Clarke Geoscience Ltd.

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Regional District of East Kootenay (RDEK)

Fairmont Creek Debris Flow Hazard and Risk Assessment

FINAL REPORT

Prepared for:
Regional District of East Kootenay

File: 12-0106
January 11, 2013

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Golder Associates

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Executive Summary

A Debris Flow Hazard and Risk Assessment for Fairmont Creek was prepared on behalf of the Regional District of East Kootenay (RDEK) by Clarke Geoscience Ltd. (CGL), together with Golder Associates Ltd. and Vast Resource Solutions Inc. Funding for the project was provided by Emergency Management BC (EMBC). The project was administered by RDEK and the Ministry of Forests Lands and Natural Resource Operations (MFLNRO) provided technical assistance in the development of the Request for Proposal, selection of the successful proponent, and technical review of the assessment report.

The Fairmont Creek watershed is located on the eastern slopes of the Columbia River valley, approximately 100 km north of Cranbrook, B.C. Situated on the Fairmont Creek fan, are approximately 350 residents of the unincorporated community of Fairmont Hot Springs and the Fairmont Hot Springs Resort (FHSR). The area was impacted by a debris flow event on July 15, 2012.

The objectives of the debris flow hazard and risk assessment are to characterize the July 2012 debris flow event, determine the hazard and risk of future debris flow events, and to identify mitigation measures if required. In addition, a hydrogeological investigation was completed to determine whether the debris flow had impacted the local groundwater regime and whether this led to seepage issues experienced by several properties on the lower part of the fan.

The hazard and risk assessment was completed using historical air photos, anecdotal evidence, and field evidence. The field investigation included a detailed foot traverse of Fairmont Creek, from the mouth upstream through the middle reaches of the mainstem channel and the north tributary, and into the headwaters of the north tributary. Recreational trails in the upper watershed were also traversed. A helicopter overview flight was videotaped to document channel conditions and sediment sources throughout the watershed and adjacent areas. The fan area was traversed and local site topography and other features were noted and photographed. In addition, a subsurface investigation included six test pits that were excavated across the fan area.

Watershed Characteristics

The Fairmont Creek watershed has an area of 11 km^2 and Fairmont Creek flows 7 km from the peak of Fairmont Mountain (elev. 2600 m) to the Columbia River (elev. 820 m). Fairmont Creek has one large unnamed tributary (referred to as the north tributary), which has a catchment area of 3 km^2.

The headwater areas of the watershed are steep, bedrock-controlled channels. Proceeding downstream, Fairmont Creek transitions to a lower gradient channel and then flows through a limestone canyon referred to as Marble Canyon. The fan apex is located at the downstream end of this canyon. The Fairmont Creek fan has an average

gradient of about 10%, indicating that it has been formed in part by debris flow processes.

Bedrock in the lower part of the watershed is characterized by massive grey limestone to white dolomite, while an alternating sequence of dolomite, argillite (shale and limestone), and phyllite (metamorphosed shale of the Horsethief Group) underlies the upper watershed area. From a geotechnical perspective, it is the phyllitic rocks of the Horsethief Group that are relevant to debris flow process in the watershed, as these rocks range in competency from a resistant quartzite and shale to a finely degraded and highly erodible loose grit. The weathered product of this bedrock constitutes a relatively fine-textured sediment source, easily capable of being mobilized in the channel, and also capable of long run out distances due to its fine texture. Almost the entire length of the upper mainstem channel of Fairmont Creek is underlain by phyllite.

The Fairmont Creek watershed has a snow-melt dominated hydrology, which means that seasonally high flows generally occur in April and May due to melting of the high elevation seasonal snowpack. Peak flows, however, commonly occur in the summer months as a result of high intensity convective rain storms.

A regional flood frequency analysis was performed for Fairmont Creek in 1994 and determined that the 1:200 year maximum flood flow is 1.92 m^3/s and the peak instantaneous flow is 2.88 m^3/s. Unique to Fairmont Creek, the hydrologic character includes a downstream influence of the FHSR pools, that are flushed on a regular basis. Approximately 1.6 million gallons of water are released each time the pools are drained.

There are no commercial forestry operations in the Fairmont Creek watershed, nor are there any clear indications of historic logging operations. Some areas traversed during the field investigation appeared to have been affected by forest fire. However, extensive forest fire was not indicated in the air photos dating back to 1945.

Land clearing and recreational trails associated with the FHSR Ski Resort occupy the mid-elevation ridge between Fairmont Creek and Cold Spring Creek. A cross-country ski trail traverses the slope into the Fairmont Creek watershed and crosses the north tributary of Fairmont Creek at two locations.

Three golf courses are present within the Community of Fairmont Hot Springs on the Fairmont Creek fan, and consist of the Riverside Golf Course, located on the west side of Highway 93/95, and the Creekside and Mountainside Golf Courses, located on the east side of Highway 93/95. Only the Mountainside Golf Course was physically impacted by the July 2012 Debris Flow event.

The July 2012 Debris Flow Event

On July 15, 2012 at approximately 4:15 pm, a debris flow occurred on Fairmont Creek. The event originated in the headwaters of the mainstem channel, cumulatively developing into a debris flow as it flowed rapidly downstream to the fan and subsequently into the Columbia River.

The July 2012 debris flow had the following impacts:

- buried the Hot Springs source wells with 5 to 7 m of debris just upstream the Hot Springs Resort Road;
- washed out the 900 mm diameter culvert on the Hot Springs Resort RV Park access road, cutting off access to the RV park area;
- severely damaged a foot bridge connecting the RV Park and Resort area;
- filled up the Marble Canyon reach with several metres of rock and debris, washing out a creekside walking trail;
- FHSR lost the main source of water for the main lodge and fire suppression flows, which resulted in a 3 week closure of the resort and approximately $1.5 million in lost revenue;
- The irrigation water source and distribution lines to the Mountainside Golf Course was destroyed and seven (7) holes on the course were affected by the event. A large pond at Hole 12 filled up with debris and required dredging, and a small pond at Hole 3 was impacted. Smaller irrigation lines and landscaping were also impacted; and,
- Homes and vehicles situated on private land across the fan were inundated with mud, rock and debris. More than 350 people were evacuated from their houses and condos and temporarily relocated.

Despite occurring late afternoon on a busy summer day in July, when residents and visitors might have been on the golf course, or trails, and despite washing out road and trail crossings and directly impacting residential areas, no injuries or deaths were reported.

Antecedent climate conditions preceding the July 15 debris flow event were determined from a review of climate and hydrometric station data. Radar imagery for July 15 shows that a localized storm cell, with rainfall intensities up to 8 mm/hr was centered within the vicinity of the study area. Rainfall data from nearby climate stations recorded between 20 and 26.4 mm of rain on the days leading up to July 15.

Data from nearby snow pillow stations indicate that 2011-2012 winter snow pack depths were higher than average; between 106 and 170% of Normal levels. All stations also recorded a delayed (approx. 2 weeks) onset of spring snow melt followed by a period of rapid snow melt starting in mid-May. Photos taken by helicopter immediately after the event indicate only small patches of snow remaining in the headwater reaches.

Although numerous small landslides and sideslope failures were observed along the middle reaches of the Fairmont Creek and the north tributary, no single landslide appears to have initiated the July 2012 debris flow. Despite some news reports and anecdotal evidence suggesting temporary dam failure, there was no evidence of a temporary dam. The 2012 debris flow initiated in the headwaters of the mainstem channel. Along the channel, based on the downstream alignment of abundant woody debris in the channel, it is likely that any previous debris jams have been removed. Rather than any single trigger factor, the 2012 debris flow is judged to have initiated by progressive destabilization of abundant bedload in the mainstem channel by a locally-intense convective rainstorm at a time when soils were already saturated from an unusually wet spring.

Debris flow or flood events did not occur on any creeks adjacent to Fairmont Creek, including Cold Spring Creek; a watershed of similar size and topography. Other large-scale landslide and debris flow events did occur in the southern Interior of British Columbia in June-July 2012. This included a catastrophic landslide and debris flow at Johnsons Landing at the north end of Kootenay Lake (80 km to the south-west of Fairmont Creek) just two days prior to the Fairmont Creek slide. Damaging floods and debris flows also occurred on June 23-24, 2012 in the Shuswap area on Sicamous Creek and Hummingbird Creek (230 km northwest).

Based on the investigation it was determined that the July 2012 debris flow event had an estimated volume of 65,000m^3. The peak flow velocity of the event is estimated to be 4-6 m/s (14-22 km/h) and the peak flow discharge of the event, approximately 165 m^3/s (54x the instantaneous peak flow). Based on the subsurface investigation, the estimated return period of the July 2012 debris flow event is judged to be on the order of 500 years.

Hydrogeological Assessment

The hydrogeological investigation concluded that the most likely cause of the observed groundwater seepage on properties along Riverview Drive is elevated groundwater levels resulting from seasonally high surface water levels in the Columbia River and generally high local and regional groundwater levels. Another possible contributing factor may be fully or partially plugged perforated drainage pipes that do not adequately discharge water, resulting in local increases in the groundwater table. Recommendations include monitoring groundwater levels and an inspection/review of the drainage structures in the area.

Debris Flow Hazard Assessment

The field investigation determined that the following historic debris flow events have occurred on Fairmont Creek:

- Event of unknown age observed in test pits on fan;
- Event occurring sometime between 1952 and 1964, but only scouring the channel and affecting only top part of fan;
- July 1984 event, only affecting top part of fan;
- Small debris flow on north tributary est. 2006-2007, did not reach fan; and,
- The July 2012 event.

Based on these findings, the analysis concluded that the estimated return period for a hazardous debris flow on Fairmont Creek is approximately 25 years. Events occurring at this frequency are judged to affect the mainstem channel and deposition will quite likely terminate upon reaching the fan apex. It is judged that the July 2012 event had an estimated return period greater than 500 years (i.e. less than a 10% probability of occurrence in 50 years).

The debris flow initiation potential on Fairmont Creek, which is a function of the watershed characteristics, the availability of sediment and/or debris within the channel, and the potential for a triggering event was assessed. The assessment concluded that the same debris flow triggering factors are present now as they were prior to the July 2012 event. The middle to lower reaches of Fairmont Creek, below 1500 m elevation, have numerous small landslides, weathered phyllite bedrock exposures, stream banks incised within unconsolidated Quaternary deposits and previous debris flow deposits, and channel bedload deposits, representing an unlimited sediment supply. With such conditions, debris flows may potentially occur whenever a critical hydroclimatic threshold is reached.

In addition, with predicted climate change effects on precipitation, the increased frequency of storm events, and the potential for increased runoff due to wildfire, there is a corresponding increase in the potential for debris flow.

Due to the destabilized nature of the middle reaches of Fairmont Creek, there may be a short-term increase in the frequency of small events and in the magnitude of medium to large events. However, debris flows affecting large areas will occur less frequently and significant inundation of areas across the fan, as occurred in July 2012, is considered to be a much rarer event with a low likelihood, or probability of occurrence. We consider that the July 2012 event, with an estimated magnitude of 65,000 m^3, is the design event on Fairmont Creek.

Debris Flow Risk Assessment

The elements at risk from a debris flow event on Fairmont Creek are largely situated on the fan and include the following:

- Approximately 16 multi-family dwellings and 88 single-family dwellings;
- Approximately 350 people, based on the number of people evacuated from the area in July 2012;
- Mountainside Golf Course and associated infrastructure;
- Community Recreation Centre and associated facilities;
- Community Fire Hall;
- Highway 93/95; and
- The only access to the Fairmont Hot Springs Resort RV Park.

The results of the risk analysis provide an indication of predicted debris flow behaviour and predicted impacts across the fan. The debris flow risk assessment results are shown on the Risk Map (Figure 5). The risk zones delineated on the map define zones of equal debris flow composition, depth and velocity. The results indicate that a large part of the fan is susceptible to debris flow.

Each risk zone has an associated debris flow return period and is described as follows:

High Risk Areas - High risk areas are classified as a direct impact zone. This zone includes the main channel of Fairmont Creek, from approximately 500 m upstream of the Resort through Marble Canyon and onto the upper part of the fan area. The upper fan area includes part of the Mountainside Golf Course, numerous townhomes, and the community recreation centre.

Moderate Risk Areas **-** Moderate risk areas, or the indirect impact zone, includes areas within the middle to lower parts of the fan including the areas along Fairmont Creek channel (and ancient relict drainage channels). Local topography affects the area classified as moderate hazard, as debris flow surges follow minor variations in slope.

Areas affected by a 1 in 10 000 year debris flow event include the moderate and high risk zones shown on the maps. Within this area, properties may be subject to variable debris flow impact, depending on the flow path. Because Fairmont Creek is vulnerable to avulsion at or slightly above the fan apex, areas affected by future debris flow events include potential alternative flow paths.

Low Risk Areas - The low risk zone, or flood zone, includes areas that may potentially experience flooding due to debris flow. These areas are almost entirely influenced by topography and are greatly affected by infrastructure such as culverts and ditches. For this reason drainage structure maintenance through the residential portion of Fairmont Hot Springs is considered important.

Debris Flow Mitigation Options

The results of the debris flow hazard and risk assessment indicate that portions of the Fairmont Creek fan are at risk from damaging and potentially life-threatening debris flow events. Thus, a variety of mitigation measures are identified to reduce the level of debris flow risk to developed areas on the Fairmont Creek fan.

An integrated system of active measures to mitigate the debris flow peak flow velocities and debris deposition across the fan are conceptualized and preliminary costs for construction and maintenance are presented. To summarize, debris flow mitigation measures on Fairmont Creek may include:

1. Increase channel capacity upstream of FHSR by widening the channel;
2. Protecting the RV Park access road by constructing a bridge, or modifying the culvert crossing to detain small debris flows;
3. Increase the channel capacity through Marble Canyon and install safety signage and refuge areas along the walking trail;
4. Construct a debris flow barrier system in Marble Canyon;
5. Restore the channel and rip rap dyke at Marble Canyon (work in progress);

6. Reconstruct the channel through the golf course that connect Marble Canyon with the golf course pond;
7. Maintain the golf course pond as a flood control structure;
8. Complete a Watershed Management Plan;
9. Install a rainfall gauge at FHSR ski resort; and,
10. Conduct periodic (5 year) inspection of Fairmont Creek and tributary channel

Combined, the identified measures would work together to ensure that each functions properly and provides the desired level of safety. The engineering design of downstream measures, for example, is dependant upon whether upstream measures are in place. However, given that it is unlikely that all measures would be constructed at the same time, a phased approach is recommended. The phased approach, shown in the table below, divides measures into those within and upstream of Marble Canyon, and those measures downstream of Marble Canyon on the Fairmont Creek fan. It is recommended that the first phase of the mitigation program include the reconstructed channel and riprap dyke, the channel connecting this with the golf course pond, and the pond itself. Work to reconstruct the dyke is already in progress and, when completed, will mitigate a 45,000 m^3 event. Channel improvements between the reconstructed channel and the golf course pond are considered priority and should be included in the first phase of mitigation work.

