013 event, a preliminary frequency analysis and a few conceptual mitigation design options.

BGC's report was followed by a more detailed report by Tetra Tech EBA (November 2016)[2]. Tetra Tech assessed the frequency and magnitude of debris floods on Pigeon Creek and completed numerical modelling. The frequency-magnitude relationship from the Tetra Tech report is summarized in Table 2-2. Note that Tetra Tech only reported the discharge values for discrete return periods (i.e. 10 year, 30 year, etc.); therefore, the values have been interpolated to correspond with the mid range of the return period.

Table 2-2. Pigeon Creek frequency-magnitude relationship compiled from Tetra Tech EBA (November 2016).

Return period (years)	Clearwater Discharge (m^3/s)	Bulked Discharge (m^3/s)	Sediment Volume (m^3)
10 to 30	33	40	36,000
30 to 100	48	58	54,000
100 to 300	80	95	74,000
300 to 1000	127	150	100,000
1000 to 3000	178	211	131,000

In 2017, Alpinfra Engineering completed an Options Analysis report for Pigeon Creek debris flood mitigation. The report presented a complementary hydrological analysis, as well as several potential structural mitigation options that would reduce debris flood risk for the TransCanada Highway and Dead Man's Flats.

Neither the Tetra Tech nor the Alpinfra reports provided climate-change adjusted peak discharge values for Pigeon Creek.

[2] for disclosure: BGC had been retained to review EBA Tetra Tech's work in various draft forms in 2015.

3. HAZARD ASSESSMENT UPDATE

3.1. Stewart Creek

Previous assessments of Stewart Creek hazards did not account for peak flow or sediment volume increases that may occur due to climate change. Therefore, the hydrology analysis and numerical modelling were updated in order to inform the risk assessment and conceptual mitigation design for the Smith Creek ASP.

3.1.1. Hydrology and Climate Change Analysis

The objective of the hydrology analysis was to establish climate-change adjusted peak discharges values for Stewart Creek as an input to numerical modelling.

The hydrology of Stewart Creek is similar to Three Sisters Creek, due to their similar watershed areas (9.1 km^2 for Stewart and 9.5 km^2 for Three Sisters). Therefore, the assessment methods used for Stewart Creek are the same as the methods used for the Three Sisters Creek Hazard Assessment Update (BGC, October 9, 2020). The following steps summarize the approach:

- Determine the expected 24-hour rainfall (hyetograph) for each return period.
- Modify the expected rainfall to account for climate change affects, using the University of Western Ontario’s IDF climate change tool (IDF_CC Tool 3.0).
- Use a rainfall-runoff model (HEC-HMS) to route the adjusted rainfall for each return period through the catchment, to determine a corresponding peak discharge and hydrograph.

Additional details on the hydrology analysis update can be found in Appendix A.

Table 3-1 shows the results of the climate change adjusted peak discharges, which have been bulked to account for mineral and organic debris that would be included in the flow during a debris flood event. Bulking factors were selected based on comparisons to other debris flood creeks in the Canmore area, estimates from the 2013 event, and watershed characteristics.

Table 3-1. Summary of updated peak discharges for Stewart Creek to include climate change and sediment bulking.

Return Period (years)	Clearwater discharge (m^3/s)	Climate change adjusted discharge (m^3/s)	Bulking Factor	Climate change adjusted, bulked discharge (m^3/s)
10 to 30	12	22	1.05	23
30 to 100	24	40	1.05	42
100 to 300	38	61	1.05	64
300 to 1000	57	87	1.1	96
1000 to 3000	80	117	1.1	129

3.1.2. Numerical Modelling Setup and Scenarios

Numerical modelling was completed using FLO-2D (2020) software, consistent with the 2017 hazard assessment (BGC, July 4, 2017). A grid size of 5 m by 5 m was used for the modelling.

BGC's Three Sisters Hazard Update report provides additional information about the modelling methods (BGC, October 9, 2020).

Nine different steep creek hazard scenarios were modelled, as summarized in Table 3-2. A base case model was completed for five return periods, using the 2013 lidar without modification. For the 30 to 100-year event and above, an avulsion scenario was also modelled. This scenario represents a channel blockage near the fan apex, causing the flow to divert into the historical channel in the middle of the fan. Avulsion could occur due to bank erosion, a blockage such as a log jam, or due to the discharge exceeding the capacity of the channel. For the 10 to 30-year return period event, an avulsion case was not considered as a full creek avulsion did not occur during July 2013 event, which was approximately a 200-year event (BGC, July 4, 2017).

Table 3-2. Stewart Creek geohazard scenarios used for numerical modelling.

Return Period (years)	Peak Discharge (m^3/s)	Base Case	Avulsion Case
10 to 30	23	✓	
30 to 100	42	✓	✓
100 to 300	64	✓	✓
300 to 1000	96	✓	✓
1000 to 3000	129	✓	✓

3.1.3. Numerical Modelling Results

The results of the numerical modelling are shown on Drawings 03 through 10. Drawing 11 shows the estimated steep creek hazard exposure area for Stewart, Smith, Marsh, Cairnes and Pigeon Creeks combined, which is based on the results of the 1000- to 3000- year return period modelling.

The modelling results were reviewed prior to use for the risk assessment or to inform mitigation design. In six grid cells within the Smith Creek ASP boundary, the calculated intensity values were interpreted to be too high for the 10- to 30-year and 30- to 100-year base models, based on comparisons with observations from the 2013 event. In all cases, the modelled flow intensities were marginally above 1 m^3/s^2 in locations where flow was not observed during the 2013 event, which was estimated to have a 200-year return period. Therefore, the intensity values were not considered to be credible, and they were adjusted to less than 1 m^3/s^2. These adjustments did not impact the results of the risk assessment.

3.2. Smith, Marsh, and Cairnes Creek

3.2.1. Debris Flood Phase

As mentioned in Section 2.3.2, Smith, Marsh and Cairnes Creeks are prone to debris flows, but the debris flows are unlikely to reach the Smith Creek ASP development boundary. Therefore, this assessment focuses on the debris flood or afterflow phase of the process, which will runout farther and could affect the proposed development. However, the debris flood phase could remobilize some of the sediment deposited by a debris flow, so the debris flow sediment volumes were also estimated. These sediment volumes represent an upper bound, rather than an estimate of the likely sediment transport on the creeks.

3.2.2. Hydrology and Climate Change Analysis

The objective of the hydrology analysis was to establish climate-change adjusted peak discharges values for Smith, Marsh and Cairnes Creeks, as an input to numerical modelling.

Due to their small watershed size and similarity to previously assessed watersheds, the afterflow peak discharges for Smith, Marsh and Cairnes Creeks were scaled based on watershed size from the peak discharges of X, Y and Z Creeks. The hydrology analysis for X, Y and Z Creeks used climate-adjusted rainfall runoff modelling and the methods are documented in BGC (December 21, 2018). This scaling approach was previously described in BGC (June 18, 2019), but the 2019 assessment used historical rather than climate change adjusted peak discharges from X, Y and Z Creeks.

Table 3-3 shows the results of the climate change adjusted peak discharges from the clearwater or afterflow phase.

Table 3-3. Climate change adjusted peak discharges for debris floods or debris-flow afterflows on Smith, Marsh and Cairnes Creeks.

Return Period (years)	Climate change adjusted discharge (m^3/s)		
	Smith Creek	Marsh Creek	Cairnes Creek
10 to 30	5	5	7
30 to 100	9	8	11
100 to 300	13	11	16
300 to 1000	18	16	24
1000 to 3000	25	21	32

3.2.3. Debris Flow Sediment Volume Analysis

The debris flow volume for each return period was estimated using the regional frequency-magnitude approach outlined in BGC (June 18, 2019). The results of the assessment are summarized in Table 3-4. As described previously, debris flows are expected to deposit on the fans upstream of the development, but some portion of the debris could be remobilized by the afterflows. Therefore, these sediment volumes represent an upper bound, rather than an estimate of the likely sediment transport on the creeks.

Table 3-4. Estimated sediment volumes for debris flows on Smith, Marsh and Cairnes Creeks.

Return Period (years)	Debris flow sediment volume (m^3)		
	Smith Creek	Marsh Creek	Cairnes Creek
10 to 30	350	450	500
30 to 100	1,700	2,000	2,200
100 to 300	3,000	3,600	3,800
300 to 1000	4,300	5,200	5,400
1000 to 3000	5,600	6,700	7,100

3.2.4. Numerical Modelling Setup and Scenarios

Numerical modelling was completed using FLO-2D Software (2020), consistent with the 2019 study area boundary assessment (BGC, June 18, 2019).

Seven different steep creek hazard scenarios were modelled, as summarized in Table 3-4. A base case model was completed for four return periods, using the 2013 lidar without modification. For the 100- to 300-year return period event and larger, an avulsion scenario was also modelled on Cairnes Creek. This scenario represents a channel blockage near the fan apex, which causes some of the flow to divert onto the western fan. Blockage could occur due to a stalled debris lobe in the channel. Avulsion scenarios were not considered for Smith and Marsh Creeks because their channels are less defined, so the modelled flows are already fairly dispersed across the fans.

Table 3-5. Smith, Marsh and Cairnes Creek geohazard scenarios used for numerical modelling.

Return Period (years)	Base Case	Avulsion Case (Cairnes only)
30 to 100	✓	
100 to 300	✓	✓
300 to 1000	✓	✓
1000 to 3000	✓	✓

3.2.5. Numerical Modelling Results

The results of the numerical modelling are shown on Drawings 03 through 10. Drawing 11 shows the estimated steep creek hazard exposure area for Stewart, Smith, Marsh, Cairnes and Pigeon Creeks combined, which is based on the results of the 1000- to 3000- year return period modelling.

The modelling results were reviewed prior to use for the risk assessment or to inform mitigation design. In six grid cells on Smith Creek within the Smith Creek ASP boundary, the calculated intensity values were interpreted to be too high for the 30- to 100-year model, based on comparisons with observations from the 2013 event. In all cases, the modelled flow intensities were marginally above 1 m^3/s^2 in locations where flow was not observed during the 2013 event, which was estimated to have a 200-year return period. Therefore, the intensity values were not considered to be credible, and they were adjusted to less than 1 m^3/s^2. These adjustments did not impact the results of the risk assessment.

3.3. Pigeon Creek

3.3.1. Simplified Climate Change Analysis

The objective of the Pigeon Creek assessment is to estimate the maximum possible inundation that could occur within the Smith Creek ASP, and inform re-grading or possibly sterilization of some areas of the development. Therefore, this section focuses only on the 1000- to 3000-year return period.

A 50% scaling factor was applied to the 1000- to 3000-year bulked peak discharge from the Tetra Tech report (211 m^3/s) to account for climate change, resulting in an estimated peak discharge of 317 m^3/s. The 50% value (1.5 x) is consistent with the climate change adjustments that were calculated for Stewart Creek (80 m^3/s to 117 m^3/s, 46%, see above) and Three Sisters Creek (66 m^3/s to 102 m^3/s, 55%, BGC, October 9, 2020). Since Stewart Creek and Three Sisters Creek have smaller watersheds than Pigeon Creek and are thereby more affected by “flashy” precipitation events, using a 50% scaling factor is likely conservative.

3.3.2. Numerical Modelling Setup

Numerical modelling was completed using FLO-2D Software (2020), consistent with the other assessments described above. Only the 1000- to 3000-year return period was modelled. The numerical model was initiated upstream of Thunderstone Quarry, immediately downstream of the waterfall.

Culverts were not integrated into the model, under the assumption that they would block with sediment or woody debris during such a high return period event. Without the culverts, the majority of the Pigeon Creek flows west towards parcel SM 04, which allows us to evaluate the maximum probable inundation in this area under the 1000- to 3000-year return period conditions.

3.3.3. Numerical Modelling Results

The results of the numerical modelling are shown on Drawing 09. The results demonstrate that SM 04 could experience flow depths up to 2.0 m. Deeper flows are not anticipated because the highway embankment overtops at this point.

QPD on behalf of TSMV has advised BGC that the risk posed to SM 04 by Pigeon Creek will be managed by increasing the grade in the area by at least 2 m plus appropriate freeboard. In that case, inundation of SM 04 is unlikely to occur, and life loss risk tolerance thresholds will not be exceeded. Additional recommendations can be found in BGC’s Smith Creek ASP Conceptual Mitigation report (December 15, 2020).

Aside from SM 04, shallow flows (<1.2 m) are also expected in a small area on the western edge of the proposed commercial area (parcel TL 02). This area will either be re-graded or sterilized (not developed) to remove the risk posed by Pigeon Creek.

In addition, a portion of TL 01 intersects the Pigeon Creek floodplain upstream of the waterfall. QPD on behalf of TSMV will amend the boundary of TL 01 to limit development to higher ground out of the floodplain. This amendment may have already been made in TSMV's development plan, although it is not reflected in the layout shown on BGC's drawings, which dates from September 2020.

3.4. Limitations

The hazard assessment is limited by the following:

- The assessment does not include snow avalanches, erosion, sinkholes or landslides. Therefore it should not be interpreted as a global hazard assessment.
- The assessment does not specifically account for post-wildfire conditions, and potential subsequent increases in steep creek hazard frequency and magnitude until the watershed re-stabilizes through tree re-growth.
- Bank erosion was not considered in the hazard assessment, as this process is unlikely to result in life-loss to persons in buildings. However, bank erosion can lead to economic loss. For specific developments, additional analysis for this process may be required at the development layout stage.
- The baseline topography used in numerical modelling was collected in August 2013 by McElhanney and does not account for minor modifications made to the Stewart Creek channel immediately following the 2013 event (BGC, August 31, 2015), or for future topographic modifications during development.

4. EXPOSURE ASSESSMENT

The risk assessment for Stewart, Smith, Marsh and Cairnes Creeks considers the potential for persons in existing and proposed development to suffer loss of life from steep creek hazard impacts. An exposure assessment was carried out to:

- Identify areas exposed to modelled steep creek hazard scenarios (Section 3).
- Estimate the number of building occupants in exposed areas, to inform risk assessment.

4.1. Exposed Areas in Existing and Proposed Development

BGC received the conceptual development layout plan from QPD on September 9, 2020 (pers. comm., Ellie Abootorabi). This package included a listing of Smith Creek parcel areas, their associated land use, and population density information (Drawing 01, Table 4-2).

To assess areas in proposed development exposed to steep creek hazards, BGC overlaid the conceptual Smith Creek ASP layout plan with the combined steep creek hazard inundation area, which was developed from the 1000- to 3000-year return period numerical model results. This boundary, also known as the 'potential steep creek hazard exposure boundary' (Drawing 11), is a conservative estimate of the potential inundation area, as locally elevated areas which may not be impacted by steep creek hazards are included. The objective is to account for potential modelling uncertainty.

Based on the overlay, BGC identified that approximately 30% of the Smith Creek ASP development is within the hazard exposure boundary (Drawing 11). Table 4-2 summarizes the parcel areas in the Smith Creek ASP that could be potentially exposed to steep creek hazards.

Building footprints in existing development were obtained by BGC from the Town of Canmore's open data portal (Town of Canmore, 2020). BGC identified no buildings in existing development that could be exposed to hazards from Stewart, Smith, Marsh or Cairnes Creeks (Drawing 11). A risk assessment for existing development on Pigeon Creek has been completed previously (BGC, September 27, 2016), and an update was not part of the scope of this project.

4.2. Population in Exposed Areas

The population in areas exposed to steep creek hazard scenarios was estimated at the model grid cell scale (i.e., 5 m x 5 m), as building layouts are currently unavailable. This was carried out by estimating the population for each parcel area, then distributing this population across all grid cells within the parcel area boundary (Table 4-2). This approach conservatively assumes that:

- All potential building occupants in parcel areas are located on ground level.
- Buildings and their occupants could be located anywhere within the proposed development parcels.

For residential areas, BGC estimated the population for each parcel area using the average household occupancy rate in Alberta (Statistics Canada, 2017) and the estimated number of building units in each parcel area. For the school zone, BGC used a population of 400 persons, which corresponds with the approximate average student population across Canmore schools (i.e., Exshaw, Elizabeth Rummel, Lawrence Grassi Middle, and Canmore Collegiate High). The flexible commercial-industrial area is identified as not exposed to potential steep creek hazards, so population in this area was not estimated.

Table 4-1. Population in Smith Creek ASP parcel areas exposed to potential steep creek hazard.

Parcel Area	Area (ha)	Land Use	Density Type	No. Units	Exposed to Steep Creek Hazard	Estimated Unit Population	Total Potential Population	Potential Population per grid cell[1]	Area Exposed to Potential Hazard (ha)[2]
TL.01	7.23	Residential	Low	162	No	2.6	421	0.15	0.00
TL.02	19.09	Commercial/Industrial	N/A	43	No	n/a	0	n/a	0.00
SM.03	6.79	Residential	Low	151	No	2.6	393	0.14	0.00
SM. 04	4.72	Residential	Low	105	Yes	2.6	273	0.14	0.74
SM.05	3.2	Residential	Med	128	Yes	2.6	333	0.26	0.09
SM.06	0.8	Residential	Med	32	Yes	2.6	83	0.26	<0.01
SM.07	3.89	Residential	Low	86	Yes	2.6	224	0.14	0.26
SM.08	3.76	Residential	Low	85	Yes	2.6	221	0.15	3.32
SM.09a	2.81	Residential	Low	62	Yes	2.6	161	0.14	1.83
SM.09b	2.29	School	N/A	1	Yes	400	400	0.44	1.75
SM.10	2.41	Residential	Med	97	Yes	2.6	252	0.26	<0.01
SM.11	11.37	Residential	Low	255	Yes	2.6	663	0.15	8.81
SM.12	8.31	Residential	Low	186	Yes	2.6	484	0.15	3.36
SC.13	3.83	Residential	Med	85	Yes	2.6	221	0.14	2.24
SC.14	6.99	Residential	Low	155	Yes	2.6	403	0.14	0.35
SC.15	2.33	Residential	Med	93	Yes	2.6	242	0.26	0.34
						Total:	**4773**	**n/a**	**23.1**

Note:

1. Model grid cells are 25m^2.
2. Does not account for areas exposed to potential hazard within open/recreational space or that are designated for transport/utilities.

5. RISK ASSESSMENT

5.1. Risk Assessment Framework

In its simplest expression, risk is the probability of loss. This can be expressed as the probability of suffering a loss of some value over some defined time period.

For this assessment, risk is defined as the probability of building occupants dying within the Smith Creek ASP due to steep creek hazards. No building occupants in existing development are at life loss risk from these steep creek hazards.

The risk assessment involves estimating the probability that steep creek hazard scenarios occur, impact building occupants in the Smith Creek ASP, and cause loss of life. BGC used a QRA approach and applied the same methods as for other risk assessment completed for Town of Canmore (e.g., BGC, January 19, 2015; BGC, January 11, 2018; BGC, December 21, 2018). This includes estimating both the risk to individuals and groups and comparing those risk estimates against risk tolerance criteria (Town of Canmore, 2016).

5.1.1. Individual Risk Analysis

Individual risk, also known as annual Probability of Death of an Individual, (PDI), evaluates the chance that a specific person will be killed by the hazard scenario. This typically focuses on the person judged to be most at risk, corresponding to a person spending the greatest proportion of time at home, such as a young child, stay-at-home person, or an elderly person. For this assessment, individual risk in the Smith Creek ASP boundary was estimated at the model grid cell scale, and is calculated as follows:

$$PDI_j = \sum_{i=1}^{n} P(H)_i P(S{:}H)_{i,j} P(T{:}S)_{i,j} V_{i,j} \qquad \text{[Eq. 5-1]}$$

Where:

- PDI_j is the PDI at a given model grid cell (j).
- $P(H)_i$ is the annual probability of a geohazard scenario (i).
- $P(S{:}H)_{i,j}$ is the spatial probability of impact of geohazard scenario (i) at a grid cell (j).
- $P(T{:}S)_{i,j}$ is the temporal probability of a person occupying a building (j).
- $V_{i,j}$ is the probability of fatality (vulnerability) given impact by the estimated hazard intensity[3]

5.1.2. Group Risk Analysis

Group risk, also known as societal risk, evaluates the number of people that could be killed by a steep creek hazard scenario.

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

[3] Intensity refers to the destructive potential of an event.

$$f_i = P(H)_i P(S{:}H)_{i,j} \quad \text{[Eq. 5-2]}$$

$$N_i = \sum_{j=1}^{n} P(T{:}S)_{i,j}\, V_{i,j} E_j \quad \text{[Eq. 5-3]}$$

Where:

- $P(H)_i$, $P(S{:}H)_{i,j}$, $P(T{:}S)_{i,j}$, and $V_{i,j}$ are the same as defined in Equation 5-1; and
- E_j is the number of people exposed to the hazard in grid cell (j).

5.1.3. Risk Evaluation

In 2016, the Town of Canmore formally adopted criteria to assess whether safety risk for individuals or groups exceed tolerable levels. The Town of Canmore's safety risk tolerance criteria for development impacted by steep creek hazards are as follows (Town of Canmore, 2016):

- For new development, the individual risk (PDI) shall not exceed 1:100,000.
- For existing development, the individual risk shall not exceed 1:10,000.
- "Group risk is within an acceptable or as Low As Reasonably Practicable (ALARP) range. Group annual risk tolerance will be based on the F-N plot[4], as shown in Figure 5-1.

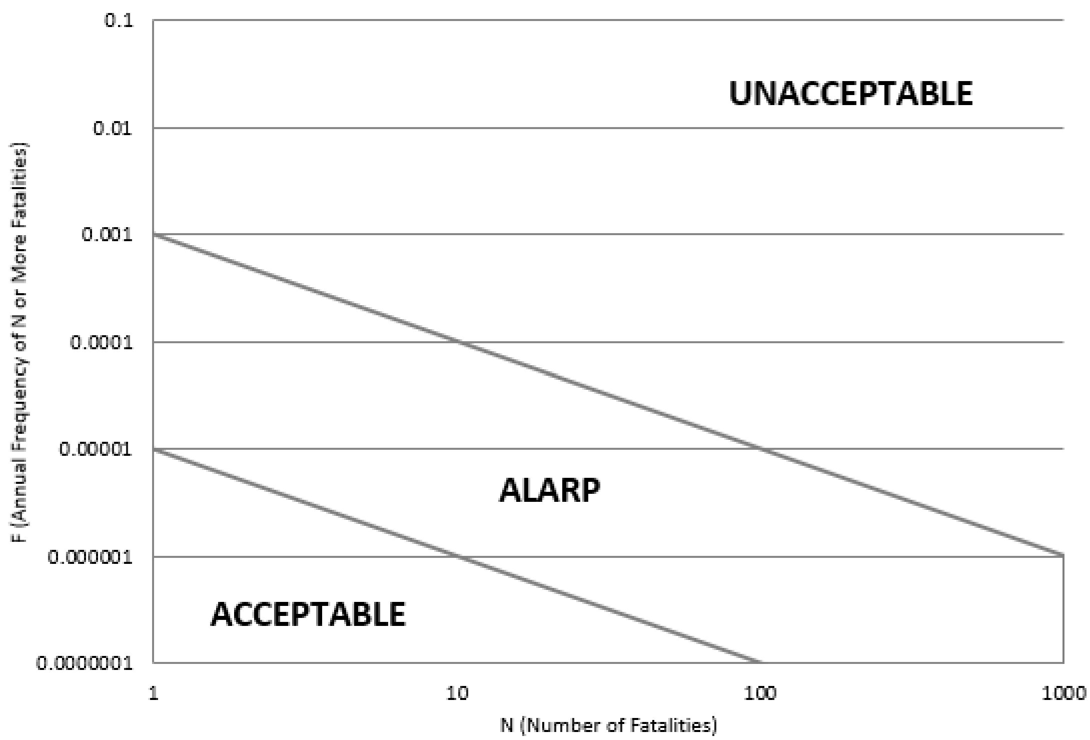

Figure 5-1. Group risk tolerance criteria.

[4] The horizontal axis represents the number of fatalities (N) and the vertical axis represents the cumulative annual probability of 'N' or more fatalities from all geohazard scenarios considered. Note that a capital F is used by convention to signify cumulative frequency; a lowercase f is used to indicate the frequency of individual geohazard scenarios.

5.2. Risk Inputs

The following sections summarizes the methods to determine inputs to the individual and group risk equations.

5.2.1. Scenario Probability, $P(H)_i$

For this assessment, scenario probability is defined as the product of hazard probability, $P(D)_i$, and steep creek hazard avulsion probability, $P(A)_i$. A geohazard scenario is therefore defined as a steep creek hazard event that occurs at a specified return period and exhibits an avulsion behaviour.

<u>Hazard Probability</u>

Hazard probability corresponds to the annual probability of occurrence of each hazard scenario, which are defined in as annual frequency ranges. The bounds of a given range are exceedance probabilities. As such, for a scenario with the annual probability range P_{min} to P_{max}, the probability of events within this range corresponds to:

$$P(D)_i = P_{max} - P_{min} \quad \text{[Eq. 5-4]}$$

For example, for the 1:30 to 1:100-year range, this would correspond to:

$$P(D)_i = \frac{1}{30} - \frac{1}{100} = \frac{1}{43} \quad \text{[Eq. 5-5]}$$

<u>Avulsion Probability</u>

Avulsion probability accounts for the possibility that a steep creek hazard scenario will avulse from the main channel. Avulsions occur when flows divert outside of the existing channel. Avulsions can be caused by obstructions that develop during a debris flow or debris flood, for example, due to log jams, deposition of coarse boulder lobes and levees, super-elevation in channel bends or flow height exceeding the banks.

As stated in Section 3, avulsions were only considered on Stewart and Cairnes Creeks. Avulsions on Smith and Marsh Creeks are possible but were not modelled because they were not judged to have a material impact on the hazard distribution or on life loss risk in the proposed development.

Avulsion probabilities were assigned to each hazard scenario based on expert judgement. For debris flow fans, the avulsion probability considers the probability of a debris plug developing, and the ratio of the potential plug depth in relation to the channel depth. For debris flood fans, avulsion probability considers the portion of flow which may escape the channel, and the potential for migration of the current channel and resultant connection with another channel.

The avulsion probability represents the probability of a particular flow scenario occurring, and the avulsion probability values for each return period sum to 100%. For example, for the Stewart Creek 30- to 100-year event, the probability of an avulsion occurring was assessed at 10% based on the partial avulsion that occurred in 2013. Therefore, the no avulsion case was assigned a 90% probability, and the avulsion case was assigned a 10% probability. Avulsion probabilities of

100% were assigned to the Smith and Marsh Creek "no avulsion" scenarios, because there is no corresponding avulsion case for these creeks.

Appendix B summarizes scenarios considered in this assessment, including their associated hazard, avulsion, and scenario probabilities.

5.2.2. Spatial Impact Probability, P(S:H)

Spatial probability of impact considers the debris-flow extents in relation to the location of elements at risk. It addresses the question, "given that a steep creek hazard scenario occurs, what is the probability a given building is impacted?".

Spatial probability, $P(S:H)$, of impact considers modelled steep creek hazard extents in relation to the location of elements at risk (i.e. each model grid cells in proposed development). Cases where modeled flows impacted (intersected) these elements were considered certain ($P(S:H)$=1) to be impacted. Those elements outside the modeled flow extent were not considered subject to impact by the scenario ($P(S:H)$=0).

5.2.3. Temporal Impact Probability, P(T:S)

Temporal probability considers the proportion of time occupants spend within buildings, and address the question, "what is the chance a person is inside a building when a steep creek hazard occurs".

For persons in residential buildings, an average value of 0.5 was assigned for analysis of risk to groups implying that about half of the residents will be in their homes during a debris flood. A more conservative value of 0.9 was used for estimation of individual risk, corresponding to a person spending the greatest proportion of time at home, such as a young child, stay-at-home person, or an elderly person.

5.2.4. Vulnerability, V

Vulnerability is defined as the probability of a fatality given a building is impacted in the hazard scenario. For life loss it addresses the question, "what is the chance of fatality for persons within buildings, given the building is impacted?".

Table 5-1 shows the criteria used to estimate the vulnerability of persons within buildings to debris flood impact as an indirect consequence of building damage. These criteria are based on the steep creek hazard intensity index (Jakob, Stein, & Ulmi, 2011), which describes the severity impact at any location in the model domain. It is calculated as:

$$\mathrm{I_{DF}} = \mathrm{d} \times \mathrm{v}^2 \qquad \text{[Eq. 5-6]}$$

where d is flow depth (m) and v is flow velocity (m/s). The debris-flow intensity index has also been referred to as momentum flux given the units of m^3/s^2 (Prieto et al., 2018).

Intensity was estimated at each grid cell based on the depth and velocity extracted from FLO-2D model results. Vulnerability was mapped to each grid cell using criteria in Table 5-1. Criteria for individual risk considers the person most vulnerable to steep creek hazards, while criteria for group risk considers the vulnerability of a typical person.

Table 5-1. Debris-flood vulnerability criteria for persons within buildings.

Hazard Intensity Index (range)	Individual Risk	Group Risk
< 1	~0	~0
1 to 10	0.01	0.005
10 to 100	0.1	0.05
> 100	0.5	0.5

Note: Values indicate the estimated probability of life loss given impact.