Given that the reconstructed dyke and channel will eventually offer some level of protection from smaller debris flow events, the second phase of work will be to detain approximately 20,000 m^3 of debris and reduce peak flows such that the downstream measures are not overwhelmed. Channel improvements above the resort and at the RV Park road crossing would sufficiently reduce the risk to a desirable level and should be considered as a second phase of work.

It is recommended that the integrated protection system of measures and all associated maintenance access corridors be established as a RDEK service area and be provincially registered as a flood control structure. Roles and responsibilities will be established for the long term.

A summary of preliminary costs, provided in the table below, indicates that the entire system of protective measures on Fairmont Creek may cost between $2.0 and $2.5 million to construct. Phase 1 of the program, downstream of Marble Canyon, will cost approximately $740,000 (less the $322,000 already committed to the reconstruction of the dyke). Phase 2 of the work program, within and upstream of Marble Canyon, will cost between $1.3 and $1.7 million depending on whether a bridge is constructed at the RV Park access road. If it is possible to design a mitigation measure above Marble Canyon that sufficiently reduces the debris flow hazard then the debris flow barrier ($780,000) would not be required. Annual maintenance costs for all measures will be between $45,000 and $53,000, but if completed together will be significantly less (est. $30,000 to $35,000) due to cost efficiencies.

Summary of Recommended Phasing and Preliminary Construction and Maintenance Costs for Debris Flow Mitigation on Fairmont Creek

	Recom-mended Phasing	Mitigation Measure	Construction Costs	Maintenance Costs
Within or above Marble Canyon	2	Increase channel capacity upstream FHSR	$270,280	$12,500
	2	Protect RV Access Road - Option A (Bridge)	$627,850	$2,000
	2	Protect RV Access Road - Option B (Culvert)	$174,730	$10,000
	2	Increase channel capacity through Marble Canyon and Install Signage/Refuge	$49,880	$2,000
	2	Debris Flow Barrier	$785,900	$14,500
Below Marble Canyon	1	Restore Channel and Riprap Dyke at Marble Canyon (from KWL, 2012)	$321,475	$7,500
	1	Reconstruct Channel through Golf Course	$407,450	$2,500
	1	Maintain Pond as a Flood Control Structure	$10,000	$4,100
	1	Inspect channel and drainage structures on fan	n/a	n/a
	3	Complete a Watershed Management Plan	n/a	n/a
	5	Install a rainfall gauge at FHSR ski resort	n/a	n/a
	4	Conduct periodic (5 year) inspection of Fairmont Creek and tributary channel.	n/a	n/a
		Total (with bridge)	$2,472,835	$45,100
		Total (with culvert)	$2,019,715	$53,100

Summary and Conclusions

In summary, the results of the Fairmont Creek debris flow hazard and risk assessment have determined that:

- The Fairmont Creek is a debris-flow prone watershed;
- Potentially hazardous debris flows occur on average every 25 years or so but do not necessarily extend down the fan past Marble Canyon;

- The July 2012 Debris Flow event was the largest debris flow event on record for Fairmont Creek and had an estimated magnitude of 65,000 m^3 and an estimated return period of approximately 500 years;
- The July 2012 event formed the basis for the hazard and risk assessment and areas on the fan were mapped according to the composition and depth of the deposit.
- Based on the likely composition of future debris flows, boulder-sized debris flow material and high flow velocities will impact areas across the upper part of the Fairmont Creek fan. These areas are designated high debris flow risk corresponding to the potential for direct impact.
- High risk areas extend down the mainstem channel, through Marble Canyon to the upper part of the fan. A large part of the high risk area is developed golf course, but there are residences (townhomes and condos) and a community recreation centre within this zone as well.
- Potential risk to other areas of the fan depends largely on channel constrictions, stream bank weaknesses, and local topography. These areas would be impacted by a saturated slurry of gravel, cobbles and fine sediments, moving at slower velocities.
- Mitigation measures, including a debris flow barrier system and reconstruction and enhancement of the flood protection structure at Marble Canyon, could reduce the risk to properties and infrastructure.

Acknowledgements

We would like to acknowledge the input, support and assistance from many individuals in the preparation of this report. Project administration, assistance and review was provided by Jim Maletta and Brian Funke of the Regional District of East Kootenay. Background information, photographs and technical review was provided by Antoine Beriault, Dwain Boyer and Peter Jordan of the Ministry of Forests, Lands and Natural Resource Operations. Field work assistance and report review was provided by Shawn Vokey, Vast Resource Solutions Inc. Background information and resources were provided by the Fairmont Hot Springs Resort Ltd., including CEO, Dean Prentice and Golf Course Manager, Tom Altmann. We are also grateful for information provided by Richard Haworth, of Haworth Development Consulting.

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1.0 INTRODUCTION AND OBJECTIVES

Clarke Geoscience Ltd. (CGL), together with Golder Associates Ltd. and Vast Resources Solutions Inc., were retained by the Regional District of East Kootenay (RDEK) to prepare the following Fairmont Creek Debris Flow Hazard and Risk Assessment. Funding for the project is provided by Emergency Management British Columbia (EMBC). The project was administered by RDEK and the Ministry of Forests Lands and Natural Resource Operations (MFLNRO) provided technical assistance in the development of the Request for Proposal, selection of the successful proponent, and technical review of the assessment report.

1.1 BACKGROUND

The Fairmont Creek watershed comprising an area of 11.1 km^2 is located on the eastern slopes of the Columbia River valley, approximately 100 km north of Cranbrook, B.C. The unincorporated community of Fairmont Hot Springs, population est. 500, and the Fairmont Hot Springs Resort (FHSR), are situated on the coalesced fans of Fairmont Creek and Cold Spring Creek (Figure 1).

On July 15, 2012 Fairmont Creek experienced a debris flow event that impacted the FHSR and portions of the community of Fairmont Hot Springs that are situated on the fan. A slurry of rock, debris and mud flowed down the mainstem channel, mobilizing material stored in the channel and along the banks. The event scoured out the main channel, destroying several road crossings, damaging the golf course and some residences, and disrupting the Resort water supply. Despite the severity of the event, there were no injuries or deaths.

The Regional District of East Kootenay is now administrating the assessment funded by EMBC to determine the short and long term risk of debris flow and to determine whether mitigation measures are necessary. The Ministry of Forests, Lands and Natural Resource Operations (MFLNRO) Water Stewardship Division provided a technical role, including development of the Request for Proposal (RFP) and technical review.

Prior to July 2012 a portion of the fan was protected from hazardous debris flow by a log crib and riprap wall (dyke) and deflection structure. The flood protection measure was overtopped by the recent event and it must now be determined what active and passive mitigation measures are available to reduce risk, given the recent event and the increased understanding of processes in the watershed.

1.2 PROJECT OBJECTIVES

The following debris flow hazard and risk assessment of the watershed and fan area of Fairmont Creek includes an information review, field investigation and analysis.

The overall objectives of the debris flow hazard and risk assessment are:

1. Characterize the July 15, 2012 debris flow event;
2. Determine the hazard and risk of future debris flow and flood events;
3. Prepare a hazard map for the fan area; and
4. Recommend hazard and risk mitigation measures and associated costs.

In addition, a preliminary hydrogeological assessment is included to assess the potential impact that the debris flow may have had on the local groundwater regime and whether this led to seepage issues affecting nearby properties on Riverview Drive (Appendix C).

2.0 STUDY METHODS

The study methods are consistent with the Association of Professional Engineers and Geoscientists of BC's (APEGBC)[1] Guidelines for Legislated Landslide Assessments for Residential Development (updated, 2010) and the BC Ministry of Water, Land and Air Protection Flood Hazard Area Land Use Management Guidelines (2004).

Recently, APEGBC published the Professional Practice Guidelines for Legislated Flood Hazard Assessments in the Changing Climate in B.C. (2012). This document is referenced. However, there are some slight differences in the risk assessment methodology used in this study as compared to that in the Flood Hazard Assessments document. Methods for debris flow hazard analysis used in this report has been drawn from published literature, including Jakob (2005)

2.1 INFORMATION REVIEW

The following information was reviewed for the assessment:

- 1:20,000 scale topographic mapping of study area, including 1 m contours generated by LiDAR;
- Digital orthophoto overlays (2007);
- Terrain stability class and bioterrain mapping (iMap BC);
- Bedrock geology mapping from the B.C. Department of Mines (Henderson (1954) and iMap BC) and soils mapping from the B.C. Soil Survey (1988);
- Historical air photographs, including:
  - 1945, Flight line A9512, No. 63-64 and No. 110-111
  - 1949, Flight line x396C, No. 17-18

[1] Association of Professional Engineers and Geoscientists of British Columbia

- 1952, Flight line BC1607, No. 61-62
- 1964, Flight line BC4229, No. 69-75
- 1968, Flight line BC5298, No. 58-59 and No. 72-74 and flight line BC5297, No. 263-265
- 1978, Flight line 15BC78147, No. 147-150
- 1985, Flight line 15BC85076, No. 154-157
- 1991, Flight line 30BCB91134, No. 220-225 and flight line 30BCB91169, No. 125-128.

- Consultation with agencies (MFLNRO, Ministry of Transportation and Infrastructure (MoTI), RDEK, other professionals and local residents who are familiar with the study area; and,
- Other related reports and studies.

2.2 FIELD INVESTIGATION

A field investigation was carried out by Ms. Jennifer Clarke, P.Geo., of CGL and Mr. Shawn Vokey, P.Eng., of Vast Resource Solutions Inc., on October 15-17, 2012, and on November 5-6, 2012. The field investigation included a detailed foot traverse of Fairmont Creek, from the mouth upstream through the middle reaches of both tributaries and into the headwaters of the north tributary. Recreational trails in the upper watershed were also traversed. A helicopter overview flight was videotaped to document channel conditions and sediment sources throughout the watershed and adjacent areas. The fan area was traversed and local site topography and other features were noted and photographed. In addition, a subsurface investigation included six test pits that were excavated across the fan area. One sample of organic material obtained from a test pit on the fan was sent to Beta Analytical Laboratory for radiocarbon dating[2].

2.3 DEBRIS FLOW HAZARD AND RISK ASSESSMENT METHODS

2.3.1 Hazard Classification

Debris flow hazard, is the probability that a potentially damaging event will occur within a defined period of time. For this study, debris flow hazard is qualitatively assessed based on evidence of past debris flow events, on an assessment of slope and stream channel conditions and on professional judgement based on past experience in similar terrain.

Hazard classes are described in Table 1 below. The classification criteria, are based on the anticipated frequency of occurrence and the predicted magnitude, or volume, of a specific debris flow event. The specific debris flow event referenced in the criteria development corresponds with the level of landslide safety considered for this assessment, discussed in Section 2.3.4.

[2] Unfortunately the results, presented in Section 4.1.3 were unable to provide a historic debris flow date.

2.3.2 Consequence Classification

Predicted debris flow impact consequences are defined on the basis of field indicators, as per Hungr et al, (1987) and are shown in Table 2. These characteristics are used to distinguish between events that may be potentially damaging and those that may be life-threatening.

Table 1: Hazard Classification Criteria

Hazard Class	**Frequency of Occurrence**	**Predicted Magnitude, or Volume**
Low – very low likelihood of experiencing a very large event	More than 10,000 years	>100,000 m^3
Moderate – subject to more frequent small events and less frequent large events	500 to 2500 years	20,000 to 100,000 m^3
High – high probability of smaller sized events	10 to 500 years	1,000 to 20,000 m^3

Table 2 Predicted Debris Flow Consequences, or Impact Characteristics

Consequence Class	**Predicted Debris Flow Impact Characteristics**
Low	<u>Flood Zone</u> • Potentially inundated with flooding that occurs after the main debris flow surge. • Material transported is fine-grained (mud) and is mostly a “nuisance” for clean up.
Moderate	<u>Indirect Impact Zone (Potentially Damaging)</u> • Lower debris flow discharge and velocity, so lower impacts. Volumes may still be high and may potentially inundate or bury areas and objects. • Material transported includes gravel to cobble sized rock and smaller woody debris.
High	<u>Direct Impact Zone (Potentially Catastrophic, or Life-Threatening)</u> • Rapidly-moving, high discharge debris flow surges • Material transported includes large (greater than 1-2 m diameter) boulders and large woody debris

2.3.3 Risk Classification

Risk is the chance of injury or loss. It is defined as the combined measure of probability and the consequence of an adverse effect to health, property, the environment, or other things of value (adapted from CSA 1997).

For this assessment, "partial risk" is assessed. Partial Risk is the product of the probability of occurrence of a specific hazardous debris flow event and the probability of that debris flow reaching or otherwise affecting the site occupied by a specific element. Information regarding the vulnerability of the element is required to estimate "total risk" or specific risk.

The risk classification scheme shown in Table 3, illustrates how debris flow hazard and the predicted impact, or consequence is combined.

Table 3: Partial Risk Classification Scheme

		Debris Flow Hazard Class		
		Low	**Moderate**	**High**
Debris Flow Consequence	**Low**	Low	Low	Moderate
	Moderate	Low	Moderate	High
	High	Moderate	High	High

Table 4 summarizes and describes the resultant risk classification in terms of the probability of occurrence and impact corresponding to each class. The risk classes are based on the levels of acceptable landslide safety, discussed below. For example, in high risk areas, the probability of a property-damaging event is greater than 1 in 475, or 10% in 50 years, and the probability of a catastrophic, or life-threatening event is greater than 1 in 10,000, or 0.5% in 50 years. Moderate risk areas have a return period greater than 1 in 475 years for a damaging event, but a less than 1 in 10,000 year return period for a life-threatening event. Low risk areas are those areas that meet the MoTI requirements for acceptable landslide safety in developed areas. Low risk areas have a less than 1 in 475 year return period for a damaging event and less than 1 in 10,000 year return period for a life-threatening event.

2.3.4 Level of Landslide Safety

There is no established national level of landslide safety in Canada. For the purposes of this assessment, the MFLNRO has directed the use of the BC MoTI defined levels of acceptable landslide safety. In reference to landslide safety, MoTI includes geohazard events, such as debris flow.

In BC, the MoTI provided some guidance with respect to levels of landslide safety in the "Subdivision Preliminary Layout Review – Natural Hazard Risk" document (2009). The MoTI indicates that the level of landslide safety is:

• for a building site, unless otherwise specified, an annual probability of occurrence of a damaging landslide of 1/475 (10% probability in 50 years; that is, P(H) = 1/475); and,

• for a building site or a large scale development an annual probability of occurrence of a life-threatening or catastrophic landslide of 1/10,000 (0.5% probability in 50 years; that is, P(H) = 1/10,000), and

• large scale developments must also consider total risk and refer to international standards.

Levels of landslide safety were used to develop the risk classes used for this assessment by distinguishing between different types of events; those that may potentially cause structural damage, and those that may threaten life.

Table 4: Partial Risk Class Descriptions in Terms of Probability of Occurrence

Partial Risk Class	Probability of Occurrence	Description of Consequences
Low	• Less than 1 in 10,000 for catastrophic events. • Less than 1 in 475 years for property-damaging events.	Flood Zone Potentially inundated with flooding that occurs after the main debris flow surge. Material transported is fine-grained (mud) and is mostly a "nuisance" for clean up.
Moderate	• Less than 1 in 10,000 for catastrophic events. • Greater than 1 in 475 years for property-damaging events.	Indirect Impact Zone Lower debris flow discharge and velocity, so lower impacts expected. Volumes may still be high and may potentially inundate or bury areas and objects. Material transported includes gravel to cobble sized rock and smaller woody debris.
High	• Greater than 1 in 10,000 for catastrophic events. • Greater than 1 in 500 years for property-damaging events.	Direct Impact Zone Rapidly-moving, high discharge debris flow surges Material transported includes large (greater than 1-2 m diameter) boulders and large woody debris

3.0 WATERSHED CHARACTERISTICS

3.1 WATERSHED MORPHOLOGY

Fairmont Creek is a third-order stream flowing 6.9 km from the peak of Fairmont Mountain (elev. 2600 m) to the Columbia River (elev. 820 m). An overview of the watershed is shown in Figure 2. The length of channel from Fairmont Mountain to the fan apex is approximately 6 km.

The upper watershed is characterized as a tree-less alpine area, with exposed bedrock mantled with talus colluvium. Mid-slopes within the watershed are forested and tributary streams expose rock and colluvium. Forested areas of the Fairmont Creek watershed are moderate to steeply sloped (35% to >70%) but appear to be relatively stable, except where oversteepened due to bank erosion along the stream channels. Immediately above the fan apex, an 850 m long section of Fairmont Creek, referred to as the Marble Canyon, has downcut through limestone bedrock. The fan of Fairmont Creek extends into the Columbia River valley between Columbia Lake and Windermere Lake, the two lakes having been separated by the formation of the Dutch Creek fan. Glaciolacustrine and glaciofluvial terraces north and south of Fairmont predate the Fairmont Creek fan, as the fan is a post-glacial feature that has downcut the terrace slopes. The downslope edge of the Fairmont Creek fan extends into the Columbia River valley floodplain.

With a relative relief of 1780 m, the Fairmont Creek watershed has a Melton Ratio[3] of 0.53. This measure of watershed morphology, in combination with watershed length, may be used to differentiate between watersheds prone to floods, debris floods and debris flows (Jackson, et al., 1987) (Wilford, et al., 2004). For its length, Fairmont Creek falls on the cusp of a debris flood-prone watershed (Melton Ratio 0.3 to 0.6) and a debris flow-prone watershed (Melton Ratio >0.6)[4]. Watersheds with fine-grained materials may, however, have a lower Melton Ratio and still be prone to debris flow, as these materials are more easily mobilized with subsequently longer run out.

3.2 STREAM CHANNEL AND FAN MORPHOLOGY

The headwaters of Fairmont Creek are located in the alpine Fairmont Range. Fairmont Creek has one main tributary, referred to the North tributary. A channel profile, shown in Figure 3, illustrates the stream channel gradient from the headwaters down to the Columbia River.

[3] Melton Ratio is the relative relief divided by the square root of the watershed area. The ratio is used to differentiate between watersheds prone to flooding and those prone to debris flood and debris flow.

[4] Debris flows can have a peak discharge of up to 20 times greater than debris floods, so it's important to distinguish from a hazard perspective.

The channel profile shows that the headwater reaches have steep channel gradients (25% to 45%). Based on field observations, these reaches appear to be predominantly bedrock-controlled. The snow accumulation zone, which lies above the 1600 m elevation (approx.), is the zone above which hydrology is dominated by snow melt and throughout which snow avalanche tracks are common.

The north tributary has a catchment area of 2.9 km^2, while the mainstem channel has a catchment area of 6.1 km^2 above the tributary confluence. The headwater areas of the mainstem channel were the source of the 2012 debris flow. Downstream of the tributary confluence, the mainstem channel transitions to a lower gradient reach and then flows through a limestone canyon referred to as Marble Canyon. The fan apex is located at the downstream end of this canyon.

The Fairmont Creek fan is approximately 28 ha in area and has an average gradient of about 10%. Studies that correlate fan gradient with the dominant fan-forming process indicate that fans that are at least partially formed by debris flow have a fan gradient greater than 4^o (7%) (Jackson, et al. 1987). The Fairmont Creek fan, therefore, is inferred to have been formed in part by debris flow processes.

3.3 BEDROCK GEOLOGY, SOILS AND TERRAIN

The study area is underlain by sedimentary and metasedimentary bedrock that ranges in age from Upper Proterozoic to Cambrian-Ordovician. Geological mapping of the Stanford Range indicates that massive grey limestone to white dolomite of Cambrian-Ordovician age underlies the lower watershed, while an alternating sequence of dolomite, argillite (shale and limestone), and phyllite (metamorphosed shale) of the Upper Proterozoic Horsethief Creek Group underlies the upper watershed area (Henderson, 1954 and iMAP).

From a geotechnical perspective, it is the phyllitic rocks of the Horsethief Group that are relevant to debris flow process in the watershed, as these rocks range in competency from a resistant quartzite and shale to a finely degraded grit. Phyllite is a highly erodible bedrock type that weathers to a very fine loose rock. The weathered product of this bedrock constitutes an infinite source of relatively fine-textured sediment, easily capable of being mobilized in the channel, and also capable of long run out distances due to its fine texture. Almost the entire length of the upper mainstem channel of Fairmont Creek follows an exposure of phyllite.

Soils mapping in the Fairmont area reflects the underlying bedrock type. Soils in the watershed are generally shallow soils derived from limestone (BC Soil Survey, 1988). Reconnaissance-level (1:50,000 scale terrain mapping is available through iMAP (Ryder and Rollerson, 1977). The mapping indicates that the mid-elevations of the watershed are mantled with till of varying thickness overlying bedrock. However, the map resolution is insufficient for detailed interpretations.

3.4 HYDROLOGY

The Fairmont Creek watershed has a snow-melt dominated hydrology, which means that seasonally high flows generally occur in April and May due to melting of the high elevation seasonal snowpack. Peak flows, however, commonly occur in the summer months as a result of high intensity convective rain storms.

The valley bottom lies within the Interior Douglas-Fir biogeoclimatic zone and transitions to montane spruce and Engelmann spruce/sub-alpine fir zone with elevation. The climate of the Columbia Valley is characterized by cold, dry winters and warm, dry summers. Precipitation, carried eastward by prevailing climate patterns, falls largely within the Purcell Range, which leaves the eastern slopes of the Columbia Valley relatively dry.

The climate in Cranbrook, located about 100 km south, is fairly representative of the valley bottom area of Fairmont Hot Springs. The mean annual temperature in Cranbrook is 5.7 ^{o}C, ranging from -7.5 ^{o}C in January to 18.3 ^{o}C in July. The total annual precipitation is 383 mm. Of this, more than half (271 mm) falls during May, June and July. The total annual snowfall in Cranbrook is 140 cm, with half of this falling in December and January (Environment Canada climate database).

A regional flood frequency analysis was performed for Fairmont Creek in 1994 and determined that the 1:200 year maximum flood flow is 1.92 m^3/s and the peak instantaneous flow is 2.88 m^3/s. (Reid Crowther and Partners Ltd., 1994b)

Unique to Fairmont Creek, the hydrologic character includes downstream influence of the FHSR pools. To maintain water quality in the pools, the Resort flushes out the pools on a regular basis (every 1 to 4 days), depending on intensity of use. Approximately 1.6 million gallons of water are released each time the pools are drained. The stream reaches affected by this release are all downstream of the Resort.

3.5 WATERSHED AND FAN LAND USE

There are no commercial forestry operations in the Fairmont Creek watershed, nor are there any clear indications of historic logging operations. Some areas traversed during the field investigation appeared to have been affected by forest fire. However, extensive forest fire was not indicated in the air photos dating back to 1945.

Land clearing and recreational trails associated with the FHSR Ski Resort occupies the mid-elevation ridge between Fairmont Creek and Cold Spring Creek. The Ski Resort is a relatively small alpine ski hill serviced by 2 to 3 chair lifts. A cross-country ski trail traverses the slope into the Fairmont Creek watershed and crosses the north tributary of Fairmont Creek at two locations.

Three golf courses are present within the Community of Fairmont Hot Springs on the Fairmont Creek fan, and consist of the Riverside Golf Course, located on the west side of Highway 93/95, and the Creekside and Mountainside Golf Courses, located on the east side of Highway 93/95. Only the Mountainside Golf Course was physically impacted by the July 2012 Debris Flow event.

4.0 FIELD OBSERVATIONS

The following documents the observations and measurements from the field investigation, helicopter overview, air photo assessment, and sub-surface investigation. Photographs are provided in Appendix A.

4.1.1 Stream Channel Characteristics

Macro-reaches were assigned to the Fairmont Creek mainstem and to the north tributary channel of Fairmont Creek. Reach breaks and noted features are shown on the Overview Map (Figure 2) and channel profile (Figure 3). The macro-reaches are described here.

Headwater Reaches - Fairmont Creek

The mainstem channel of Fairmont Creek experienced the primary surge of the July 2012 debris flow. Field evidence indicates that an accumulation of runoff from the headwater basin resulted in an ever-increasing amount of water with sufficient flow to entrain the abundant amount of unconsolidated material present within the channel.

The 4.3 km long headwater reaches, with stream gradients ranging from 15 to 25%, represent a zone of debris flow initiation and transport. Fairmont Creek originates on the north side of Fairmont Mountain, where major snow accumulation zones provide source water for Fairmont Creek. The headwater reaches are steep, bedrock controlled sections that traverse alpine areas.

Proceeding downstream, the channel begins to downcut through talus deposits that underlie the valley bottom. There are numerous locations where undercutting of streambanks has resulted in shallow slump failures, depositing sediment directly into the channel.

There are numerous steep tributary channels contributing runoff to the channel. Although there is evidence of snow avalanche occurring within many of these tributary channels, the alpine snow pack and terrain shape is considered unlikely to generate extremely large, landscape-modifying snow avalanches. Large accumulations of sediment and/or woody debris are absent at the base of the tributary channels. In general, the angle of entry into Fairmont Creek nears perpendicular. Tributaries with a perpendicular entry are less likely to trigger debris flows in the channel than tributaries with a narrow angle of entry.

The mainstem channel, within several hundred metres of the tributary confluence, has an average channel width of 12 m and channel depth of 3 m.

Fairmont Creek has since downcut through in-channel deposits and the channel now has an average width of 7 m and a depth of 1.5 m.

Headwater Reaches - North Tributary Fairmont Creek

The north tributary of Fairmont Creek drains a smaller catchment area than the mainstem channel but, similarly, it originates in a steep alpine area. Runoff from snow melt is supplemented by spring (cold) water sources as observed in the field at approximately 1500 m elevation.

The north tributary channel is 3.4 km long with steep (18-25%) channel gradients and represents a zone of debris flow initiation and transport. The average channel width ranges from 5.5 m to 7.2 m, with a few wider sections. The channel depth ranges from 0.5 m to 0.9 m.

Throughout the reach there are numerous debris jams and sediment wedges. Some appear to have been formed recently (i.e. within the last 5 years), while others appear to be much older (est. 50 years) based on the age of established vegetation.

Large lateral bars and sediment accumulations in the headwater channel indicate that the tributary experienced a significant flood event approximately 5 years previous (est. 2007) but that the event did not likely reach the Fairmont Creek fan.

There are three trails traversing the slope from the ski area to Fairmont Creek. The upstream trail accesses a water intake site situated at a bedrock notch in the channel. Waterworks appear to be intact but the status of these works is unknown. The second and third trails are cross-country ski trails that traverse the slope and cross the creek. The upper crossing (culvert) has been completely washed out and a 20 m long section of trail and a few other sections of trail adjacent to the creek have been washed out. Above the creek on the left bank[5] the trail traverses a steep till exposure with hoodoo formations and a steep ravelling bank crest. The lower trail crossing consists of a bridge crossing that was damaged but not destroyed by the July 2012 event.

The cross-country ski trails switchback the ridge between the north tributary and the mainstem. In general, the terrain is relatively benign, with no indications of drainage or stability issues. However, as the trail begins to traverse moderately-steep (50%) slopes above the north tributary, there are numerous signs of slope instability. In this area, there are several small (1-1.5 m high) headscarps along the irregular, almost hummocky terrain. Although signs of instability are not expressed by the vegetation, it is likely that the area has experienced some slope deformation. Upstream of the tributary confluence and downstream of the third trail crossing, indications of recent slope instability were observed. A 20 m long

[5] It is standard convention to refer to the right bank and left bank of a stream channel, as viewed in a downstream direction. For Fairmont Creek, right bank is on the north side and south bank is on the south side.

tension crack, with 0.5 to 1.0 vertical displacement, situated approximately 20 m upslope of the stream on left bank, represents a potential source of sediment. This area is underlain by unconsolidated till material over phyllite bedrock.