5.2.5. Exposure, E

Exposure is the number of potential building occupants exposed to the steep creek hazard scenario. For individual risk it is assumed to be 1, corresponding to a single person being impacted. For group risk, the number of persons estimated at each model grid cell within proposed development (Section 4.2) was applied.

5.3. Results and Mitigation Implications

The results of the risk assessment are summarized in Table 5-2 and discussed in the following sections.

Table 5-2 describes individual risk in micromorts, which is defined as a one in a million chance of death. The Town of Canmore's individual steep risk tolerance threshold for existing development ($1x10^{-4}$) is equivalent to 100 micromorts, and the threshold for proposed development ($1x10^{-5}$) is equivalent to 10 micromorts.

Table 5-2. Summary of risk assessment results

Creek	Comparison with Tolerance Thresholds		Highest Individual Risk (Micromorts) (If Intolerable)
	Individual	Group	
Stewart	Intolerable	Tolerable (N<1)	67
Smith	Intolerable	Tolerable (N<1)	87
Marsh	Tolerable	Tolerable (N<1)	n/a
Cairnes	Intolerable	Tolerable (N<1)	87

5.3.1. Individual Risk

Within the Smith Creek ASP, areas exposed to hazard from Stewart, Smith, and Cairnes Creeks contain estimated PDI values that exceeds the individual tolerance standard for new developments (i.e., 1:100,000 risk of fatality per year). However, areas exposed to hazards from Marsh Creek are below this threshold.

Individual risk exceeds the tolerance standard for new development in five locations (Drawing 11). This includes areas where flows may channelize, such as within topographic depressions or along historic flow channels. The following is noted about each location, organized by creek:

- Stewart Creek: PDI exceeds the tolerance standard for new development along an elevated channel which branches from Stewart Creek approximately 50 m downstream from the proposed Three Sisters Parkway centerline and creek crossing. This channel extends for about 65 m through Parcel Area SC 13.
- Smith Creek: PDI exceeds the tolerance standard for new development along two northeast trending ephemeral channels located in the northeast corner of Parcel Area SM 12, and approximate center of SM 11. Modelled flow depths in these areas are less than 0.75 m for the 1000 to 3000-year return period event. Based on the current topography, Smith Creek flows may concentrate along these features downstream of the Stewart Creek alluvial fan, however BGC notes that no continuous flow occurs in these locations. From QPD on behalf of TSMV, BGC understands that these channels will be adjusted or infilled through site grading during construction. Given PDI estimates are below 1:100,000 for remaining areas where there are no localized topographic depressions, the associated PDI will be less than the tolerance standard for new development after site construction, in absence of any creek mitigation.
- Cairnes Creek: PDI exceeds the tolerance standard for new development along two channels that discharge into Cairnes Creek approximately 75 m upstream from the proposed Three Sisters Parkway crossing. The eastern channel is a side-channel of Cairnes Creek and is prone to creek avulsions.

5.3.2. Group Risk

The estimated number of fatalities (N) for each steep creek hazard scenario considered in this assessment were less than 1 and therefore do not plot on an F-N curve. As such, the group risk tolerance criteria outlined in Section 5.1.2 is met.

5.4. Mitigation Implications

In areas with intolerable life loss risk, the results of the risk assessment can inform the selection of the mitigation design event. Since group risk was considered tolerable for this study, design event selection is informed by individual risk.

Individual risk is estimated by calculating the partial risks associated with each geohazard scenario, and then summing the partial risks to obtain a total risk. For design event selection, we consider the partial risks for each scenario to identify the scenarios that need to be mitigated for the total risk to be reduced to below the risk tolerance threshold. In the Town of Canmore, the individual life loss risk tolerance threshold is 1:100,000 or 10 micromorts.

Figure 5-2 shows the risk posed by events of each return period for Stewart, Smith and Cairnes Creeks in the locations where individual risk is considered intolerable.

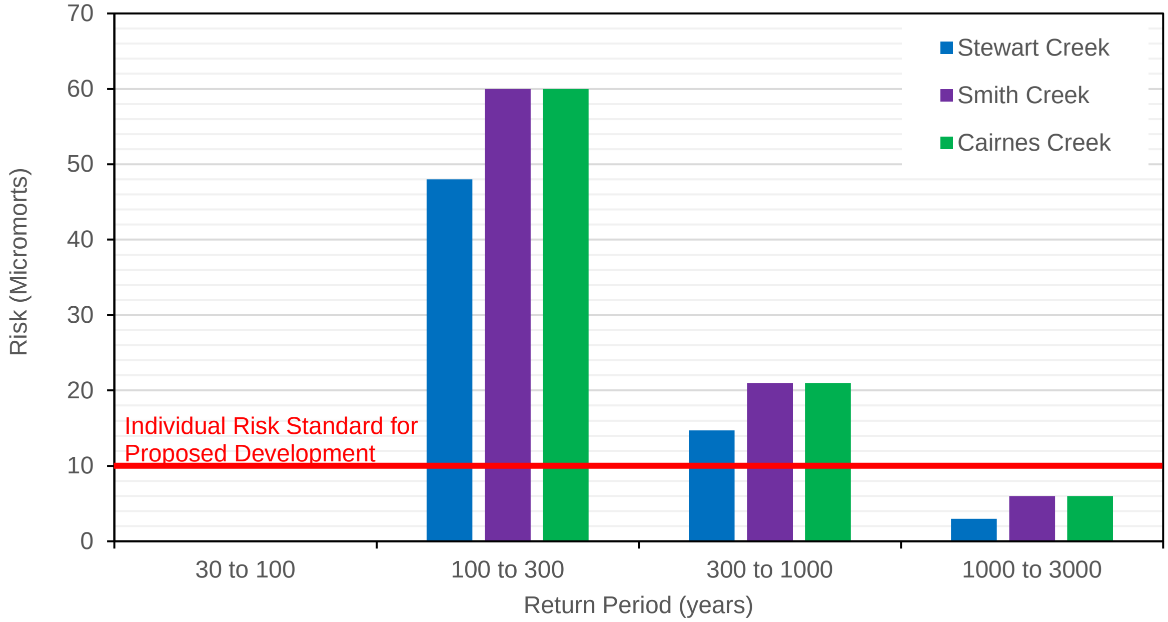

Figure 5-2. Individual risk posed by events of each return period on Stewart-, Smith- and Cairnes Creeks.

In Figure 5-2, the only return period that results in life loss risk that is below 10 micromorts is the 1000- to 3000-year event. This suggests that the risk posed by that event is below the tolerance threshold for proposed development, but the risk for more frequent events (< 1000-year return period) needs to be mitigated. Therefore, the recommended mitigation design event when considering safety from Stewart, Smith and Cairnes creek hazards is the 300- to 1000-year event. The mitigation design can also focus on reducing flows in areas where individual risk is considered above the individual risk standard for proposed development (Drawing 11).

6. CONCLUSION

Development within the proposed Smith Creek ASP has the potential to be impacted by steep creek hazards. The purpose of this assessment was to quantify the life loss risk posed by hazards from Stewart, Smith, Marsh, Cairnes and Pigeon creeks to the proposed development and evaluate if those risks are considered tolerable according to the Town of Canmore's 2016 Municipal Development Plan.

The results of the assessment demonstrated that:

- Pigeon Creek could affect two areas within the proposed development, given current topography. The affected areas will be excluded from development or re-graded as part of the development construction; therefore, life loss risk tolerance threshold will not be exceeded.
- Areas exposed to hazard from Stewart, Smith, and Cairnes creeks contain estimated PDI values that exceeds the individual tolerance standard for new developments of 1:100,000 (10 micromorts or $1x10^{-5}$) risk of fatality per year. This includes areas where flows may channelize, such as within topographic depressions or along historic flow channels.
- Steep creek hazards from Marsh Creek do not result in PDI values exceeding the individual risk tolerance standard for new developments.
- The number of potential fatalities from all steep creek hazard scenarios considered in the assessment was less than 1. This implies that group risk tolerance criteria for each creek are met.
- Areas where estimated PDI from Smith Creek hazards exceeds the individual risk tolerance standard include local topographic depressions which will be infilled as part of site construction. This will reduce the PDI values in these locations below the tolerance standard for new development.

7. CLOSURE

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

Yours sincerely,

BGC ENGINEERING INC.
per:

PROFESSIONAL ENGINEER
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Dec 15, 2020

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BCP/HW/mj

PERMIT TO PRACTICE
BGC ENGINEERING INC.

RM SIGNATURE: ____________

RM APEGA ID #: 119399

DATE: ____________

PERMIT NUMBER: P005366
The Association of Professional Engineers and Geoscientists of Alberta (APEGA)
2020-12-15

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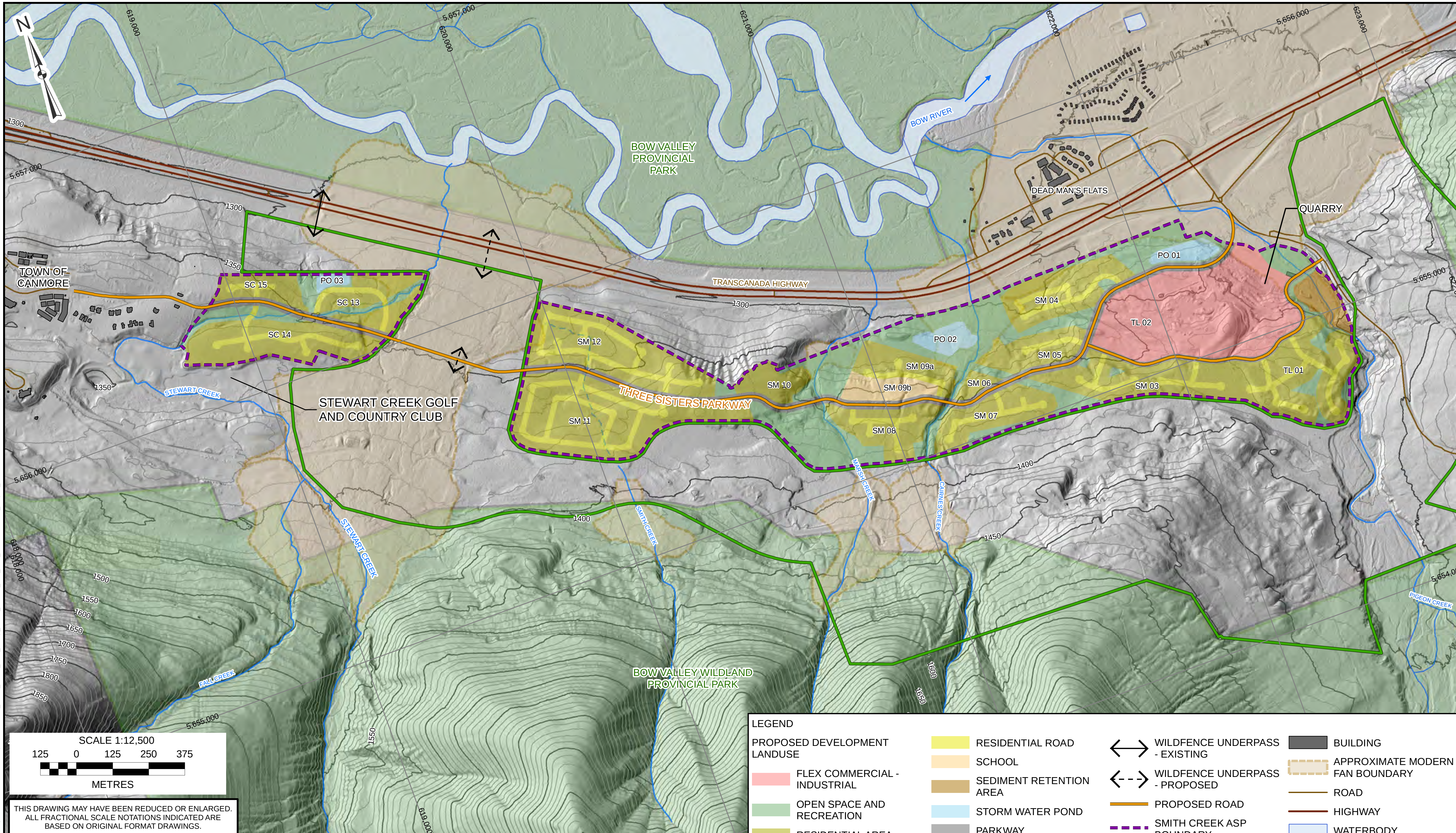
DRAWINGS



NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "SMITH CREEK ASP - STEEP CREEK HAZARD AND RISK ASSESSMENT" AND DATED DECEMBER 2020.
3. SMITH CREEK ASP LAYOUT OBTAINED FROM THREE SISTERS MOUNTAIN VILLAGE, DATED SEPTEMBER 9, 2020.
4. EXISTING BUILDINGS AND ROADS IN DEAD MAN'S FLATS OBTAINED FROM THE MUNICIPAL DISTRICT OF BIGHORN.
5. EXISTING BUILDINGS IN CANMORE OBTAINED FROM TOWN OF CANMORES OPEN DATA PORTAL ON OCTOBER 26, 2020.
6. CREEK ALIGNMENT IS APPROXIMATE FOR SMITH CREEK.
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CHECKED:	EM
APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
THREE SISTERS mountain village