Weathered phyllite bedrock is exposed along sections of the north tributary, including the section experiencing slope instability, however, the headwater reaches of the north tributary are underlain by the more resistant limestone and dolomite bedrock.

Fairmont Creek - Reach 4 below tributary confluence

This 500 m long reach extends downstream from the confluence of the north tributary (approximately 3 km upstream of the Columbia River) to the former water intake site. This reach is characterized as having an average bankfull width of about 22 m (range 19 to 26 m), an average depth of 1.5 m, and a stream gradient ranging from 10 to 17%, with gradient decreasing downstream. It is distinguished from adjacent reach R3 by having greater connectivity to the adjacent hillslopes, with several small (150 m^3) slumps evident along the left bank. A large escarpment on the right bank, at 2+700 m, exposes glacio-lacustrine clayey sandy-silts.

Reach 4 represents a zone of transition between debris flow transport and debris flow deposition. The channel is still relatively confined and steep enough for most material entrained in a debris flow surge to continue downstream. However, several large (1.5 to 1.8 m diameter) boulders transported downstream during previous events are present within this reach. Also noted, were several massive debris blocks (4 to 5 m diameter) above the channel banks on both sides of Fairmont Creek. These may have been deposited by debris flow along the channel when the channel was at a higher topographic level; it has since downcut.

Fairmont Creek - Reach 3 above Hot Springs Resort Road

This reach extends for 750 m downstream from the former FHSR water intake site to the Hot Springs Resort Road and is characterized as a highly aggraded, boulder cascade-pool channel with an average stream gradient of about 15%.

Within this reach, Fairmont Creek occupies a relatively wide (20 to 50 m) valley that has been partly confined along the right bank by a constructed berm. The 3 m high berm is comprised of alluvial materials (sands, gravels and cobbles) with side slopes ranging from 2H:1V to 1H:1V. It is understood that the berm existed prior to the event and was constructed over time to deflect the creek away from the Hot Springs wells located near the right bank (A. Beriault, pers. comm., 2012). The Hot Springs wells were buried subsequent to the July 2012 event and, immediately following, material was excavated and placed to re-establish creek flow between the berm and the left bank.

The berm reduces the available bankfull width of Fairmont Creek to an average of about 10 m (range 8.5 m to 18 m) with a depth of about 2.5 m (range 2.3 m to

3 m). Currently, the stream has downcut (and assisted by post-debris flow excavation) to form a channel that is about 4 m wide on average and about 0.5 m deep.

Along the left bank, oversteepened unconsolidated fluvial and debris flow deposits are exposed. At one exposure, there is stratigraphic evidence of two previous debris flow events separated by interbeds of fluvial sands and gravels. In addition, a cut slice was obtained from a small (DBH=0.35 m) tree that was inundated by the 2012 event and scarred from a previous event. Tree-ring data indicates that the 52 year old tree was also damaged by an event around 1984, which is consistent with evidence presented in a report by Boyer (1989).

Based on the average stream gradient, and a widening of the channel, this reach is considered to represent a zone of both deposition and transport. Coarse materials will start to be deposited within this reach, as indicated by evidence of the July 2012 event and by evidence of previous events. Because much of the material entrained in the debris flow is comprised of fine-textured weathered phyllite clasts, a large proportion of material comprising the debris flow will continue downstream.

Fairmont Creek - Reach 2 below Hot Springs Resort Road (Marble Canyon)

Reach 2 comprises the 850 m long Marble Canyon section of Fairmont Creek and extends downstream from the Resort Road crossing to the upstream edge of the Mountainside Golf Course.

Fairmont Creek was previously conveyed across the asphalt access road connecting the Hot Springs Resort to the RV park by a 900 mm diameter steel culvert with an unspecified amount of headspace on the upstream side of the road. The July 2012 debris flow completely filled the area upstream of the culvert, burying the road and the Hot Spring source wells upstream of the road, resulting in a 3-4 m high waterfall that undercut the road bed materials. Currently, a 1600 mm diameter culvert is in place at the road crossing and the reconstructed channel has been lined with sub-rounded boulders.

Downstream of the road, the July 2012 event utilized almost the full width of the canyon, washing out a walking trail along the left bank and much of the vegetation. Along this reach the average width of the channel is about 22 m, average depth is 2.5 to 3 m, and the channel gradient ranges from about 8 to 15%. The current stream occupies a channel, excavated and partly downcut into the debris flow deposits, that is about 2 to 4.5 m wide and 0.5 m deep.

Stream bank exposures along this reach expose interbedded fluvial, debris flow and limestone (travertine) deposits. At least two debris flow layers besides the July 2012 event were noted in bank deposits and where adventitious roots of a 70-100 year old cottonwood tree were exposed (photo x).

Two points of discharge for the Fairmont Hot Spring Resort pools form waterfalls along the right bank of this reach. Travertine rock formations, formed by rapid chemical precipitation of calcium carbonate from supersaturated meteoric waters, are characteristic through this reach and further downstream where travertine lines the channel bottom and/or is interbedded with fluvial sands and gravels where exposed along the banks. Layers of travertine, representing formation over hundreds to thousands of years, are inferred to denote long periods of debris flow inactivity.

Approximately 150 m upstream of the golf course bridge at the apex of the fan, Fairmont Creek avulsed from its original channel during the July 2012 event and formed a new channel (partly excavated post-event). It is likely that the initial debris flow surge, largely comprised of coarse rock and debris, filled the channel with material and then an afterflow of fine-textured material and water flowed over the banks. The debris flow overtopped the right bank and inundated adjacent homes with a slurry of mud less than 0.5 m thick. Coarse material (up to 1-1.5 m diameter) and the primary force of the debris flow overtopped the left bank, flowing across the 16th fairway of the golf course and into an area of several townhomes.

Reach 2 of Fairmont Creek, because of its degree of confinement in the bedrock canyon, will continue to be a transport zone for material entrained in a future large debris flows. Stream channel gradients are sufficiently shallow (generally 10%) to facilitate deposition of coarse-grained material, however, during high flows a large amount of material will likely be transported downstream to the point where channel confinement is lost (i.e. at the end of Reach 2, at the end of Marble Canyon and upstream of the Mountainside Golf Course.

Fairmont Creek - Reach 1 Fan

Reach 1 of Fairmont Creek is 950 long and extends downstream from the fan apex at the edge of the Mountainside Golf Course all the way to its mouth on the Columbia River.

Historic air photos show that Fairmont Creek flowed along a more northerly alignment, through what is now residential area. The stream prior to 1968 flowed south-west through the end part of Wilder Loop Road and into the Columbia River just upstream of the Highway 93 bridge (which was reconstructed along with a revised highway alignment prior to 1964). Early air photos indicate that there was considerable channel instability across the lower part of the fan and that starting in the late 1960's, Fairmont Creek avulsed to its current alignment.

<u>The Golf Course Pond:</u> Downstream from Reach 2 (Marble Canyon), Fairmont Creek within Reach 1 is conveyed within a constructed channel that leads to a constructed pond on the 12th fairway of the golf course. Across the golf course fairway, the channel is rock-lined and it transitions to a log crib walled channel as it flows past the adjacent townhomes and into the pond.

Air photos indicate that in the mid-1960's, construction on the golf course had been initiated and that a large pond was constructed. It is likely that Fairmont

Creek was at that time directed into the pond and that, downstream of the pond the channel followed what is now the current channel alignment to its mouth on the Columbia River (approximately 200 m upstream of the former mouth).

It is understood that the pond was constructed as an aesthetic feature on the golf course and is not a provincially-registered flood control structure. Water levels in the pond (2,590 m^2 surface area) are controlled by a concrete weir structure at the downstream end. There is also a bypass valve, set at a depth of approximately 2.5 to 3 m, which is used to drain the pond. At the bottom depth of the valve, the pond capacity is estimated to be approximately 7,000 m^3.

As fine-textured sediments (i.e. silts and sands) gradually infill the pond, the pond is periodically dredged. It is understood that the pond had not been dredged for the previous 10 to 15 years but was scheduled for dredging in 2012. It is possible, therefore, that the pond capacity was reduced at the time of the July 2012 event.

In July 2012 the pond was completely inundated and filled with material consisting mostly of fine to cobble-sized sediment. Anecdotal reports are that the pond filled in a matter of minutes.

<u>Downstream of the Pond:</u> Downstream of the pond, Fairmont Creek flows within a small alluvial channel that proceeds through a residential area, flowing through back yards, along roadside ditches, and through culverts, before reaching the Columbia River just upstream of the Highway 93 bridge crossing. The channel is lined throughout with travertine. In July 2012, mud and water from the debris flow overtopped channel banks and followed topographic features across the fan. Flows were diverted where drainage structures, such as at culverts, occurred. It is not clear what state of maintenance the roadside drainage structures were in at the time of the event, but subsequent correspondence between the residents and the RDEK indicates that this have been an issue in the past.

Slopes on the Fairmont Creek fan range from 5% below the highway to 10-12% at the upslope end near the fan apex. In general, the fan surface slopes at about 10%, which as previously discussed suggests that it has been constructed by a combination of fluvial processes and debris flow activity. Topographic features on the Fairmont Creek fan have been almost completely obscured by development (golf course, residential, highway). Based on historic air photos and field observations (surface and subsurface) it is likely that the lower gradient area occupied by the pond is an area that has partially aggraded due to the precipitation of calcium carbonate. Historically, Fairmont Creek fanned out into several channels across the fan below this point. Where historic channels flowed across the fan, prolonged exposure to water saturated with calcium carbonate led to precipitation and coating of alluvial sediments. Test pits across the fan confirm historic alluvial activity across the fan as indicated by layers of travertine and tufa.

4.1.2 Sediment Sources and Supply

Sediment sources identified by air photo review, during the helicopter overview flight and by field traverses are shown on Figure 2. The figure shows that, in general, the middle reaches of Fairmont Creek and the north tributary flow through zones with major sources of sediment. The channels downcut through sections underlain by easily erodible phyllite bedrock and unconsolidated till deposits.

Along the mainstem channel upstream of the tributary confluence numerous small (100-500 m^3) slumps appear to be relatively fresh, perhaps occurring in the spring of 2012 (prior or during the July event). Approximately 700 to 800 m upstream of the confluence and on the north facing slope above the left bank, there appears to be a large (approximately 2,000 m^3) bedrock slump. The headscarp, situated about 120 upslope of the creek, was observed during the helicopter reconnaissance. The lower portion of the slump is vegetated and does not appear to be active. Renewed instability at this site, however, could potentially result in temporary damming of the channel.

Numerous sediment sources, including small (100-500 m^3) slumps and eroding phyllite bedrock slopes were also identified along the north tributary. In addition, several fill slope failures from the cross-country ski trail that traverses an oversteepened till exposure were observed. Side slopes above the north tributary below the trail crossings are also unstable, with several small active slumps as indicated by fresh tension cracks.

Downstream of the tributary confluence, sediment sources to Fairmont Creek are from erodible streambank deposits and from minor ravelling of side slopes. Potential for a possible slope failure of a fluvioglacial and/or glaciolacustrine deposit exposured within Reach 4 was also noted.

Based on the results of this assessment, the Fairmont Creek watershed is judged to have an unlimited sediment supply (supply-unlimited condition). As such, debris flows may initiate whenever a critical hydroclimatic threshold is reached and/or when an appropriate triggering mechanism occurs.

4.1.3 Subsurface Investigation and Assessment

Six (6) test pits were excavated on the Fairmont Creek fan in an effort to determine the distribution and return periods of previous debris flows (location shown on Figure 4). The test pits were located on FHSR property in areas that would least impact resort operations and infrastructure. Test pits were excavated to approximately 4 m depth and the stratigraphy was logged (Appendix B). It was noted that no test pits intercepted groundwater.

Debris flow deposits are characterized by a lack of sorting with matrix-supported fragments. Wood debris often marked by torn ends may be contained within these deposits.

Test pits 1 and 2 were located at the distal end of the fan close to Highway 93. The pits, however, may have been sited on or near the old highway 93 alignment, so subsurface soils may have been disturbed. Test pits 3 and 4 were located mid-fan and Test pits 5 and 6 were located at the upper end of the fan.

Test pits 1 to 4 all exhibit a white/yellowish tufa layer within the first metre (range 0.6 m to 0.9 m) which indicates a fairly stable period of alluvial (not debris flow) activity. Similar to travertine, a softer and more porous rock deposit, called tufa[6], forms where calcium carbonate precipitates from ambient temperature waters in fluvial environment.

A root collected from a layer just below the tufa (2.15 m) in Test pit 3 was submitted for radiocarbon dating. The results indicate that the root fragment is contemporary in age; less than 100 years old. Within Test pit 3 the tufa layer, appears to lie above a debris flow deposit consisting of a clayey silt matrix with supported sandy gravel with few cobbles. Wood debris was not observed in this layer.

Test pit 5, located near the constructed pond has a complex stratigraphy showing a number of buried organic layers. Based on the history of development around the pond and nearby town homes, it is possible that the upper meter or two has been disturbed. In Test pit 5 between 0.7 and 2.2 m depth, a firm sandy- gravel deposit with cobbles and some boulders, may reflect a debris flow or debris flood event and is positioned above a yellowish clayey silt layer. The silt layer lies above a clayey-silt sandy gravel deposit with cobbles and boulders, similar to what was found at the lower depths of Test pit 3.

At Test pit 6, located at the apex of the fan just above the golf course, a 1.3 m thick deposit from the July 2012 event was observed. The deposit was comprised of cobble to boulder-sized particles with a silty sand matrix. Below this, a cobble-boulder deposit representing a previous event was observed to be more than 2.7 m thick. The largest sized boulders (up to 1.1 m diameter) prevented further deepening of this excavation.

To summarize, deposits from at least one previous debris flow event (other than 2012 event) was observed in test pits at the top end of the fan. Further downslope on the fan subsurface deposits indicate that the area experienced a long period of debris flow inactivity characterized by fluvial activity including channel instability.

5.0 HISTORIC DEBRIS FLOW EVENTS

Fairmont Creek has long been recognized as being prone to debris flow. In 1989, a preliminary assessment of debris flow conducted by Ministry of Environment staff concluded that professional assessments would be required for future subdivision of lands owned by Fairmont Hot Springs Resort Ltd. (Boyer, 1989).