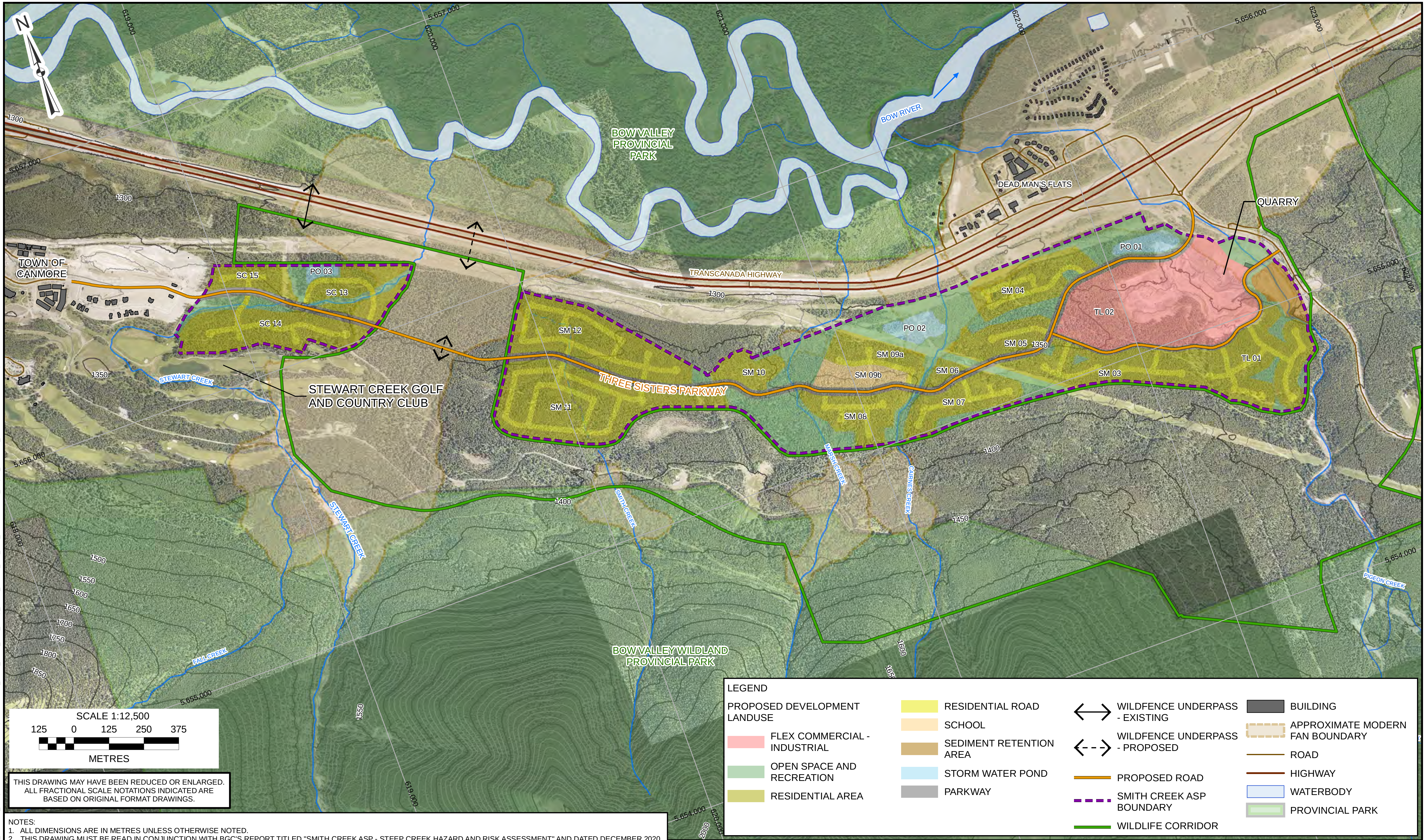
PROJECT: SMITH CREEK ASP - STEEP CREEK HAZARD AND RISK ASSESSMENT

TITLE: PROJECT OVERVIEW

PROJECT No.: 1531006

DWG No.: 01

X:\Projects\1531_Three_Sisters_Mountain_Village\006\GIS\Production\Report\20201021_Smith_Creek_ASP_Steep_Creek_Hazard_and_Risk_Assessment\01_Project_Overview.mxd Date: Thursday, December 10, 2020 Time: 4:33 PM



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APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: THREE SISTERS mountain village

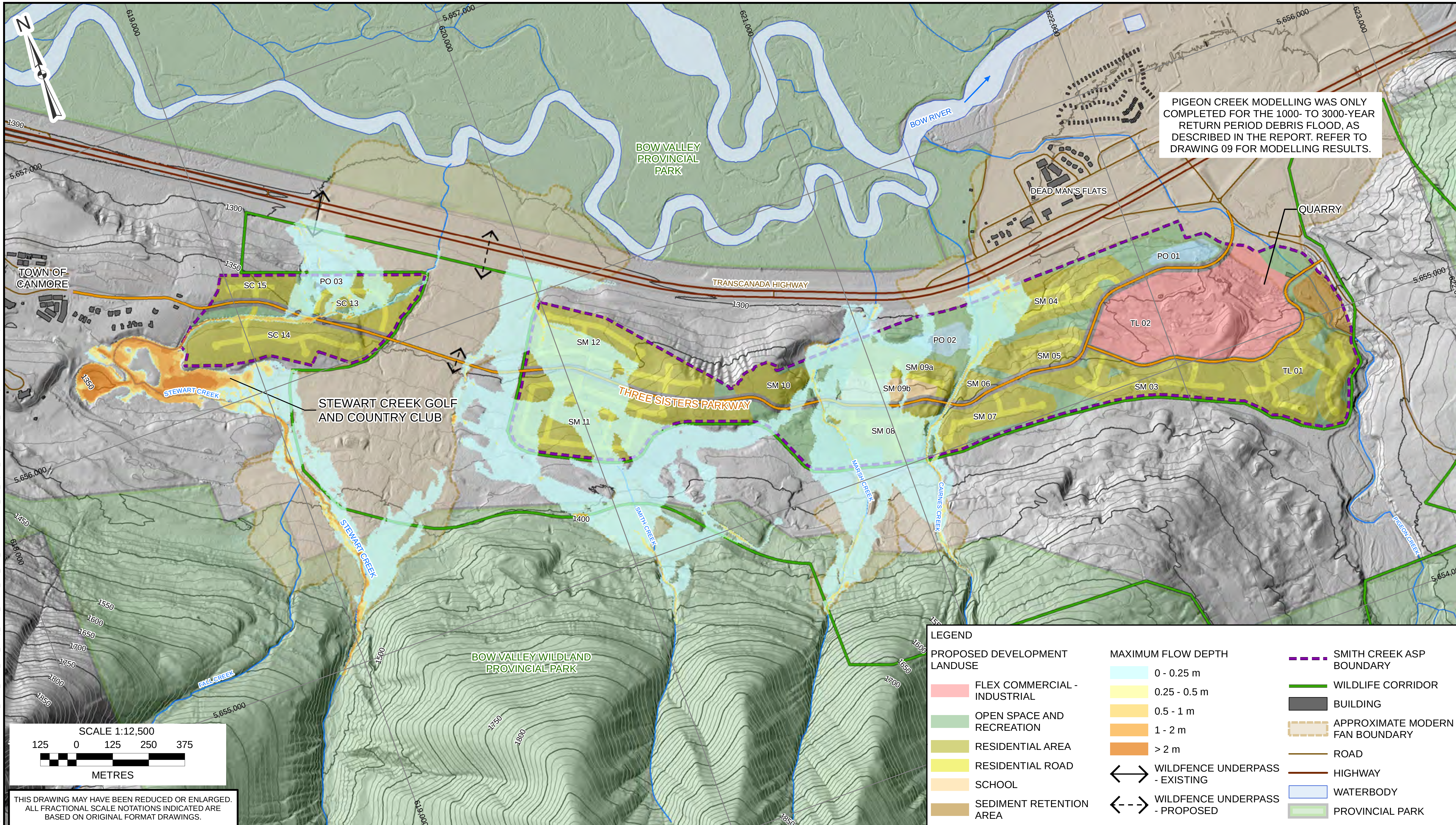
PROJECT: SMITH CREEK ASP - STEEP CREEK HAZARD AND RISK ASSESSMENT

TITLE: PROJECT OVERVIEW ORTHOPHOTO

PROJECT No.: 1531006

DWG No.: 02

X:\Projects\1531_Three_Sisters_Mountain_Village\006\GIS\Production\Report\20201021_Smith_Creek_ASP_Steep_Creek_Hazard_and_Risk_Assessment\02_Project_Overview_Ortho.mxd Date: Thursday, December 10, 2020 Time: 4:36 PM



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BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: THREE SISTERS mountain village

PROJECT: SMITH CREEK ASP - STEEP CREEK HAZARD AND RISK ASSESSMENT

TITLE: BASE CASE 30 TO 100-YEAR RETURN PERIOD FLOW DEPTHS FROM NUMERICAL MODELLING

PROJECT No.:	DWG No.:
1531006	03

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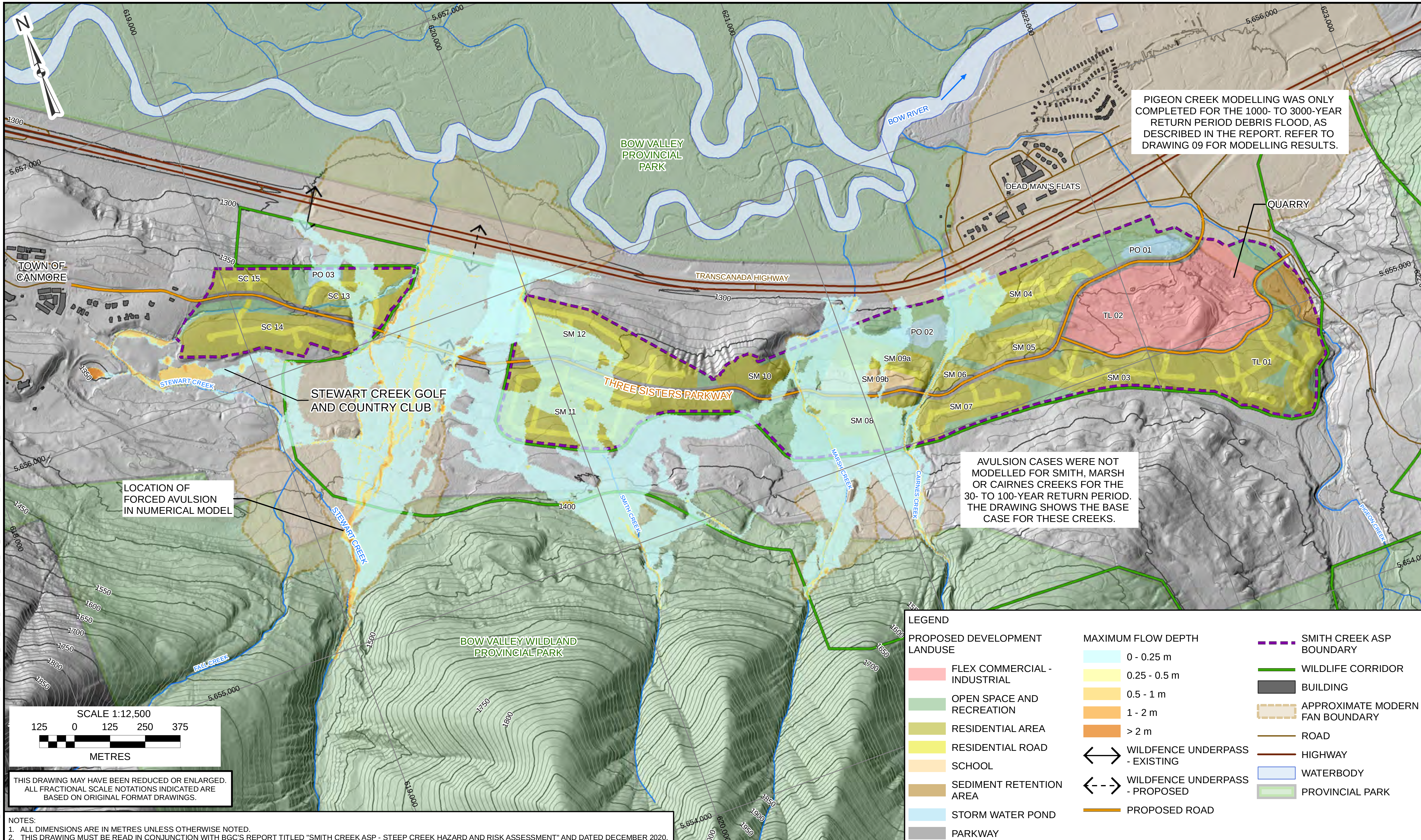

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BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: THREE SISTERS mountain village

PROJECT: SMITH CREEK ASP - STEEP CREEK HAZARD AND RISK ASSESSMENT

TITLE: AVULSION CASE 30 TO 100-YEAR RETURN PERIOD FLOW DEPTHS FROM NUMERICAL MODELLING

PROJECT No.: 1531006
DWG No.: 04

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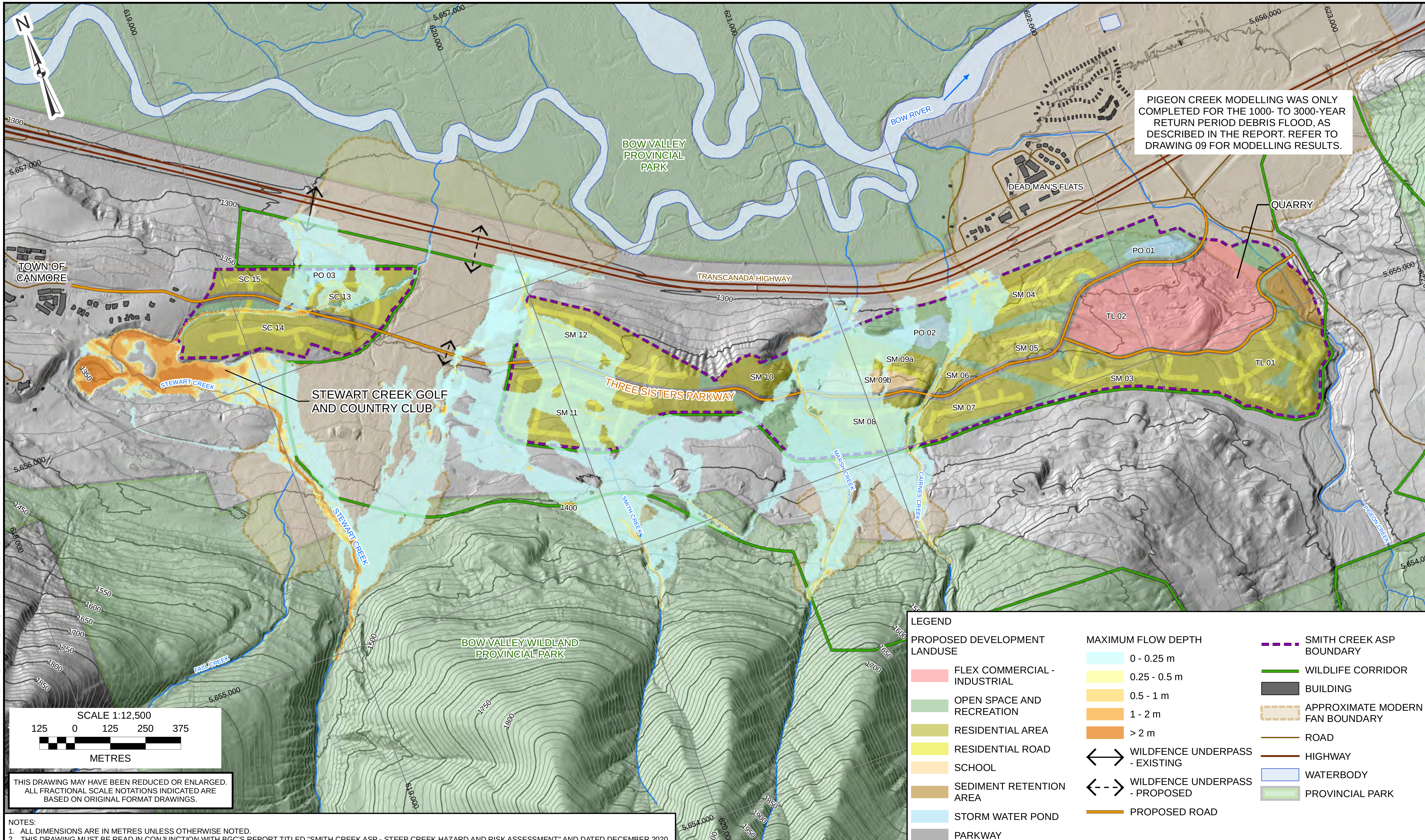