[6] Tufa – a porous calcium carbonate deposit, is not to be confused with “tuff” a consolidated volcanic ash deposit.

The Fairmont Creek fan is also delineated as a Non-Standard Flooding and Erosion Area (NSFEA) by the Ministry of Environment (Kootenay Region) (2002). The delineated fan area is identified as being potentially subject to debris flow (Rated "E) and land use proposals require an assessment of hazard, including siting of proposed buildings and site specific recommendations.

5.1 THE JULY 2012 DEBRIS FLOW EVENT

On July 15, 2012 at approximately 4:15 pm, a debris flow occurred on Fairmont Creek. The event originated in the headwaters of the mainstem channel, cumulatively developing into a debris flow as it flowed rapidly downstream to the fan and subsequently into the Columbia River.

The July 2012 debris flow had the following impacts:

- buried the Hot Springs source wells with 5 to 7 m of debris just upstream the Hot Springs Resort Road;
- washed out the 900 mm diameter culvert on the Hot Springs Resort Road, cutting off access to the RV park area;
- severely damaged a foot bridge connecting the RV Park and Resort area;
- filled up the Marble Canyon reach with several metres of rock and debris, washing out a creek side walking trail;
- FHSR lost the main source of water for the main lodge and fire suppression flows, which resulted in a 3 week closure of the resort and approximately $1.5 million in lost revenue[7];
- The irrigation water source and distribution lines to the Mountainside Golf Course was destroyed and seven (7) holes on the course were affected by the event. A large pond at Hole 12 filled up with debris and required dredging, and a small pond at Hole 3 was impacted. Smaller irrigation lines and landscaping were also impacted;
- Homes and vehicles situated on private land were inundated with mud, rock and debris. More than 350 people were evacuated from their houses and condos and temporarily relocated.

Eyewitness accounts, recorded and downloaded to YouTube, document the sudden inundation of the canyon area and the movement of water and debris across the fan area. A few videos include:

http://www.youtube.com/watch?v=X_v6svQF2uk
http://www.youtube.com/watch?v=aGN5fJwrwRg&NR=1&feature=fvwp
http://www.youtube.com/watch?v=NaNjfx3pN_s&NR=1&feature=endscreen

[7] Mr. Dean Prentice, CEO, Fairmont Hot Springs Resort Ltd., personal communication, Oct. 2012.

Despite occurring late afternoon on a busy summer day in July, when residents and visitors might have been on the golf course, or trails, and despite washing out road and trail crossings and directly impacting residential areas, no injuries or deaths were reported.

Immediately after the event, the site was inspected by a representative of the RDEK and of the MFLNRO (J. Penson). Photographs taken from helicopter and the ground provide valuable information regarding the event.

5.1.1 Antecedent Climate Conditions

Antecedent climate conditions preceding the July 15 debris flow event were determined from review of climate and hydrometric station data. The geographic location of the stations used in the analysis are shown on Figure 1.

On July 15, 2012, there were anecdotal reports that a convective storm cell moved through the Fairmont Hot Springs area. Radar imagery on that day shows that a localized storm cell, with rainfall intensities up to 8 mm/hr was centered within the vicinity of the study area. Rainfall data from nearby climate stations recorded between 20 and 26.4 mm of rain on the days leading up to July 15, 2012 (Table 5).

Table 5: Rainfall Data from Nearby Climate Stations for Period Preceding July 15, 2012 Debris Flow Event in Fairmont Hot Springs

Station	Date	Precipitation (mm)
Fort Steele @ Dandy Creek (Stn. 1153034; elev. 856 m)	July 13 July 14 July 15	26.4 mm 0 mm 20 mm
Kimberley (Stn. 1154203; elev. 889 m)	July 13 July 14 July 15	20 mm 0 mm 0 mm
Cranbrook Airport (Stn. 1152102; elev. 940 m)	July 13 July 14 July 15	Trace 23.4 mm (thunderstorms) 2.4 mm (thunderstorms)
Emily Creek (MOF Fire weather station; elev. 1190 m)	July 13 July 14 July 15	0 mm 0 mm 5.2 mm

Automated snow pillow stations, recording snow pack accumulation in high alpine areas closest to Fairmont Creek, are located to the south at Moyie Mountain and Morrisey Ridge, to the north at Floe Lake, or to the west at East Creek. The data indicate that 2011-2012 winter snow pack depths at these stations were higher than average (Table 6). For example, 2012 snow depths at Floe Lake exceeded the maximum recorded snow pack since 1994. Snow water equivalent measured on May 15, 2012 at Morrisey Ridge, south of Fairmont Creek, were 170% of Normal levels. All stations recorded a delayed onset of spring snow melt (approx. 2 weeks) followed by a period of rapid snow melt starting in mid-May. The noted stations lost all snow cover between mid-June and the end of July.

Table 6: Snowpack Data from Nearby Snow Pillow Stations for Period Preceding July 15, 2012 Debris Flow Event in Fairmont Hot Springs

	Station	Snow water equivalent measured on May 15, 2012
South	Moyie Mountain (Stn. 2C10P; elev. 1840 m)	131% of Normal, 31 year record
South	Morrisey Ridge (Stn. 2C09Q; elev. 1800 m),	170% of Normal, 27 year record
North	Floe Lake (Stn. 2C14P; elev. 2110 m)	141% of Normal, 17 year record
West	East Creek (stn. 2D08P; elev. 2004 m)	106% of Normal, 30 year record

Debris flow or flood events did not occur on any creeks adjacent to Fairmont Creek, including Cold Spring Creek; a watershed of similar size and topography. Other large-scale landslide and debris flow events did occur in the southern Interior of British Columbia in June-July 2012. This included a catastrophic landslide and debris flow at Johnsons Landing at the north end of Kootenay Lake (80 km to the south-west of Fairmont Creek) just two days prior to the Fairmont Creek slide. Damaging floods and debris flows also occurred on June 23-24, 2012 in the Shuswap area on Sicamous Creek and Hummingbird Creek (230 km northwest).

There are no hydrometric stations on the Columbia River near Fairmont Hot Springs, nor are there any stations on Columbia Lake or Windermere Lake. Stream flow data from nearby hydrometric stations was examined (Table 7). The only hydrometric station to show a response in stream flow on or near July 15, 2012 was a station on the Kootenay River (at Fort Steele).

Table 7: Streamflow Data from Nearby Hydrometric Stations for Period Preceding July 15, 2012 Debris Flow Event in Fairmont Hot Springs

Station	Stream flow Response
Kootenay River @ Kootenay Crossing (Stn.08NF001)	water levels show drop on July 14 and no response on July 15
Spillimacheen River near Spillimacheen (Stn. 08NA011)	diurnal variation in water levels indicate ongoing snow melt contributions. Steady decreases in flow through to July 15th
Kootenay River @ Fort Steele (Stn. 08NG065)	shows steady drop in water levels from July 10 to July 14 then a sharp response with a peak in flow on July 15.

5.1.2 Event Magnitude

The July 2012 debris flow magnitude, measured as the volume of material deposited on the fan, was estimated from field observations. Damaged turf grass surfaces on the golf course and mud lines on trees and structures provided a measure of the surface area and depth of inundation by the event.

The area inundated by the debris flow was measured to be about 13.6 ha, and is shown on Figure 4. The delineated area is divided into zones of similar depth and sediment composition. The debris flow composition at the upper part of the fan at the apex was cobble to boulder sized and the depth of material ranged from 1.5 m outside the channel and 3.0 m within the channel. The total area covered by the thickest and coarsest material was measured to be about 1.19 ha (9% of area inundated), representing an approximate volume of 26,800 m^3.

Downslope of this zone the debris flow composition is gravel to cobble sized and has an approximate depth of 0.5 m. The inundated area included the large golf course pond on Hole 12, which was almost completely filled in. Based on a measured pond surface area (2590 m^2) and an average depth between 2.5 and 3 m, the estimated storage capacity of the pond is approximately 7,000 m^3. The area covered by gravel to cobble sized material was measured to be about 1.7 ha (12% of area inundated), representing an approximate volume of 14,200 m^3 (assuming that the pond was already partially filled prior to the event).

Smaller sized material (mud to gravel) extended much further from the fan apex and followed topographic areas of low relief. These areas were affected by flood flow and saturated debris flow afterflow and generally followed small tributary channels, or remnant historic channels that were interpreted from air photo review. The thickness of deposition in this zone ranged from 0.1 to 0.3 m. The area inundated by saturated debris flow and flood flows was measured to be about 10.74 ha (78% of the affected area).

Based on the areas affected and the estimated average depth of deposit, it is estimated that the July 2012 event had a magnitude in the order of 62,000 to 65,000 m^3.

The estimates for Fairmont Creek are within the predicted size range for a basin this size (Van Dine, 1985)

In comparison, Hummingbird Creek (watershed area of 16 km^2) located 230 km north-east experienced a debris flow in 1997 that had an estimated volume of 92,000 m^3 and a peak discharge of 1000 m^3/s (50x the 200 year flow) (Jakob, et al., 2000). Another large debris flow event occurred on Testalinden Creek (area 13.1 km^2), near Oliver, BC in June 2010. An estimated volume of 75,000 to 125,000 m^3 was deposited by a debris flow triggered by the failure of a small earth-filled dam on a headwater lake (Jordan, 2012).

5.1.3 Debris Flow Peak Flow Estimates

Peak flow estimates of the July 2012 event were made using empirical correlations between debris flow magnitude and watershed characteristics. For a supply-unlimited basin (Bovis and Jakob, 1999).

Using the forced vortex equation (Hungr et al., 1984), the mean flow velocity of the July 2012 event was estimated. Based on super-elevated mud lines along a confined section of the mainstem channel upstream of the fan, the July 2012 flow velocity is estimated to have been in the order of 4 to 6 m/s (14 to 22 km/hr).

Using the mean channel width and depth at this location, the estimated peak discharge of the event is judged to be approximately 165 m^3/s. It is noted that Reid Crowther (1994b) estimated the 1:200 yr debris flow discharge to be 120 m^3/s. The peak debris flow discharge estimate is 85x the estimated 200 year flood flow and 57x the instantaneous peak flow (see Section 3.4).

Using the empirical relationship between total volume and peak discharge (after Mizuyama et al., 1992) the July 2012 event on Fairmont Creek falls within the range of non-granitic debris flows.

5.2 OTHER HISTORIC DEBRIS FLOW EVENTS

A debris flow frequency analysis includes documenting other historic events using a variety of information sources. Debris flow frequency was obtained through historic air photo interpretation, anecdotal evidence (published and unpublished), and field investigation.

Historical air photos document watershed conditions at 8 different dates over a period of 67 years, from 1945 to 1991. Within this period, the 1964 and 1991 photos indicate a possible debris flow event. The event visible on the 1964 photos occurred sometime after 1952 and resulted in channel disturbance from tributary confluence through the Marble Canyon reach, but did not result in a significant deposit on the fan.

A debris flow event on the North tributary visible on the 1991 air photos occurred sometime after 1978 (the scale is too small on the 1985 photos to distinguish an event). The debris flow event initiated in the headwater reaches of the tributary, near the water intake site, and resulted in visible channel disturbance onto the upstream portion of the fan. The 1991 air photos indicate that there is a fresh sediment deposit at the channel entrance to the large golf course pond.

These air photo observations are consistent with reports by Boyer (1989) that a rainstorm-triggered flood and debris flow occurred in July 1984 and that the event resulted in deposition on the upstream portion of the Fairmont Creek fan.

On the ground, signs of debris flow in the transport zone include: mud lines, scour marks and impact scars on trees well above the flood limit, boulders much larger than what could be moved by flood flow, and boulder levees or coarse overbank deposits.

On the North tributary, field indicators suggest that the most recent event occurred on the upper reaches about 5 to 6 years ago (est. 2006-2007). Field indicators on the mainstem channel upstream of the tributary confluence were obliterated by the 2012 event. Downstream of the tributary confluence, along Reaches 3 and 2, evidence of multiple debris flows was observed.

Evidence of at least one previous debris flow event, characterized by unsorted matrix-supported stratigraphy, was observed in streambank exposures along Reach 3 and Reach 2. Dating the impact scar on a tree collected from the edge of Fairmont Creek upstream of the Resort corroborates the 1984 event.

The subsurface investigation on the Fairmont Creek fan indicated that, prior to the July 2012 event, at least one other debris flow has occurred in the last 100 years.

To summarize, historic debris flow events on Fairmont Creek include:

- Event of unknown age observed in test pits on fan;
- Sometime between 1952 and 1964;
- July 1984;
- Small debris flow on North tributary est. 2006-2007, did not reach fan; and,
- July 2012.

Based on these findings, the estimated return period for a hazardous debris flow on Fairmont Creek is considered to be approximately 25 years.

6.0 HYDROGEOLOGICAL ASSESSMENT OF RIVERVIEW DRIVE AREA

A hydrogeological assessment of the Riverview Drive area was completed as part of the Fairmont Creek Debris Flow Hazard and Risk Assessment. Some general information regarding the assessment and the overall findings are presented below and a complete report may be found in Appendix C.

6.1 BACKGROUND AND STUDY OBJECTIVE

At the end of August 2012, approximately six weeks after the debris flow event, groundwater seepage was observed in the area of four properties (lots 1 through 4; three of which contained residences) along Riverview Drive, west of Highway 93/95 at the south end of the Riverside Golf Course (see Figure 4). Reportedly, groundwater was observed in the basement of one of the homes (lot 3) and had filled a sunken hot tub in another home (lot 1).

The objective of the hydrogeological assessment was to assess whether or not there was a connection between the discharging groundwater noted in the area of the four properties along Riverview Drive and the July 15, 2012 slide event. If a connection was inferred, short term and long term recommendations would be provided.

6.2 DISCUSSION REGARDING SEEPAGE ISSUES

Detailed subsurface information such as soil types and groundwater levels in the immediate area is limited, and as such, no direct correlation can be made between the July 15 2012 Debris Flow event and the groundwater seepage noted August 31, 2012 in the area of Lots 1 through 4. With the exception of the temporary increase in water levels in the Columbia at the time of the July flow event, there appears to be little evidence of significant surface water ponding in up-gradient areas that would have recharged groundwater and then discharged in the area of the residences six weeks later.

Although the draining of the large golf course pond, located 750 m west, occurred a few days prior to the flooding in the area of the residences, it is our opinion that this did not result in the increase of water levels in the area of the Residences. The released water flowed along the existing creek, discharging into the Columbia River. Although the increased release from the pond may have resulted in some localized increase in surrounding groundwater levels, it is unlikely that they would have contributed to increases in groundwater levels nearest to the Residences.

The most likely cause of the observed groundwater seepage in the area of the Residences is elevated groundwater levels resulting from seasonally high surface water levels in the Columbia River and generally high local and regional groundwater levels.

Although detailed surface water level information is unavailable, it is inferred that surface water levels of the Columbia River were up to 1 m higher in 2012 than in 2011, with the highest water levels recorded in June and July. Although no groundwater level information is available for the area, it is likely that local groundwater levels were also higher in 2012, as groundwater patterns within shallow, unconfined aquifers often follow a subdued and possibly delayed replica of surface water level fluctuations.

The presence of groundwater in the service trench in the late 1980s infers that the historical depth to groundwater in the area of Lots 1 to 4 is shallow and in the order of approximately 1 m below ground surface in the vicinity of the affected Residences.

Fluctuating, shallow groundwater levels in the area of the residences are the likely cause of the groundwater seepage noted in this area. Another possible contributing factor may be fully or partially plugged perforated drainage pipes that do not adequately discharge water, resulting in local increases in the groundwater table.

6.3 RECOMMENDATIONS REGARDING SEEPAGE ISSUES

The following recommendations are provided regarding the hydrogeological assessment:

- Data logger(s) should be installed at several local water supply wells to monitor water levels. It is recommended that the affected property owners enter into discussions with Fairmont Hot Springs Resort regarding the possibility of installing a data logger within the Resort's water supply well located along the Columbia River to the east of the intersection of Highway 93/95 and the Columbia River.
- A surface water level monitoring station should be installed at the Highway 93/95 bridge deck to collect ongoing water level information for the Columbia River.
- Ongoing and regular maintenance is required for the drainage system (catch basins, perforated piping, etc.) associated with road drainage and golf course drainage in the area of the golf course, specifically along Riverview Drive.
- A review of the drainage system surrounding Lots 1 through 4 should be conducted to determine the condition of the existing drainage system along the west side of the lots; specifically, whether or not they are fully or partially plugged and functioning as anticipated. In addition, the discharge point of the 4" drainage pipe that leads from the two catch basins along Riverview Road through Lot 4 should be confirmed (i.e. does it discharge to a gravel pit or to the golf course).

Should the property owners wish to further assess the potential relationship between the Debris Flow event and elevated water levels in the area of Lots 1 through 4, additional subsurface investigations would be required, including the drilling and installation of monitoring wells and in situ hydraulic conductivity testing. The purpose of the drilling and monitoring well installation program would be to confirm underlying soil and groundwater conditions between the area of the Residences and the large pond that collects water from Fairmont Creek. In addition, the elevation of the residence foundations and the high water mark of the Columbia River can be surveyed to assess differences in elevation and aid in water elevation interpretation.

7.0 Debris Flow Hazard and Risk Assessment Results

7.1 DEBRIS FLOW INITIATION POTENTIAL

The debris flow initiation potential on Fairmont Creek is a function of the watershed characteristics, the availability of sediment and/or debris within the channel, and the potential for a triggering event.

7.1.1 Sediment Supply

The field investigation found that headwater reaches above approximately 1500 m elevation are bedrock-dominated. Sediment supply along these upper reaches is primarily coarse rock fall debris with a high hydraulic conductivity. The reaches are, therefore, considered to be supply-limited; these reaches require some interval of time for the replenishment of in-stream material between debris flow events.

The middle to lower reaches of Fairmont Creek, below 1500 m elevation, have numerous sediment sources constituting an almost continuous sediment supply. Numerous small landslides, weathered phyllite bedrock exposures, streambanks incised within unconsolidated Quaternary deposits and previous debris flow deposits, and channel bedload deposits represent an unlimited sediment supply. With such conditions, debris flows may occur whenever a critical hydroclimatic threshold is reached.

Debris entrainment is the destabilization and transport of unconsolidated material stored within the channel. Entrainment is considered to be an important factor for debris flow initiation potential on Fairmont Creek. Within-channel destabilization occurs by the forces imposed by overriding water flow on channel gradients exceeding 10^{o} (18%). On Fairmont Creek, this threshold gradient occurs along both tributaries above the confluence up to approximately 1800 m elevation, above which sediment sources are coarse rock fall and avalanche deposits.

Along the mainstem channel and north tributary, the length of stream channel considered to be supply-unlimited and thus capable of generating a debris flow was measured. The depth of material available for transport within the channel was estimated to determine a yield rate. Estimation is difficult and subjective along reaches lacking a shallow, firm substrate. These two measures were used to estimate the potential volume of material (magnitude) available for a debris flow.

The estimated debris flow magnitude is based on a channel length of 4.8 km, and an estimated yield rate of 15 m^3/m. This results in a magnitude of 72,000 m^3. The mobilization of material stored within and along the channel may account for the small difference between this estimate and that which was experienced in July 2012 (65,000 m^3).

The ability for this material to be mobilized and transported down to the fan area is dependent upon channel conditions (gradient and degree of confinement) and the nature of the triggering event.

7.1.2 Potential Triggering Events

Debris flows may be initiated by landslides entering the channel, the sudden failure of temporary landslide or debris jams, or by progressive destabilization of the material stored in the channel by high stream flows.

Landslides entering the creek channel at an oblique angle may transform into a debris flow such as at Hummingbird Creek in 1997 (Jakob, et al., 2000). Debris flows may also occur with sudden failure of a temporary dam, formed by debris jam or a landslide-produced dam. The Testalinden Creek debris flow in 2010 occurred due to a failure of a constructed earth dam. Debris flows may also occur when stream flows are sufficiently large enough to progressively destabilize the bedload material, transforming from a debris flood to a debris flow as it progresses downstream.

Although numerous small landslides and sideslope failures were observed along the middle reaches of the Fairmont Creek and the north tributary, no single landslide appears to have initiated the July 2012 debris flow. Despite some news reports and anecdotal evidence suggesting temporary dam failure, there was no evidence of a temporary dam. The 2012 debris flow initiated in the headwaters of the mainstem channel. Along the channel, based on the downstream alignment of abundant woody debris in the channel, it is likely that any previous debris jams has been removed. Rather than any single trigger factor, the 2012 debris flow is judged to have initiated by progressive destabilization of abundant bedload in the mainstem channel by a locally-intense convective rainstorm at a time when soils were already saturated from an unusually wet spring. Photos taken by helicopter immediately after the event indicate only small patches of snow remaining in the headwater reaches.

Unstable and potentially unstable areas in the Fairmont Creek watershed occur on side slopes above the stream. Although unlikely to trigger a debris flow event independently, landslides entering the channel may form temporary dams that could generate a debris flow upon sudden failure.

With respect to potential for future debris flow initiation on Fairmont Creek, the same triggering factors are present now as they were prior to the July 2012 event. Although the 2012 debris flow scoured down to bedrock along the mainstem channel, there remain thick deposits of loose unconsolidated material within and along the channel banks. It is also possible that, due to the abundance of loose in-stream bedload, the critical hydroclimatic threshold required to initiate a future debris flow may now be lower than before (i.e. the current channel conditions may be more vulnerable to debris flow initiation and a lower intensity rainfall event may be sufficient to mobilize this material in the short term before vegetation becomes re-established).

7.2 MAGNITUDE AND FREQUENCY OF FUTURE EVENTS

The estimated magnitude and frequency of future debris flow events forms the basis for the debris flow hazard assessment. The investigation of Fairmont Creek has determined that the estimated return period for a hazardous debris flow is about 25 years. Events occurring at this frequency are judged to affect the mainstem channel and deposition will quite likely terminate upon reaching the fan apex.

Due to the destabilized nature of the middle reaches of Fairmont Creek, there may be an increase in the frequency of small events and in the magnitude of medium to large events.

That said, debris flows that affect large areas are less frequent and significant inundation of areas across the fan, as occurred in July 2012, is considered to be a much rarer event with a low likelihood, or probability of occurrence. We consider that the July 2012 event, with an estimated magnitude of 65,000 m^3, approximates the design event on Fairmont Creek with an estimated return period of approximately 475 years (i.e. less than a 10% probability of occurrence in 50 years).

These results are roughly consistent with previous design flow estimates. Design parameters for the previously constructed flood mitigation works on Fairmont Creek were based on a 1 in 200 year return period debris flow and a magnitude of 45,000 m^3 (Reid Crowther & Partners Ltd., 1994b).

7.3 RISK ANALYSIS RESULTS

7.3.1 Elements at Risk

The elements at risk from a debris flow event on Fairmont Creek are situated on the fan that is delineated on Figure 5 and include the following:

- Approximately 16 multi-family dwellings and 88 single-family dwellings;
- Approximately 350 people, based on the number of people evacuated from the area in July 2012;
- Mountainside Golf Course and associated infrastructure;
- Community Recreation Centre and associated facilities;
- Community Fire Hall;
- Highway 93/95; and
- The only access to the Fairmont Hot Springs Resort RV Park.

7.3.2 Risk Analysis and Mapping

The results of the risk analysis provide an indication of predicted debris flow behaviour and predicted impacts across the fan. The debris flow risk assessment results are shown on the Risk Map, provided as Figure 5. The risk zones delineated on the map define zones of equal debris flow composition, depth and velocity. The results indicate that a large part of the fan is susceptible to debris flow. Each zone also has an associated debris flow return period and is described as follows:

High Risk Areas

High risk areas are classified as occurring within the direct impact zone of a debris flow. This zone is judged to include the main channel from approximately 500 m upstream of the Resort, through Marble Canyon and onto the upper part of the fan area. The upper fan area includes part of the Mountainside Golf Course, numerous townhomes, and the community recreation centre.

Moderate Risk Areas

Moderate risk areas, or the indirect impact zone, includes areas occurring at the mid to lower parts of the fan including the areas along Fairmont Creek channel (and ancient remnant channels). Topographic details affect the area classified as moderate hazard, as debris flow surges follow the slope.

Areas affected by a 1 in 10 000 year event include the moderate and high risk zones shown on the maps. The area may be subject to variable debris flow impact, depending on the flow path. Because Fairmont Creek is vulnerable to avulsion at or slightly above the fan apex, areas affected by future debris flow events include potential alternative flow paths.

Low Risk Areas

The low risk zone, or flood zone, includes area that may potentially experience flooding due to debris flow. These areas are almost entirely influenced by topography and are greatly affected by infrastructure such as culverts and ditches. For this reason drainage structure maintenance through the residential portion of Fairmont Hot Springs is considered important.

7.4 CLIMATE CHANGE AND LAND SURFACE CHANGE CONSIDERATIONS

Note that the risk map represents a snapshot in time, based on conditions observed in 2012. Over time, factors such as channel scour, smaller debris flows, channel aggradation and development that alters the fan topography (roads, structures, culverts, landscaping) can affect the predicted risk zones. Additionally, predicted climate change can influence the debris flow hazard potential.

Projected climate change in southern British Columbia will result in drier summers and wetter winters (Pike, *et al.*, 2010). For a snow-melt dominated watershed such as Fairmont Creek, this will result in the following:

- a shorter snow accumulation season with less snow stored over the winter;
- more winter precipitation falling as rain (and snow at high elevations);
- more rapid melt of the seasonal snowpack with increases in extreme spring flood flows in order of 10% (APEGBC, 2012);
- an increase in rain-dominated floods due to increased summer storm precipitation intensity (Schnorbus, et al., 2010) and spring floods due to more snow at high elevations;
- a shift in timing and magnitude of annual peak flows with an earlier start to the spring freshet; and
- a lengthening of the low flow season in the late-summer or early-fall.

The net result of the above factors is that runoff and flood flows will change for Fairmont Creek through the 21st century. These potential changes in runoff are considered in the hazard assessment and should be considered in the design of mitigation measures.

8.0 DEBRIS FLOW RISK MITIGATION OPTIONS

The results of the debris flow hazard and risk assessment indicate that portions of the Fairmont Creek fan are at risk from damaging and potentially life-threatening debris flow events. Based on the results of the risk assessment, options for debris flow risk mitigation are identified below.

8.1 DEBRIS FLOW MITIGATION APPROACH AND GENERAL COMMENTS

Strategies to mitigate debris flow risk fall into two categories: active measures to mitigate the hazard, and passive measures to mitigate the potential for damage through avoidance (Huebl and Fiebiger, 2005). The most effective protection strategy will combine active and passive measures to form an integrated mitigation approach.

Passive measures include land use planning tools (i.e. planning setbacks and non-developable areas), and are most effective when applied to undeveloped areas.

In an area such as Fairmont Hot Springs, where the fan area is largely developed, passive measures are used, where possible, to complement active measures that offer protection in high risk areas.

Because of the availability of sediment for future debris flow events on Fairmont Creek, it is judged that there are few practical options available to mitigate or alter the probability of debris flow occurrence. However, watershed management and land use planning measures may direct activities in the watershed with an objective to safely manage runoff, reduce surface erosion and increase slope stability. A watershed management plan should be developed with the intent of minimizing the availability of sediment to Fairmont Creek. This plan should be considered a long term management tool which could have a future impact on the risk rating of the fan. No cost estimate has been produced for this plan within this report

Concepts for debris flow mitigation were reviewed in available literature (Van Dine, 1996) (Huebl and Fiebiger, 2005). Several alternatives for active mitigation measures, including those that reduce peak flow discharge, those that deflect deposition, and those that control deposition by containment were reviewed. For example, the peak discharge of an event may be reduced by channel widening. Active measures to deflect deposition are not feasible for Fairmont Creek, as there are no low consequence areas available as alternate deposition zones. Debris flow deposition may be temporarily or permanently contained through the use of a debris flow barrier.

The debris flow mitigation approach, presented here, offers a variety of active and passive measures to reduce risk of a design event to a tolerable level. The location of each option discussed below is shown on Figure 6. Mitigation options are conceptual and estimated costs are to a preliminary level, intended for comparison and discussion purposes and for the purpose of identifying funding opportunities. Please note that none of the estimated costs include any provision for land acquisition as the land ownership situations and potential transfer costs are unknown.