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BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: THREE SISTERS mountain village

PROJECT: SMITH CREEK ASP - STEEP CREEK HAZARD AND RISK ASSESSMENT

TITLE: BASE CASE 100 TO 300-YEAR RETURN PERIOD FLOW DEPTHS FROM NUMERICAL MODELLING

PROJECT No.: 1531006

DWG No.: 05

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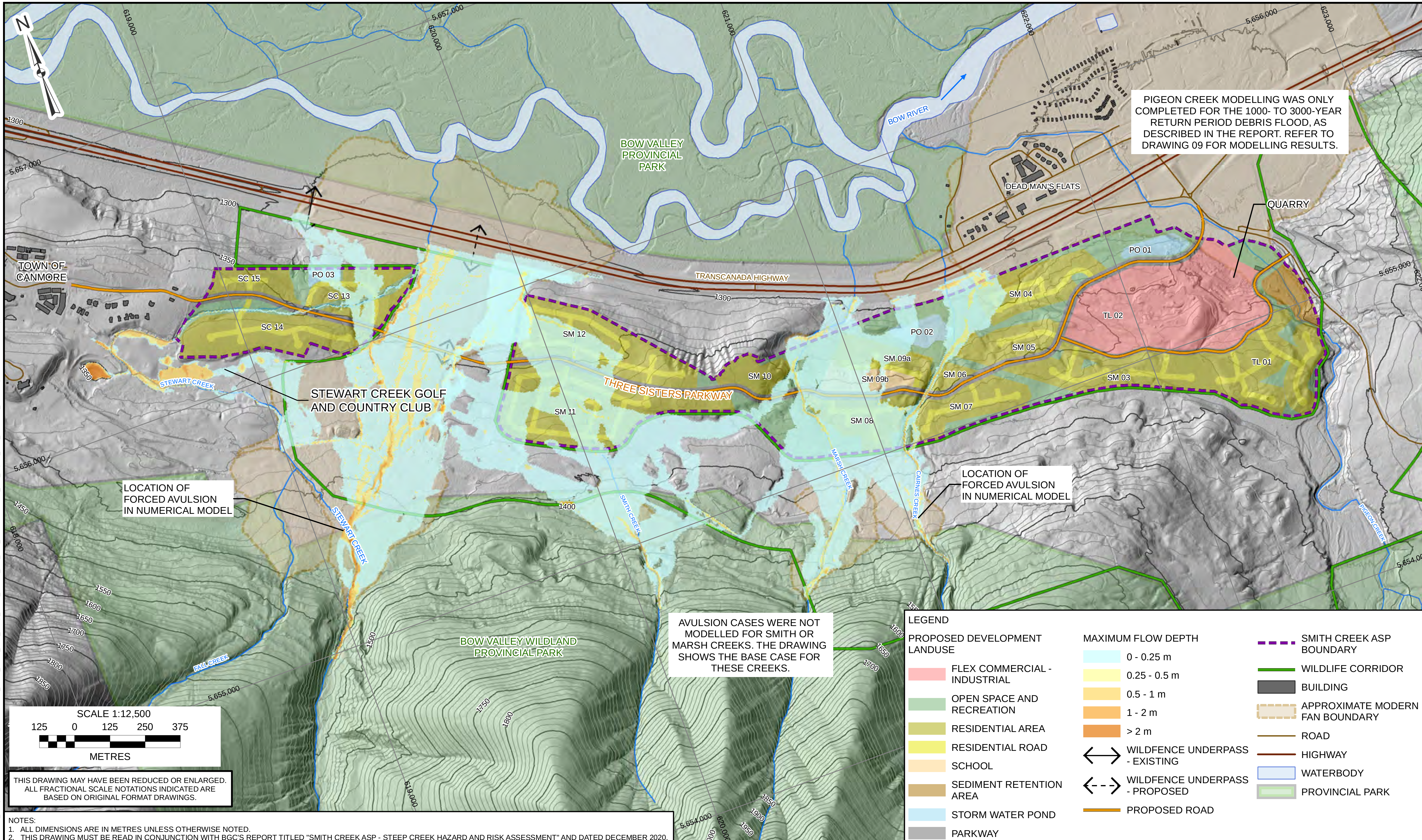

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APPROVED:	MJ

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: THREE SISTERS mountain village

PROJECT: SMITH CREEK ASP - STEEP CREEK HAZARD AND RISK ASSESSMENT

TITLE: AVULSION CASE 100 TO 300-YEAR RETURN PERIOD FLOW DEPTHS FROM NUMERICAL MODELLING

PROJECT No.: 1531006

DWG No.: 06

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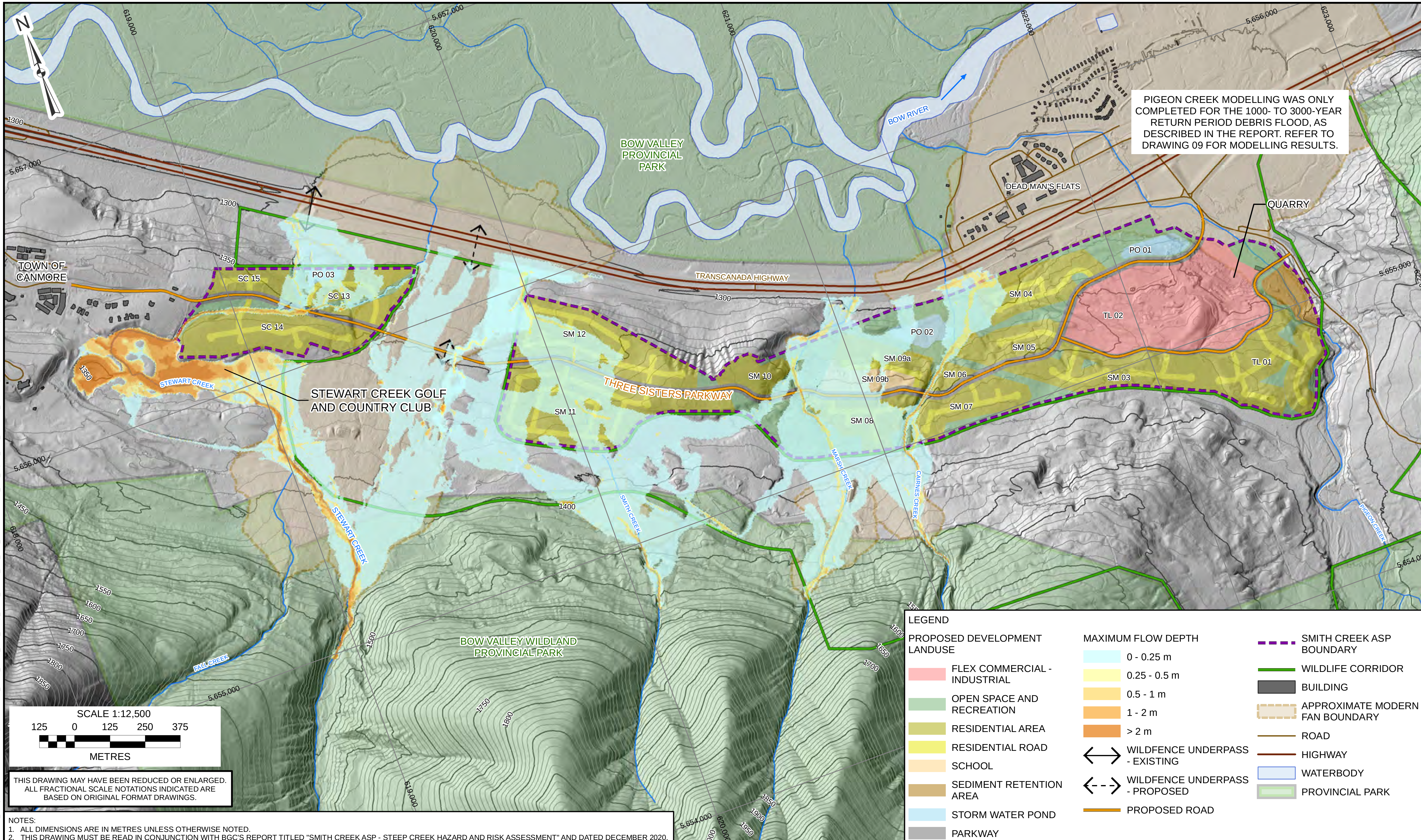

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AN APPLIED EARTH SCIENCES COMPANY

CLIENT: THREE SISTERS mountain village

PROJECT: SMITH CREEK ASP - STEEP CREEK HAZARD AND RISK ASSESSMENT

TITLE: BASE CASE 300 TO 1000-YEAR RETURN PERIOD FLOW DEPTHS FROM NUMERICAL MODELLING

PROJECT No.: 1531006

DWG No.: 07

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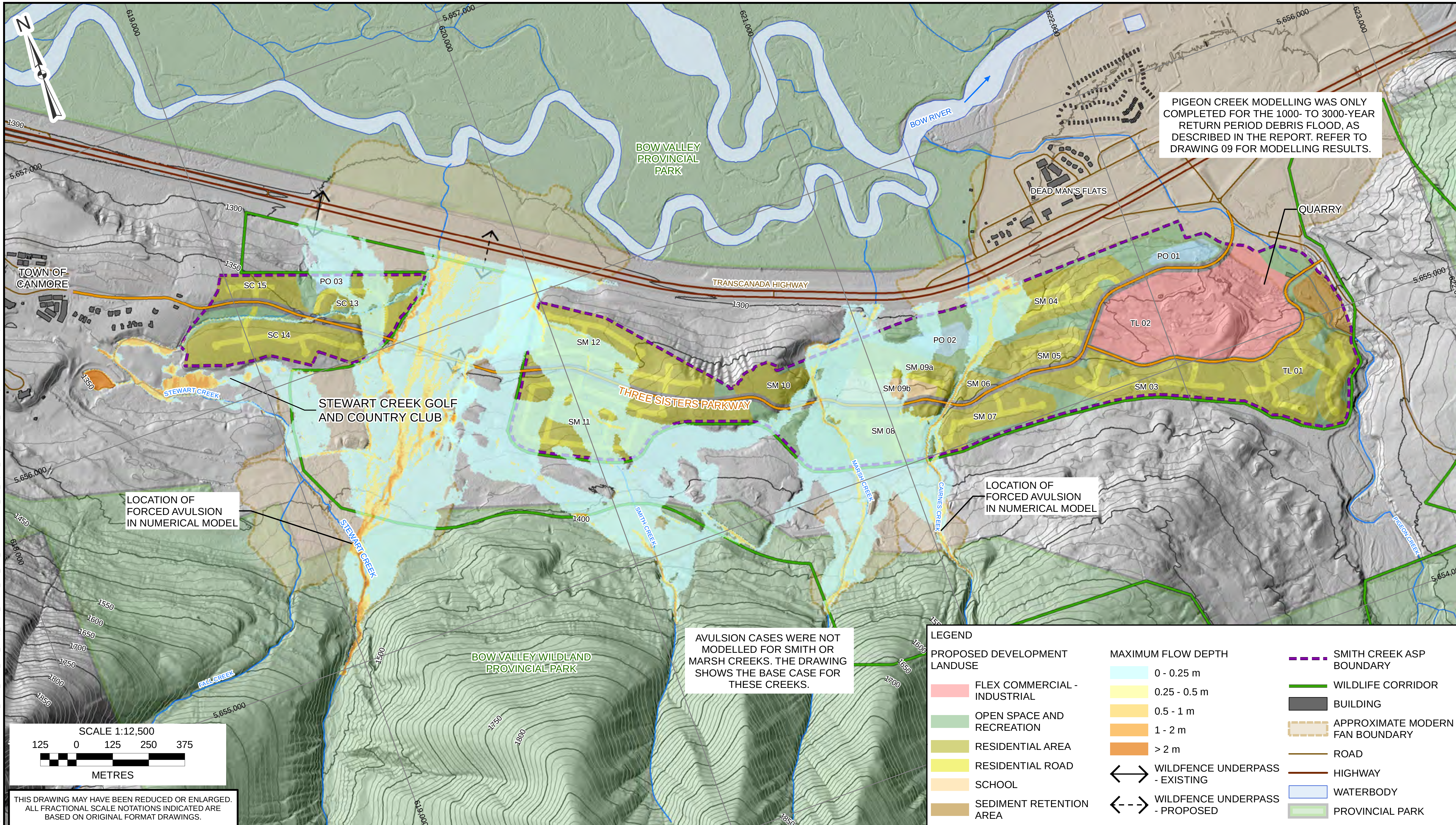

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LEGEND

PROPOSED DEVELOPMENT LANDUSE
- FLEX COMMERCIAL - INDUSTRIAL
- OPEN SPACE AND RECREATION
- RESIDENTIAL AREA
- RESIDENTIAL ROAD
- SCHOOL
- SEDIMENT RETENTION AREA
- STORM WATER POND
- PARKWAY

MAXIMUM FLOW DEPTH
- 0 - 0.25 m
- 0.25 - 0.5 m
- 0.5 - 1 m
- 1 - 2 m
- > 2 m
- WILDFENCE UNDERPASS - EXISTING
- WILDFENCE UNDERPASS - PROPOSED
- PROPOSED ROAD

- SMITH CREEK ASP BOUNDARY
- WILDLIFE CORRIDOR
- BUILDING
- APPROXIMATE MODERN FAN BOUNDARY
- ROAD
- HIGHWAY
- WATERBODY
- PROVINCIAL PARK

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BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: THREE SISTERS mountain village

PROJECT: SMITH CREEK ASP - STEEP CREEK HAZARD AND RISK ASSESSMENT

TITLE: AVULSION CASE 300 TO 1000-YEAR RETURN PERIOD FLOW DEPTHS FROM NUMERICAL MODELLING

PROJECT No.:	DWG No.:
1531006	08

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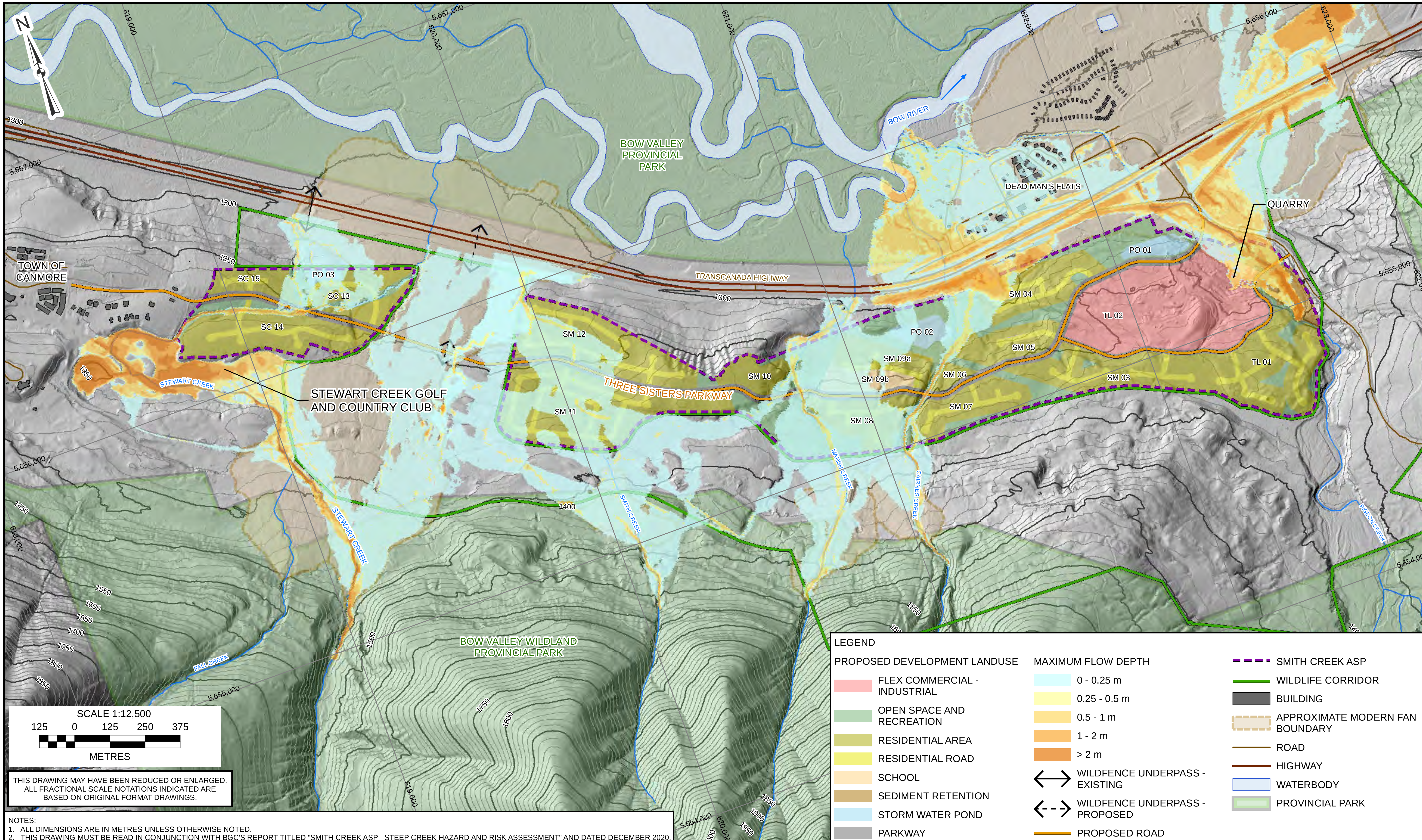

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BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: THREE SISTERS mountain village

PROJECT: SMITH CREEK ASP - STEEP CREEK HAZARD AND RISK ASSESSMENT

TITLE: BASE CASE 1000 TO 3000-YEAR RETURN PERIOD FLOW DEPTHS FROM NUMERICAL MODELLING

PROJECT No.: 1531006

DWG No.: 09

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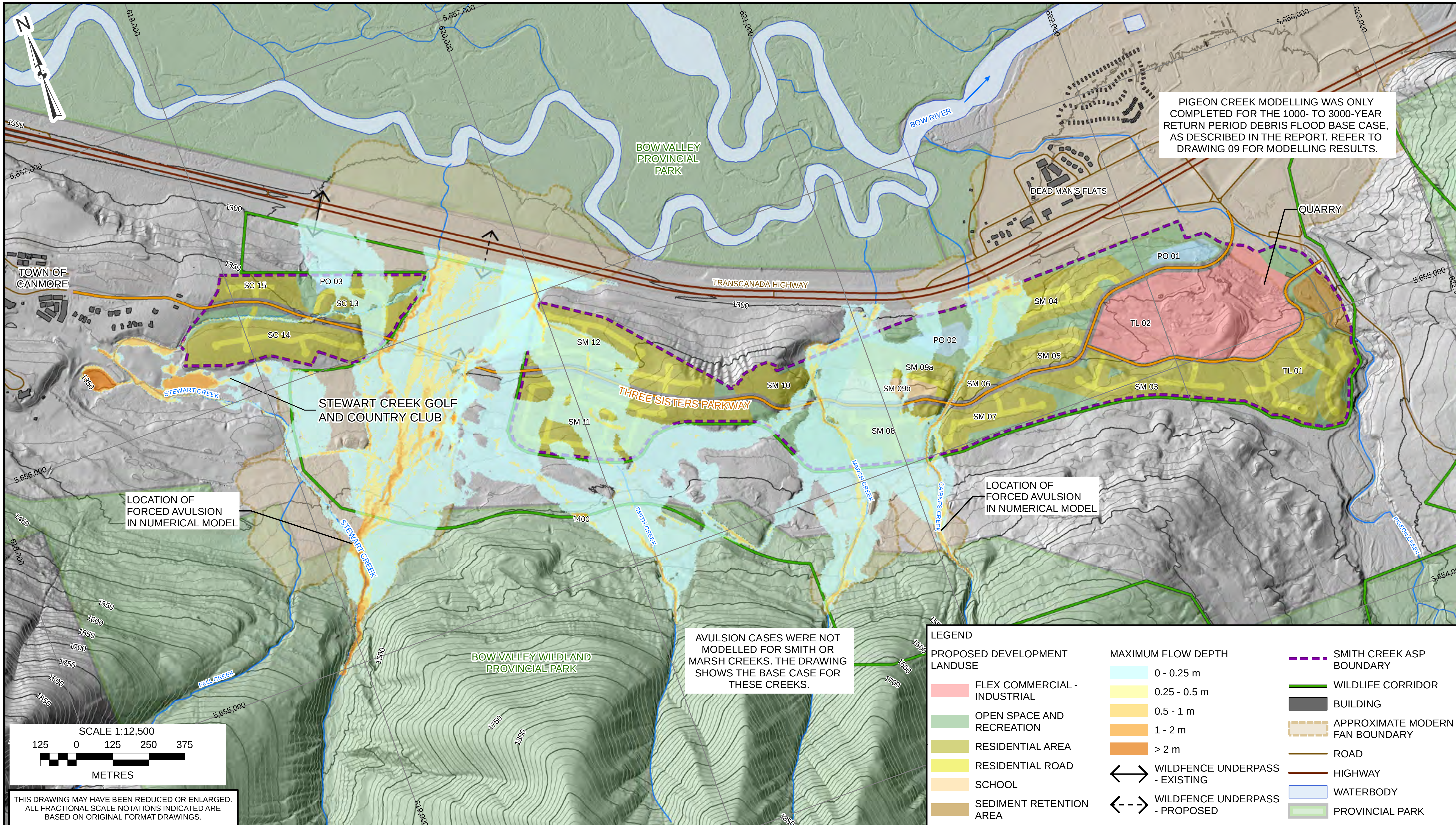

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BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: THREE SISTERS mountain village

PROJECT: SMITH CREEK ASP - STEEP CREEK HAZARD AND RISK ASSESSMENT

TITLE: AVULSION CASE 1000 TO 3000-YEAR RETURN PERIOD FLOW DEPTHS FROM NUMERICAL MODELLING

PROJECT No.: 1531006

DWG No.: 10

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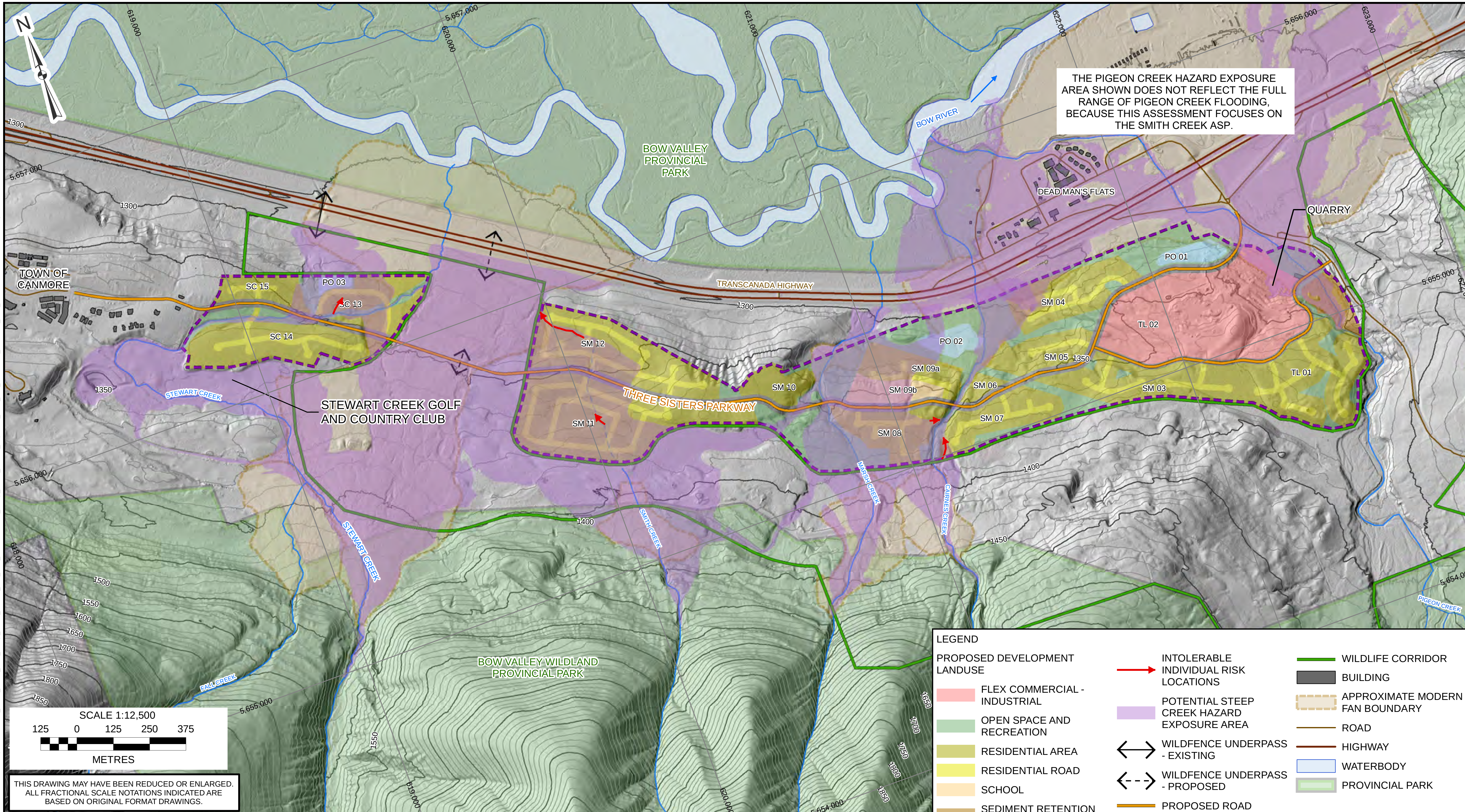

THIS DRAWING MAY HAVE BEEN REDUCED OR ENLARGED. ALL FRACTIONAL SCALE NOTATIONS INDICATED ARE BASED ON ORIGINAL FORMAT DRAWINGS.

NOTES:

1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "SMITH CREEK ASP - STEEP CREEK HAZARD AND RISK ASSESSMENT" AND DATED DECEMBER 2020.
3. INTOLERABLE INDIVIDUAL RISK TOLERANCE LOCATIONS INCLUDE AREAS WHERE ESTIMATED INDIVIDUAL RISK EXCEEDS THE TOWN OF CANMORE'S RISK TOLERANCE STANDARD FOR NEW DEVELOPMENT (1:100,000).
4. THE POTENTIAL STEEP CREEK HAZARD EXPOSURE AREA IS DEFINED AS THE BOUNDARY THAT SURROUNDS THE COMBINED STEEP CREEK HAZARD SCENARIO NUMERICAL RUN-OUT MODELLING RESULTS. THIS AREA SHOULD NOT BE CONSTRUCTED AS A HAZARD MAP OR USED FOR LAND USE PLANNING DECISIONS. THE PIGEON CREEK HAZARD EXPOSURE AREA IS LIMITED BECAUSE ONLY ONE SCENARIO WAS MODELLED.
5. SMITH CREEK ASP LAYOUT OBTAINED FROM THREE SISTERS MOUNTAIN VILLAGE, DATED SEPTEMBER 9, 2020.
6. EXISTING BUILDINGS AND ROADS IN DEAD MAN'S FLATS OBTAINED FROM THE MUNICIPAL DISTRICT OF BIGHORN.
7. EXISTING BUILDINGS IN CANMORE OBTAINED FROM TOWN OF CANMORE'S OPEN DATA PORTAL ON OCTOBER 26, 2020.
8. CREEK ALIGNMENT IS APPROXIMATE FOR SMITH CREEK.
9. THE FAN BOUNDARIES ARE APPROXIMATE AND ARE INTENDED TO DELINEATE THE LANDFORM. THE BOUNDARIES SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DO THEY SHOW THE SPATIAL EXTENT OF POTENTIAL FLOODING.
10. PROJECTION IS NAD 83 UTM ZONE 11N. VERTICAL DATUM UNKNOWN.
11. BASE TOPOGRAPHIC DATA BASED ON LIDAR, RECEIVED FROM MCELHANNEY, 2013. CONTOUR INTERVAL IS 10 m.
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BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: THREE SISTERS mountain village

PROJECT: SMITH CREEK ASP - STEEP CREEK HAZARD AND RISK ASSESSMENT

TITLE: STEEP CREEK HAZARD EXPOSURE AREA AND INTOLERABLE INDIVIDUAL RISK LOCATIONS

PROJECT No.: 1531006

DWG No.: 11

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APPENDIX A
STEWART CREEK HYDROLOGY AND CLIMATE CHANGE ASSESSMENT

APPENDIX A– STEWART CREEK HYDROLOGY AND CLIMATE CHANGE ASSESSMENT

A.1 INTRODUCTION

Hydrology and climate change are a fundamental input into the assessment of credible debris flood hazard scenarios, as these are largely driven by upstream influences. BGC conducted rainfall-runoff modeling using HEC-HMS (Version 4.4.1), a software package developed by the US Army Corps of Engineers (USACE) to determine the peak discharge for a range of return periods. BGC also conducted a climate change assessment to evaluate the changes in precipitation and peak flow during the period from 2050 to 2100. Both analyses are described in the sections below.