Mitigation options are presented with the intent of working together as an integrated system, and not independent of one another. Upstream measures will mitigate some risk, with the remainder to be accommodated by downstream measures. Thus, a cumulative reduction of risk to areas on the fan is achieved. Thus, if portions of the mitigation measures are not completed, the risk on the fan will be higher than was intended with the conceptual mitigation plan. If a full set of complementary measures is unable to be funded, a priority of measures can be assembled to attempt to maximize the risk reduction with the available funds.

Conceptual level measures, presented here, will require additional work prior to implementation. Additional work includes detailed design, including any additional analysis for design, surveying and preparation of engineering drawings for tender documents. Cost estimates must be refined based on the detailed design work and when work sequencing is established. Cost efficiencies on the general costs component (i.e. equipment mob/demob, bonding, and environmental permitting) may be achieved if measures are completed at the same time.

8.2 INCREASE CHANNEL CAPACITY ABOVE FAIRMONT HOT SPRINGS RESORT

In July 2012, debris flow deposition filled in the channel upstream of the FHSR (Reach 3). The 900 mm culvert in the road accessing the RV Park became plugged and then acted as a partial detention structure, causing infill of sediment behind and upstream of the road. After the event, sediment and organic debris overtopping the existing Hot Springs source wells was removed and material was added used to an existing streamside berm. The berm, reaching heights of 3 m, extends almost 500 m upstream to a point just downstream of the old water intake.

Currently, the berm reduces the available channel width for Fairmont Creek and constricts flow. In the event of a moderate to large sized debris flow, the unconsolidated, gravels and cobbles comprising the berm material would be mobilized, increasing the bedload of the event. The existing channel constriction would also result in an increased flow velocity along this length, increasing the risk to downstream areas on the fan.

To reduce the risk to downstream areas, active measures to reduce the peak flow of future debris flow events are recommended. A reduction in peak flow may be accomplished by increasing the channel capacity in the reach above the FHSR RV Park access road. The channel capacity may be increased by pulling back or removing the existing berm. Pull back/removal should be completed upstream from the RV Park access road for an approximate distance of 500 m. A short section of berm immediately above the road should remain in place to protect the Hot Springs well source. Consideration should be given to armouring this remaining berm to reduce the potential of it being re-mobilized.

Approximate costs, shown below, are based on the assumption that approximately 9000 m^3 of material will need to be removed from the channel. End haul costs assume a local site is available for material at no cost. Maintenance, comprising of material clean out (and possibly end haul), to ensure that the capacity of the channel is maintained is estimated to be required every two years. Environmental permitting may be required every time work is scheduled to occur.

Table 8: Estimated Mitigation Costs to Increase Channel Capacity Upstream FHSR

Design and Construction	Unit	Quantity	Unit Cost	Total
General costs (bonding/mob/permits/ environmental)	l.s.	1	$20,000	$20,000
Excavate, remove berm, end haul material	cu. m	9000	$16	$144,000
Reconstruct channel	excav days	14	$1,600	$22,400
Engineering & Management			15%	$27,960
Contingency			30%	$55,920
		TOTAL		$260,280
Annual Maintenance				
Material clean out		every 2 years	$25,000	$12,500
		TOTAL	$25,000	$12,500

8.3 PROTECT THE RV PARK ACCESS ROAD

The only access road to the RV Park was washed out in July 2012, stranding visitors and separating family members until temporary access was reinstated. At the time of the event, the access road descended from the crossing to the RV Park, allowing water and debris to flow down the road towards the RV Park.

Although a larger (1600 mm) culvert was installed after the event, the capacity of the culvert and the rock-lined channel upstream is considered to be insufficient to convey a similar sized debris flow event. Further mitigation measures to reduce risk are recommended.

To protect the access road from future damage and to maintain access during a future event, one option is to reconstruct the crossing as a full-spanning bridge structure that is elevated from the creek bottom. This measure would also reduce the potential of material entering the RV Park area.

Alternatively, the road may be designed to detain small debris flow events, and some of the larger-sized material conveyed by large events. The road crossing could be designed to be an open barrier system with a large culvert protected by a trash rack, which would retain large material but encourage dewatering and some deposition. Large events would, for the most part, pass overtop of the road, necessitating post-event clean-up to re-establish access.

If a full-spanning bridge structure is not built then it is also recommended that the road grade into the RV Park be realigned so that the road climbs slightly from the crossing. Constructing a grade break would prevent flows from entering into the RV Park area.

Estimated costs for the construction and maintenance of each option are shown below.

Table 9: Estimated Costs to Protect RV Access Road – Option A Bridge

Design and Construction	Unit	Quantity	Unit Cost	Total
General costs (bonding/mob/permits/ environmental)	l.s.	1	$15,000	$15,000
Construct bridge approaches	l.s.	1	$18,000	$18,000
Bridge structure	l.s.	1	$400,000	$400,000
Engineering & Management			15%	$64,950
Contingency			30%	$129,900
		TOTAL		$627,850

Annual Maintenance

Inspection and maintenance	l.s.	1	$2,000	$2,000
		TOTAL	$2,000	$2,000

Table 10: Estimated Costs to Protect RV Access Road – Option B Culvert

Design and Construction	Unit	Quantity	Unit Cost	Total
General costs (bonding/mob/permits/ environmental)	l.s.	1	$18,000	$18,000
Remove existing culvert	excav days	4	$1,600	$6,400
Rebuild road, approaches	l.s.	1	$18,000	$18,000
Install 1 lg and 2 sm culverts	l.s.	3	$3,000	$9,000
Install debris barrier	l.s.	1	$8,000	$8,000
Surface road (concrete)	sq. m	400	$150	$60,000
Engineering & Management			15%	$17,910
Contingency			30%	$35,820
		TOTAL		$174,730

Annual Maintenance

Inspection and maintenance		1	$8,000	$8,000
Replace trash rack components		every 5 years	$10,000	$2,000
		TOTAL	$18,000	$10,000

8.4 INCREASE CHANNEL CAPACITY IN MARBLE CANYON AND COMMUNICATE RISK TO TRAIL USERS

Mitigative measures downstream of the Hot Springs Resort within the Marble Canyon (Reach 2) would reduce the risk to portions of the upper fan and to trail users.

Similar to impacts along Reach 3, the channel was filled by the July 2012 debris flow. After the event, the channel was excavated to improve stability and to restore the channel to its original condition. Rather than remove the accumulated material, the new channel was excavated within the debris flow deposits and material was placed along the left side of the channel. The berm of material acts to constrict flow along this reach and in the event of a debris flow, the peak discharge would not diminish significantly along the confined channel. Therefore, it is recommended that the berm along Reach 2 be pulled back or removed to reduce the peak flow velocity and to allow for increased flow conveyance.

In addition to this measure, it is recommended that if the hiking trail through the canyon is re-established, and that signage communicating the debris flow / flood risk be installed. Points of egress (evacuation) and/or areas of refuge should also be provided along the trail.

Estimated costs for the mitigation work, shown below, are based on selective excavation work along the reach. Detailed survey work is required to direct excavation activities and to located suitable refuge locations along the trail.

Table 11: Estimated Costs to Increase Channel Capacity through Marble Canyon

Design and Construction	Unit	Quantity	Unit Cost	Total
General costs (bonding/mob/permits/ environmental)	l.s.	1	$10,000	$10,000
Excavate and modify sections of channel	excav days	4	$1,600	$6,400
Reestablish trail	excav days	4	$1,000	$4,000
Install signage	l.s.	4	$1,000	$4,000
Establish refuge areas	l.s.	4	$2,500	$10,000
Engineering & Management			15%	$5,160
Contingency			30%	$10,320
		TOTAL		$49,880

Annual Maintenance

Inspection and maintenance		1	$2,000	$2,000
		TOTAL	$2,000	$2,000

8.5 INSTALL A DEBRIS FLOW BARRIER WITHIN MARBLE CANYON

A debris flow barrier is an open barrier structure designed to allow smaller sized material to pass, while retaining large boulders having a high destructive potential. Design considerations focus on the volume of material to be detained. For Fairmont Creek, the design debris flow event has a magnitude of 75,000 m^3.

A debris flow barrier, positioned at the downstream end of Marble Canyon, upstream of the Fairmont Creek fan, would work together with other mitigative measures to reduce the risk to downstream properties. Marble Canyon provides a bedrock-confined stream reach within which deposition may be accommodated. Two barrier options have been considered; a traditional debris basin such as what may be found along the Sea to Ski Highway (Hwy 99), and a commercially available flexible flow net barrier.

Option 1 - Debris Basin

A traditional debris flow basin includes a rigid barrier (such as concrete), above which the debris flow material is retained. The structure includes a grated outlet structure that is designed to allow passage of water and smaller-sized material. Rigid barriers are costly to construct due to foundation requirements and may be damaged by larger rock fragments.

Based on the topography of the Marble Canyon, retention of a full 75,000 m^3 debris flow would require considerable height/area and is considered to be impractical as a single structure.

Option 2 – Debris Flow Net Barrier

A net barrier, such as the type manufactured by Geobrugg, is a flexible net comprised of interconnected steel rings that is designed for dynamic expansion and to withstand impact forces. The net barrier will retain debris and dewater the flow. The net barrier is fastened to bedrock on either side and is stretched across the entire width of the canyon. The height of the net depends on the design flow but could be as high as 4 m.

The debris flow net barrier is a flexible structure built to quickly diminish the energy of the debris flow front and retain debris. The bottom of the barrier is open to allow natural passage of creek flow, while the top of the barrier has a wing-shaped arrangement and abrasion protection to handle overtopping after an event.

A net barrier is less expensive than a debris basin and has a less invasive method of construction. The net barrier may be considered more aesthetically palatable as it blends into landscape more easily than a large concrete barrier.

A single net barrier is unlikely to be able to withstand the design event (65,000 m^3). Thus, more detailed design work is required to determine whether multiple barriers built in a sequence along the canyon are feasible. Estimated costs for the debris flow barrier are based on a single barrier, as this structure, together with other downstream structures, may sufficiently reduce risk to acceptable levels.

Associated maintenance requirements for the debris flow net barrier include periodic removal of retained debris. Machine access to remove debris on a periodic basis is required. Based on the abundance of material available for transport, at least some excavation is assumed on a bi-annual frequency. Damaged to the net, or anchor components, incurred by larger sized material, may be required on a less frequent basis but should be included in annual maintenance cost estimates.

The estimated cost for a multiple (2x) debris flow net barrier, provided below, is based on 2x40 lineal metres, which is more than the available width but allows for additional contingency based on the conceptual nature of the foundation design and installation requirements.

Table 12: Estimated Costs for a Multiple (2x) Debris Flow Net Barrier

Design and Construction	Unit	Quantity	Unit Cost	Total
General costs (bonding/mob/permits/ environmental)	l.s.	1	$30,000	$30,000
Geobrugg DF Barrier System	lin. M	40	$6,000	$240,000
Geobrugg DF Barrier System	lin. M	40	$6,000	$240,000
Construction earth works	excav days	20	$1,600	$32,000
Engineering & Management			15%	$81,300
Contingency			30%	$162,600
		TOTAL		$785,900

Annual Maintenance

Material clean out		every 2 years	$15,000	$7,500
Barrier components		every 5 years	$35,000	$7,000
		TOTAL	$50,000	$14,500

8.6 RESTORE THE CHANNEL AND FLOOD MITIGATION STRUCTURE UPSTREAM OF THE MOUNTAINSIDE GOLF COURSE WITHIN THE RDEK SERVICE AREA

Flood protection and training works at the top of the fan, upstream of the Mountainside Golf Course, were built to mitigate hazard to homes situated above the right bank of Fairmont Creek.

An 85 m long section riprap bank protection was constructed over existing log crib wall in 2002 to mitigate hazards to proposed residential development. The structure is situated along the right bank of Fairmont Creek in front of the Marble Canyon condos, just upstream of the Mountainside Golf Course. The structure is registered to the RDEK as GPS No. 52 in the Provincial Flood Protection Structures database. The corresponding RDEK Service Area is confined to the 85 m long section.

Based on as-constructed drawings the structure was comprised of riprap with an average nominal size (D50) of 500 mm (200 kg) and was placed at a slope of 2H:1V or shallower (McElhanney Consulting Services, 2002).

The structure design was based on a debris flow design event having a 1 in 200 year return period and a magnitude of 45,000 m^3. The report indicates that with the training works, the average depth of deposition across the fan area downstream would be approximately 0.5 m, with a 2 to 4 m depth of deposition at the top of the fan near the golf course and lesser amounts reaching the golf course irrigation pond. The report indicates that the pattern of deposition across the fan would ultimately be controlled by depositional patterns and topography.

In July 2012, the section of Fairmont Creek containing the structure was entirely overwhelmed and the existing channel was buried, leaving the protective structure in a non-functioning condition. Based on the results of this assessment, it is judged that the works were overwhelmed by an event exceeding that for which it was designed. The protective structure offered at least some protection and deflected debris as it was designed to do. Siting of the townhomes impacted by the July 2012 event was likely carried out assuming that overtopping of the mitigative structure would not occur. In retrospect, the observed inundation area and composition of the July 2012 event was close to what was predicted in 1994, before the structure was built.

When the July 2012 debris flow infilled Fairmont Creek and avulsed to a new channel upstream of the golf course, the protective capacity of the existing mitigation works was compromised. As such, the flood mitigation structure no longer functions to protect the condos adjacent to the stream.

It is, therefore, recommended that the original channel be restored and the flood mitigation structure rebuilt to mitigate risk on the upper fan area. It is also recommended that the current channel remain as an overflow channel, thus increasing the width of channel available for debris flow detention and sediment deposition. Design consideration for the mitigation structure will depend on what is put into place upstream. Mitigative works above FHSR and within the Marble Canyon will have an effect on debris flow peak flow velocity and debris volumes realized at this location.

It is understood that current Emergency Management BC funding has provided for the reconstruction of the original flood mitigation structure and that this work is currently in the construction tendering stage. Funding provides for the restoration of the structure but not necessarily enhancement. Assuming that the structure is rebuilt to withstand a 45,000 m^3 event, then upstream measures are required to reduce the 65,000 m^3 design event to this magnitude (a 30% reduction in peak flow magnitude) otherwise it will be overwhelmed.