The hydrology of Stewart Creek is similar to Three Sisters Creek, due to their similar watershed areas (9.1 km^2 for Stewart and 9.5 km^2 for Three Sisters). Therefore, the assessment methods used for Stewart Creek are the same as the methods used for the Three Sisters Creek Hazard Assessment Update (BGC, October 9, 2020).

A.2 RAINFALL-RUNOFF MODELING

The purpose of conducting the rainfall-runoff modelling was to develop a flood frequency analysis (FFA) from nearby historical precipitation data, in lieu of a gauge to directly measure discharge, to predict peak discharge for return periods ranging from 10 to 3000 years. The U.S. Soil Conservation Service (SCS) unit hydrograph method (USDA, 1986) was used, which requires the following inputs:

- A storm hyetograph (rainfall distribution over time) or a 24-hour precipitation depth together with specified Soil Conservation (SCS) standard rainfall distribution (USDA, 1986).
- The time of concentration (conceptually the time needed for water to flow from the most remote point in a watershed to the watershed outlet), which was estimated using the SCS lag-time method.
- Initial abstraction (I_a) refers to all initial losses such as surface depression storage, vegetation interception, and infiltration).
- The SCS runoff curve number (CN)[1], which takes a value between 0 and 100 and determines the proportion of the rainfall that infiltrates into the soil and is stored as soil moisture (i.e., does not contribute to the storm hydrograph and thus the effective runoff). The CN value is a function of soil type, ground cover and antecedent moisture condition (AMC) which describes the soil moisture condition at the beginning of a storm.

[1] SCS-CN is the Soil Conservation Service curve number which is dimensionless and lumps the effects of land use and hydrologic conditions on surface runoff. It relates direct surface runoff to rainfall.

A.2.1 Model Calibration

BGC has developed a number of rainfall-runoff models for a number of creeks in the Bow Valley following the damaging storm event of June 2013 (e.g., BGC, 2020). Calibration for these models was provided by high water marks observed along the creeks, as well as rainfall data collected from nearby climate stations. These calibrated models show that CN values of 60 for vegetated areas and 79 for unvegetated rocky areas are appropriate, as well as using the SCS method for calculating the lag time.

For Stewart Creek, the lag time is estimated at 28 minutes, while a composite CN value of 69 was used for the watershed (i.e., a lumped model). The SCS unit hydrograph method is highly dependent on the CN value; a higher CN value will cause a higher peak flow as less precipitation goes into soil storage.

Using the above parameter set and the SCS unit hydrograph method, a peak flow of 27 m^3/s is estimated for the June 2013 rainfall event (Figure A-1). BGC (July 4, 2017) has previously hiked the mainstem channel of Stewart Creek for most of its length; however, no suitable high water marks from the 2013 flood were recorded during that traverse to validate the modelled peak flow.

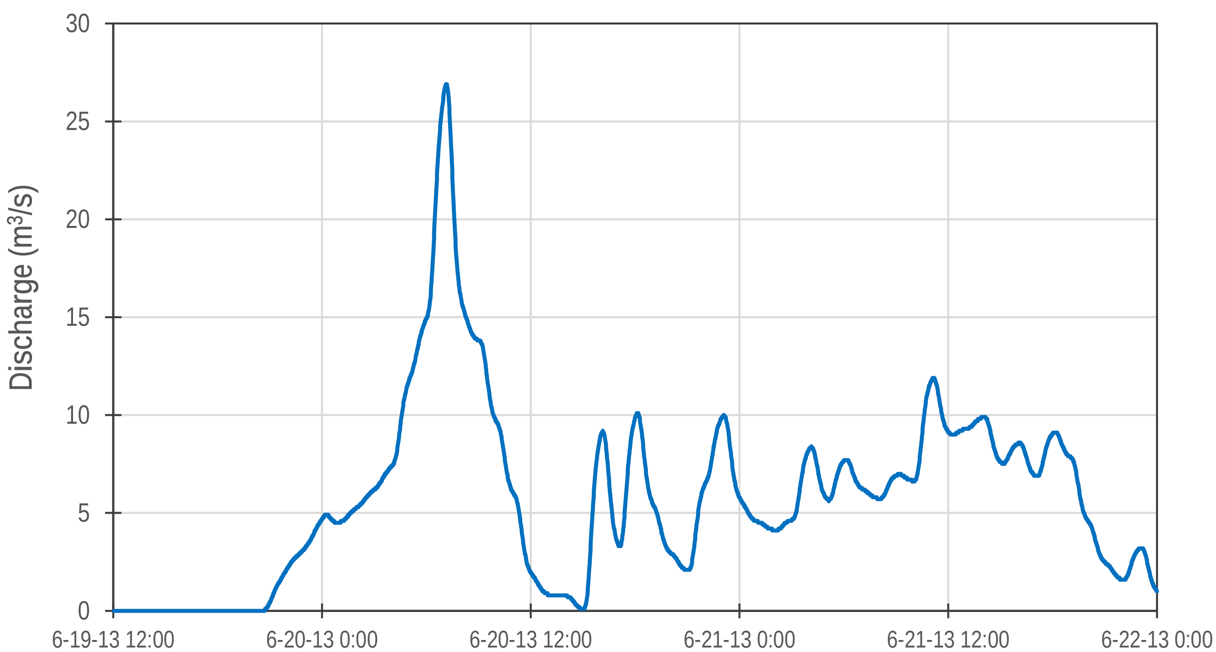

Figure A-1. HEC-HMS hydrograph for June 2013 flood on Stewart Creek.

The Stewart Creek hydrograph is similar to the Three Sisters Creek hydrograph because: 1) the same precipitation was used to simulate the June 2013 storm (the available rainfall data are not sufficient to parse between the watersheds); and 2) the watershed sizes are similar (and hence time of concentration). A slightly CN value was used for Stewart Creek (CN = 69) compared to Three Sisters Creek (CN = 63), due to a higher percentage of unvegetated areas.

A.2.2 Rainfall Data

BGC (July 4, 2017) had previously used Environment and Climate Change Canada (ECCC) published intensity-duration-frequency (IDF) rainfall data from the Kananaskis climate station (ID 3053600) for rainfall-runoff modelling of Stewart Creek (Table A-1). Rainfall depths for the longer return periods of 300, 1000, and 3000 years, the data were extrapolated in BGC (July 4, 2017) based on a semi-log relation.

Table A-1. ECCC IDF rainfall data for the Kananaskis climate station (ID 3053600, 1982-1998).

Return Period (years)	Rainfall Depth (mm)				
	30-min	1-hr	2-hr	6-hr	24-hr
2	7	10	14	25	42
10	14	21	28	52	75
25	17	26	35	66	91
30	18	27	36	68	94
50	20	30	40	76	103
100	22	34	45	86	115
300	27	41	54	104	136
1000	31	49	64	122	158
3000	36	55	72	139	178

Note: Values shaded in light red were interpolated/extrapolated from published values.

The Kananaskis IDF 24-hour rainfall totals were used as input to the 2014 HEC-HMS modelling. However, the ECCC frequency analysis was completed with a Gumbel distribution for which higher return periods cannot necessarily be extrapolated based on a semi-log distribution. Furthermore, the quantiles summarized in Table A-1 are based on a limited dataset (12 years), resulting in significant uncertainty for higher return period estimates. Therefore, for the analysis herein, BGC extended the 24-hour rainfall dataset by analyzing daily rainfall data for the 1940-2019 period from the Kananaskis station. Maximum annual daily rainfall totals were abstracted from the record and converted to 24-hour values by a factor of 1.1 (Figure A-2), which is the average ratio between 24-hour and daily maximum values for the overlapping period (1982-1998) of record at the Kananaskis station. Updated 24-hour totals are provided in Table A-2 and Figure A-3 based on four probability distributions: Pearson Type III (PIII), log Pearson Type III (LPIII), Generalized Extreme Value (GEV, linear moments (lm)), and GEV (maximum likelihood estimate (mle)). Significant differences between the distributions are noted at higher return periods.

Table A-2. Historical 24-hour rainfall quantile estimates for the Kananaskis climate station (ID 3053600) based on data from the period 1940-2019.

Return Period (years)	24-hour Rainfall (mm)				
	1940-2019 Dataset				IDF (1982-1998) Dataset
	GEV_lm	LPIII	GEV_mle	PIII	
2	42	43	43	42	42
10	75	75	75	78	75
30	103	100	100	103	103
50	118	113	114	115	118
100	142	132	135	130	142
300	189	167	174	155	189
500	215	186	196	167	215
1000	256	213	228	183	256
3000	336	263	289	208	336

Note: *Interpolated/extrapolated value.

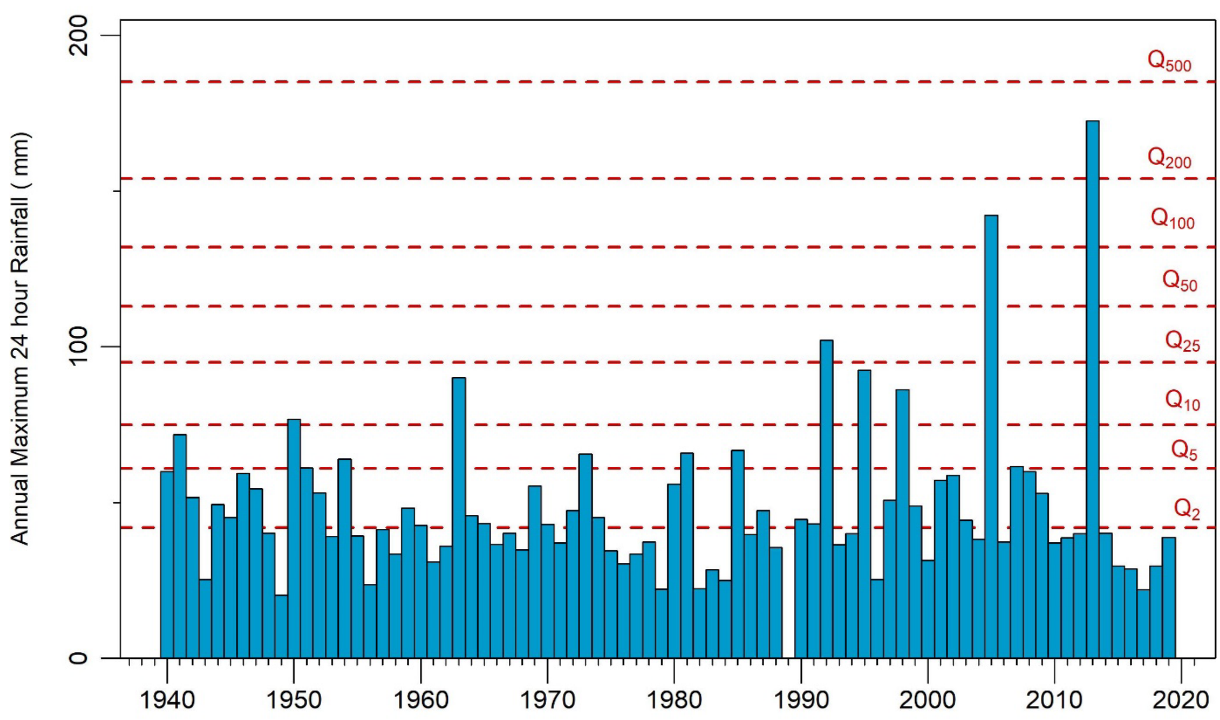

Figure A-2. 24-hour maximum annual rainfall at the Kananaskis climate station (1940-2019).

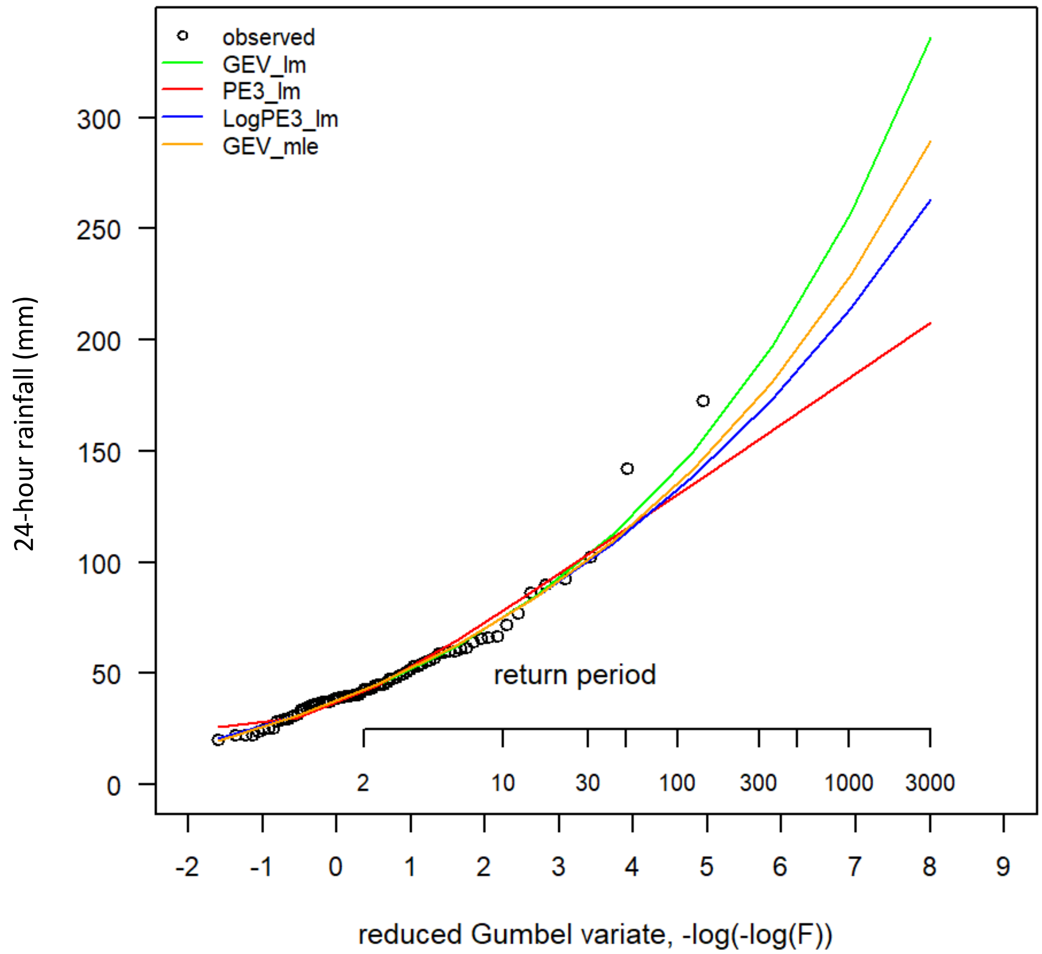

Figure A-3. R-generated 24-hour rainfall frequency analysis of the Kananaskis climate station from using data from 1940 to 2019 with multiple probability distributions.

Although the gauge has a long period of record (79 years), the uncertainty associated with the discharge estimates increases considerably for return periods exceeding the record length (i.e., >100-year return period estimates). To assess which 3000-year return period rainfall estimates were reasonable, they were compared with 24-hour probable maximum precipitation (PMP) values recently estimated for the adjacent Elbow River basin (Kappel et al., 2018). That analysis estimated general storm 24-hour PMP values of 294 to 376 mm and local storm 6-hour PMP values of 160 to 307 mm. Northwest Hydraulic Consultants (NHC, June 27, 2017) also estimated a 24-hour PMP value of 400 mm for the nearby Cougar Creek watershed. Koutsoyianiss (1999) has argued that the PMP has an associated return period of 60,000 years[2]. Extrapolating the frequency analysis to a return period of 60,000 years, the GEV distributions yield 24-hour rainfall totals in excess of 500 mm, 420 mm is obtained with the LPIII, and 275 mm for PIII. These values suggest that the GEV distribution values are too high for the Kananaskis station, while the PIII

[2] It should be noted that others note even higher return periods for a PMP event.

distribution appears to underestimate higher return periods as indicated by its poor fit to the two highest storms recorded. Therefore, the LPIII distribution was chosen moving forward.

A.2.3 Hyetograph

Having chosen the magnitude of the storms to evaluate, the rainfall distribution (i.e. hyetograph) has to be selected. The SCS type (I, 1A, II and III) distributions are commonly used in North America. For the previous hazard assessment of Stewart Creek, BGC (July 4, 2017) used an SCS Type I distribution. To test this hypothesis, the distribution of the June 2013 storm was plotted with the SCS distributions (Figure A-4). That analysis suggests that a Type IA SCS storm may be more applicable for the snowmelt season, a period when a majority of recorded hydrogeomorphic events in the Bow Valley have occurred (BGC, May 1, 2018). Type I storms likely occur in the Canmore area but are expected later into the summer, when antecedent conditions are drier, and a lower CN value would apply.

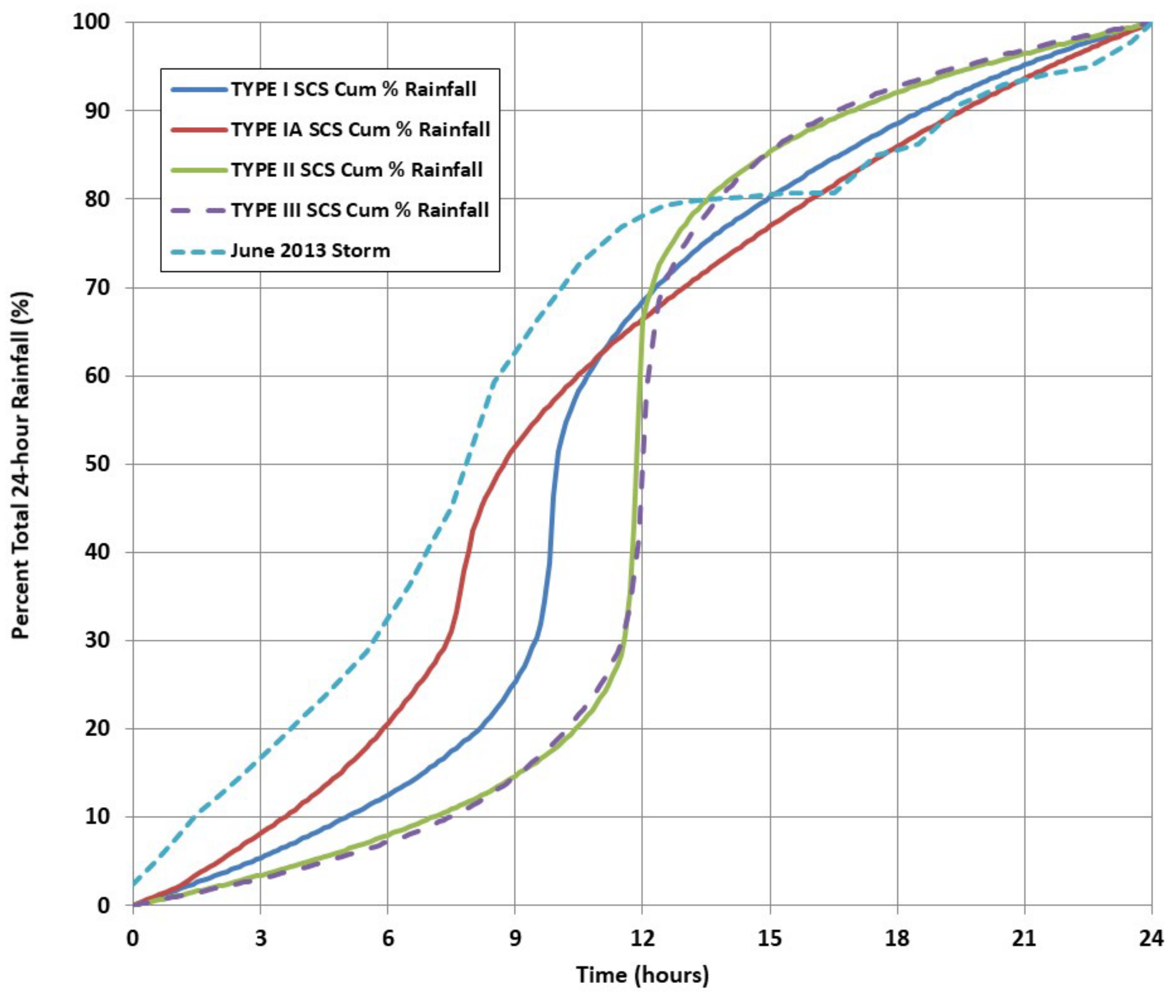

Figure A-4. SCS and June 2013 rainfall distributions.

A.2.4 Climate Change

Draft guidelines have been prepared for steep creek risk assessments in Alberta (BGC, September 4, 2015). Those guidelines stipulate that the qualified registered professional (QRP) consider projected climate change in steep creek assessments. Therefore, BGC also assessed the potential impacts of climate change on Stewart Creek peak flows.

The rainfall-runoff modeling was repeated for future conditions based on predicted changes to 24-hour rainfall amounts. While climate change is expected to alter temperatures and precipitation in the future, it is also expected to affect the magnitude and frequency of extreme precipitation events (Prein et al., 2017). The frequency of extremes predicted to increase approximately 2-fold in southwestern Alberta in June, July, and August (Figure A-5). The increase is due to a shift towards moister and warmer climatic conditions (Prein et al., 2017). Changes in short-term precipitation extremes contributes to the frequency and magnitude of debris floods and debris flows.

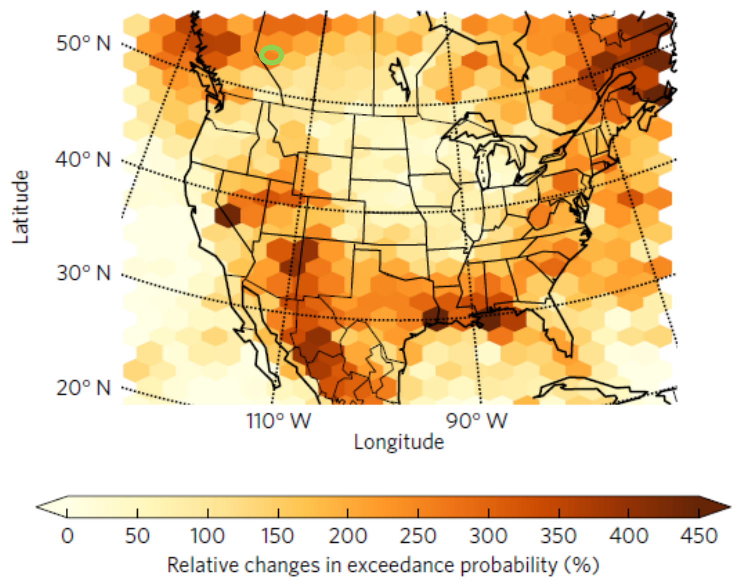

Figure A-5. Change in the exceedance probability of hourly precipitation intensities for June, July, and August (Prein et al., 2017). The study area location is circled in green.

BGC used the University of Western Ontario's IDF climate change tool (IDF_CC Tool 3.0) to evaluate the potential impacts of climate change on rainfall for a range of return periods. The tool was designed to analyze the effects of various Representative Carbon Pathway (RCP) scenarios on rainfall events based on GCM outputs.

The IDF_CC Tool allows for historical and climate change adjusted IDF data to be generated for gauged and ungauged sites at any location in Canada. The gauged Kananaskis climate station was selected within the tool and IDF data were generated using the model ensemble listed in Table A-3. As the IDF_CC Tool requires a minimum projection period of 50 years for climate change assessments, the period from 2021 to 2100 was selected along with Representative Concentration Pathway (RCP) 8.5 (i.e., emissions continue to rise in the 21st century, also known as the business-as-usual scenario). The results show an upward adjustment of 21% for the

100 year 24-hour rainfall depth compared to historical data. These results are also consistent with the projections of Zhang et al. (2019), who assessed potential climate change impacts on temperature and precipitation across Canada.

Table A-3. GCM ensembles used by BGC for the IDF_CC Tool.

University of Western Ontario IDF_CC Tool
CNRM-CM5
CanESM2
CSIRO-Mk3-6-0
CCSM4
MIROC5
MPI-ESM-LR
MRI-CGCM3
GFDL-ESM2G
HadGEM2-ES

BGC also evaluated an ensemble of 9 different bias-corrected GCMs from the Pacific Climate Impacts Consortium[3] (PCIC) for the time period from 2050 to 2100. Two RCP scenarios were considered: the RCP 4.5 scenario and the RCP 8.5 scenario. RCP 4.5 is a reasonably optimistic scenario that represents reaching a radiative forcing[4] of 4.5 W/m^2 between now and 2100, accompanied by an increase in annual global temperature of 2°C over pre-industrial levels. Both RCP scenarios project 24-hour rainfall increasing by approximately 30%.

For this study, an increase in the 24-hour rainfall depths of 30% was adopted.

[3] The Pacific Climate Impacts Consortium (PCIC) is a climate service center out of the University of Victoria. PCIC focuses on climate studies and the impacts of a changing climate for the BC and Yukon regions.

[4] Radiative forcing is the net radiative flux on the Earth's atmosphere. It is expressed as power per area (Watts per square meter). Net radiative flux is the amount of energy absorbed by the Earth compared to the amount of energy redirected to space.

A.2.5 Rainfall Summary

Table A-4 summarizes the 24-hour rainfall estimates adopted for the HEC-HMS modelling.

Table A-4. Summary of 24-hour rainfall estimates for the Kananaskis (3053600) climate station using data from 1940 to 2019 and LPIII distribution.

24-hour Rainfall (mm)	Return Period (Years)						
	10	30	100	300	1000	3000	PMP
Existing Conditions	75	100	132	167	213	263	300-400
Climate Change (2050-2100)	100	130	170	215	275	340	

A.3 HEC-HMS MODELLING

The 24-hour rainfall values were input to the HEC-HMS model to determine the peak discharge for a given return period both for existing conditions and under climate change. The resulting peak discharge values are summarized in Table A-5.

Table A-5. Estimated peak discharge for Stewart Creek based on historical rainfall at the Kananaskis climate station and under possible climate change conditions.

	Units	Return Period (Years)					
		10	30	100	300	1000	3000
BGC (July 4, 2017)	m^3/s		29	41	57	68	82
BGC, (2020)	m^3/s	5	12	24	38	57	80
2050-2100 RCP 8.5	m^3/s	11	22	40	61	87	117

The lower peak flow values estimated in the analysis here-in compared to the 2017 assessment are primarily a result of the change in the rainfall hyetograph.

As noted earlier, the 2013 storm had an estimated peak discharge of 27 m^3/s. Based on Table A-5, the associated return period would be 100 to 300 years. This return period is consistent with work on Cougar Creek where BGC (December 11, 2013) estimated that the return period of the 2013 flood could be between 200 and 350 years, while NHC (June 27, 2017) estimated a return period of approximately 200 years.

Of note is that the significant increase in peaks for the climate change scenario. This increase is a result of the increased rainfall contributing directly to runoff, rather than proportional soil storage.

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APPENDIX B
STEEP CREEK HAZARD SCENARIOS

Table B.1. Steep Creek Hazard Scenarios, and associated Hazard, Avulsion and Scenario Probability.

Creek(s)	Scenario No.	Detail	Hazard Probability	Avulsion Probability	Scenario Probability
Stewart Creek	1	10 to 30 return period event, no avulsion.	0.07	1.0	0.07
	2	30 to 100 return period event, no avulsion.	0.02	0.9	0.02
	3	30 to 100 return period event, avulsion case.	0.02	0.1	0.002
	4	100 to 300, return period event, no avulsion.	0.007	0.8	0.005
	5	100 to 300, return period event, avulsion case.	0.007	0.2	0.001
	6	300 to 1000, return period event, no avulsion.	0.002	0.7	0.002
	7	300 to 1000, return period event, avulsion case.	0.002	0.3	0.0007
	8	1000 to 3000, return period event, no avulsion.	0.0007	0.5	0.0003
	9	1000 to 3000, return period event, avulsion case.	0.0007	0.5	0.0003
Smith and Marsh Creeks	1	30 to 100 return period event, no avulsion.	0.02	1.0	0.02
	2	100 to 300, return period event, no avulsion.	0.007	1.0	0.007
	3	300 to 1000, return period event, no avulsion.	0.002	1.0	0.002
	4	1000 to 3000, return period event, no avulsion.	0.0007	1.0	0.0007
Cairnes Creek	1	30 to 100 return period event, no avulsion.	0.023	1.0	0.02
	2	100 to 300, return period event, no avulsion.	0.0067	0.9	0.006
	3	100 to 300, return period event, avulsion case.	0.0067	0.1	0.0007
	4	300 to 1000, return period event, no avulsion.	0.0023	0.7	0.002
	5	300 to 1000, return period event, avulsion case.	0.0023	0.3	0.0007
	6	1000 to 3000, return period event, no avulsion.	0.00067	0.6	0.0004
	7	1000 to 3000, return period event, avulsion case.	0.00067	0.4	0.0003