Estimated costs to complete the works at this location were prepared by Kerr Wood Leidal Associates (KWL) (October 2012). KWL completed an assessment of the area and determined that approximately 8,000 m^3 of material would need to be removed to restore the channel and expose the protective structure for inspection. KWL also estimates that the structure was sufficiently damaged to require full reconstruction. Estimated costs for the removal of material and reconstruction of the rip rap mitigation structure are based on the KWL estimates and are summarized below.

Table 13: Estimated Costs to Restore Channel and Rip Rap Dyke at Marble Canyon

Design and Construction	Unit	Quantity	Unit Cost	Total
General costs (bonding/mob/permits/ environmental)	l.s.	1	$20,000	$20,000
Excavate channel	cu. M	8000	$13	$104,000
Supply rip rap	tonnes	1500	$65	$97,500
Place rip rap	tonnes	1500	$8	$12,000
Repairs to storm outfall	lin. M	4	$500	$2,000
Engineering & Management			15%	$35,325
Contingency			30%	$70,650
		TOTAL		$321,475

Annual Maintenance

Material clean out		every 2 years	$5,000	$2,500
Riprap components		every 5 years	$25,000	$5,000
		TOTAL	$30,000	$7,500

8.7 INCREASE CHANNEL CAPACITY ACROSS MOUNTAINSIDE GOLF COURSE

After the July 2012 event, Fairmont Creek was reconstructed from the cart bridge crossing, across the 16th fairway of the Mountainside Golf Course, and downstream to the townhomes just upstream of the large pond. It is judged that the capacity of the rock-lined channel is insufficient to convey the design event debris flow and would be easily overwhelmed. In addition, the sub-rounded rock armour is more easily mobilized and displaced by high flows. Flows overtopping the channel would be directed onto the golf course and towards the community recreation centre, affecting areas similar to those affecting in July 2012.

To mitigate the risk to residential areas on the fan, it is recommended that the capacity of the channel downstream to the golf course pond be increased. If some overtopping may be tolerated, debris flow material could be directed onto the golf course and away from inhabited areas. Construction of a low (0.5-0.75 m high) berm, constructed upslope of the community recreation centre along the edge of the golf course would serve to mitigate potential risk to the centre.

The estimated costs to reconstruction the channel through the golf course are provided below. Bi-annual maintenance to removed accumulated material from within the channel is assumed.

Table 14: Estimated Costs to Increase Channel Capacity Across Mountainside Golf Course

Design and Construction	Unit	Quantity	Unit Cost	Total
General costs (bonding/mob/permits/ environmental)	l.s.	1	$10,000	$10,000
Construction earth works	lin. M	250	$500	$125,000
Supply rip rap	tonnes	2000	$65	$130,000
Place rip rap	tonnes	2000	$8	$16,000
Engineering & Management			15%	$42,150
Contingency			30%	$84,300
		TOTAL		$407,450

Annual Maintenance

Material clean out		every 2 years	$5,000	$2,500
		TOTAL	$5,000	$2,500

8.8 MAINTAIN GOLF COURSE POND AS A FLOOD CONTROL STRUCTURE

Although it was not likely intended as a flood control structure, the large golf course pond on hole #12 of the Mountainside Golf Course did provide flood protection to residences located downslope and downstream on the fan during the July 2012 event by effectively detaining debris flow material and reducing the energy in the flow. Currently, upstream of the pond, Fairmont Creek remains in a somewhat unstable condition, with freshly deposited material within the channel and along the banks. This material is easily mobilized by future flows (whether generated by precipitation or by the regular flushing of the FHSR pools) and will continue to infill the pond over the short-term.

To ensure that the pond plays an ongoing role in mitigating downslope risk, it is recommended that the pond capacity for debris detention be maintained. It is recommended that the entire creek corridor, from Marble Canyon to the pond be established as a provincially-registered flood control structure with established roles and responsibilities for inspection and maintenance.

By November 2012, FHRS had largely completed the excavation of the pond, so estimated costs to maintain the pond as a flood control structure are based on a periodic inspection and monitoring of accumulated material within the pond. Inspections may be completed every year just prior to the spring freshet by measuring pond depth across two transects of the pond. Estimated costs to establish the pond as a flood control structure, includes a one-time dam safety inspection of the concrete weir structure at the outlet. Annual inspection and maintenance costs are estimated as shown below. Environmental permitting requirements will need to be negotiated as an ongoing in-stream activity and should be included with other work on Fairmont Creek.

Table 15: Estimated Costs for Inspection and Maintenance of Golf Course Pond as a Flood Control Structure

Design and Construction	Unit	Quantity	Unit Cost	Total
Complete dam safety inspection	l.s.	1	$10,000	$10,000
		TOTAL		$10,000
Annual Maintenance				
Inspection and monitoring		every year	$2,500	$2,500
Material clean out		every 5 years	$8,000	$1,600
		TOTAL	$10,500	$4,100

8.9 INSPECT AND MAINTAIN DRAINAGE STRUCTURES ON THE FAN

Mitigative measures to reduce the level of impact due to flooding and saturated debris flow to residential areas on the Fairmont Creek fan are recommended.

In July 2012, flooding impacts occurred in areas where culverts were overwhelmed or plugged. Debris and/or mineral deposits observed in the culverts reduced their capacity. A report prepared by the Fairmont Hot Springs Community Association (October 2012) suggests that lack of maintenance of drainage structures affected the manner in which areas were inundated during the July 2012 event. The report provides a comprehensive inventory of drainage structures on the fan.

It is noted that maintenance of culverts located on private land are the responsibility of the land owner. Inspection and maintenance of culverts owned by MoTI are the responsibility of the roads contractor. Regardless of jurisdiction, it is recommended that the Fairmont Creek channel and all other drainage structures on the fan be regularly monitored to ensure that culvert entrances are not blocked and the culverts are performing as intended.

8.10 LAND USE PLANNING

There are limited opportunities for land use planning as a risk mitigation tool on the Fairmont Creek fan as it is already developed. Land use planning measures could, however, be considered in conjunction with the active measures listed above to minimize risk. These include:

- Establish a Development Permit (DP) Area on the Fairmont Creek fan (as shown on Figure 5). This is consistent with the requirements associated with development in a Non-Standard Flooding and Erosion Area. In the DP area, flood hazard assessment reports should be completed for new development. The assessment reports would provide comments on siting and provide site specific recommendations for flood proofing such that the risk of increasing hazard to neighbouring properties is reduced;
- Consider the need for land acquisition requirements associated with debris flow mitigation structures. This will include provision of easements for maintenance access.
- New roads, major excavations and/or larger-scale land development proposals on the fan area should be reviewed with the debris flow hazard in mind and, if necessary, modify the map if the approved works alter the hazard zone boundaries.
- Require terrain hazard assessments with a focus on slope stability for all new land development proposals within the watershed including, but not necessarily limited to, water intake structures or water lines, access roads, recreational hiking or ski trails, and bridge crossings. New bridges or trail crossings are at risk of washout and/or damage from floods or debris flows and should be designed such that the natural creek process is not disturbed.

8.11 OTHER RECOMMENDATIONS

Other recommendations that arise from the assessment include:

- Install a remotely-monitored real-time rainfall gauge at the FHSR ski area to measure precipitation amounts at higher elevations. This may be used to monitor precipitation, determine rainfall intensity, and later used to develop rainfall thresholds with the intent of developing an advance warning system; and,
- Periodic inspection of the Fairmont Creek channel, and north tributary channel, by a qualified professional to check for slope instability, sediment accumulation/jams, blockages that could cause channel avulsion, channel aggradation/reduced channel capacity, and effects of upslope development or condition changes (logging, wildfire). An overview helicopter flight, with video, is recommended as a means of documenting channel conditions for future review.

8.12 SUMMARY OF MITIGATION MEASURES AND ESTIMATED COSTS

The results of the debris flow hazard and risk assessment indicate that portions of the Fairmont Creek fan are at risk from damaging and potentially life-threatening debris flow events. Thus, a variety of mitigation measures are identified to reduce the level of debris flow risk to developed areas on the Fairmont Creek fan.

An integrated system of active measures to mitigate the debris flow peak flow velocities and debris deposition across the fan are conceptualized and preliminary costs for construction and maintenance are presented. To summarize, debris flow mitigation measures on Fairmont Creek are shown on Figure 6 and may include:

- Increase channel capacity upstream of FHSR by widening the channel;
- Protecting the RV Park access road by constructing a bridge, or modifying the culvert crossing to detain small debris flows;
- Increase the channel capacity through Marble Canyon and install safety signage and refuge areas along the walking trail;
- Construct a debris flow barrier system in Marble Canyon;
- Restore the channel and rip rap dyke at Marble Canyon;
- Reconstruct the channel through the golf course that connect Marble Canyon with the golf course pond;
- Maintain the golf course pond as a flood control structure;
- Complete a Watershed Management Plan;
- Install a rainfall gauge at FHSR ski resort; and,
- Conduct periodic (5 year) inspection of Fairmont Creek and tributary channel.

Combined, the identified measures would work together to ensure that each functions properly and provides the desired level of safety. The engineering design of downstream measures, for example, is dependant upon whether upstream measures are in place. However, given that it is unlikely that all measures would be constructed at the same time, a phased approach is recommended. The phased approach, shown in Table 16 below, divides measures into those within and upstream of Marble Canyon, and those measures downstream of Marble Canyon on the Fairmont Creek fan. It is recommended that the first phase of the mitigation program include the reconstructed channel and riprap dyke, the channel connecting this with the golf course pond, and the pond itself. Work to reconstruct the dyke is already in progress and, when completed, will mitigate a 45,000 m^3 event. Channel improvements between the reconstructed channel and the golf course pond are considered priority and should be included in the first phase of mitigation work.

Given that the reconstructed dyke and channel will eventually offer some level of protection from smaller debris flow events, the second phase of work will be to detain approximately 20,000 m^3 of debris and reduce peak flows such that the downstream measures are not overwhelmed. Channel improvements above the resort and at the RV Park road crossing would sufficiently reduce the risk to a desirable level and should be considered as a second phase of work.

It is recommended that the integrated protection system of measures and all associated maintenance access corridors be established as a RDEK service area and be provincially registered as a flood control structure. Roles and responsibilities will be established for the long term.

A summary of preliminary costs, provided in the Table 16 below, indicates that the entire system of protective measures on Fairmont Creek may cost between $2.0 and $2.5 million to construct. Phase 1 of the program, downstream of Marble Canyon, will cost approximately $740,000 (less the $322,000 already committed to the reconstruction of the dyke). Phase 2 of the work program, within and upstream of Marble Canyon, will cost between $1.3 and $1.7 million depending on whether a bridge is constructed at the RV Park access road. If it is possible to design a mitigation measure above Marble Canyon that sufficiently reduces the debris flow hazard then the debris flow barrier ($780,000) would not be required. Annual maintenance costs for all measures will be between $45,000 and $53,000, but if completed together will be significantly less (est. $30,000 to $35,000) due to cost efficiencies.

Table 16: Summary of Recommended Phasing and Preliminary Construction and Maintenance Costs for Debris Flow Mitigation on Fairmont Creek

	Recom-mended Phasing	Mitigation Measure	Construction Costs	Maintenance Costs
Within or above Marble Canyon	2	Increase channel capacity upstream FHSR	$270,280	$12,500
	2	Protect RV Access Road - Option A (Bridge)	$627,850	$2,000
	2	Protect RV Access Road - Option B (Culvert)	$174,730	$10,000
	2	Increase channel capacity through Marble Canyon and Install Signage/Refuge	$49,880	$2,000
	2	Debris Flow Barrier	$785,900	$14,500
Below Marble Canyon	1	Restore Channel and Riprap Dyke at Marble Canyon (from KWL, 2012)	$321,475	$7,500
	1	Reconstruct Channel through Golf Course	$407,450	$2,500
	1	Maintain Pond as a Flood Control Structure	$10,000	$4,100
	1	Inspect channel and drainage structures on fan	n/a	n/a
	3	Complete a Watershed Management Plan	n/a	n/a
	5	Install a rainfall gauge at FHSR ski resort	n/a	n/a
	4	Conduct periodic (5 year) inspection of Fairmont Creek and tributary channel.	n/a	n/a
		Total (with bridge)	$2,472,835	$45,100
		Total (with culvert)	$2,019,715	$53,100

9.0 SUMMARY AND CONCLUSIONS

In summary, the results of the Fairmont Creek debris flow hazard and risk assessment have determined that:

- The Fairmont Creek is a debris-flow prone watershed;
- Potentially hazardous debris flows occur on average every 25 years or so but do not necessarily extend down the fan past Marble Canyon;
- The July 2012 Debris Flow event was the largest debris flow event on record for Fairmont Creek and had an estimated magnitude of 65,000 m^3 and an estimated return period of approximately 500 years;

- The July 2012 event formed the basis for the hazard and risk assessment and areas on the fan were mapped according to the composition and depth of the deposit.
- Based on the likely composition of future debris flows, boulder-sized debris flow material and high flow velocities will impact areas across the upper part of the Fairmont Creek fan. These areas are designated high debris flow risk corresponding to the potential for direct impact.
- High risk areas extend down the mainstem channel, through Marble Canyon to the upper part of the fan. A large part of the high risk area is developed golf course, but there are residences (town homes and condos) and a community recreation centre within this zone as well.
- Potential risk to other areas of the fan depends largely on channel constrictions, stream bank weaknesses, and local topography. These areas would be impacted by a saturated slurry of gravel, cobbles and fine sediments, moving at slower velocities.
- Mitigation measures, including a detention basin upstream of the Resort, and reconstruction and enhancement of the flood protection structure at Marble Canyon, could reduce the risk to properties and infrastructure.

10.0 CLOSURE

This report was prepared for the exclusive use of the Regional District of East Kootenay. This includes distribution as required for the purposes for which this assessment was commissioned. The assessment has been carried out in accordance with generally accepted practice. Conclusions and recommendations presented herein are based on visual site inspection, limited subsurface investigation, and additional information from air photos. Professional judgement has been applied in developing the recommendations of this report. No other warranty is made, either expressed or implied. Clarke Geoscience Ltd. does not in any way accept responsibility for the potential hazards identified and the corresponding consequences.

We trust that this report meets your current requirements. If you have any questions or comments, please contact the undersigned.

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12.0 DEFINITIONS

Following are definitions for some technical terms used in this report. They are sourced from Wise, et al. (2004) and other noted sources.

Debris Flow, commonly referred to as a mudslide by the media, is a moving mass of mud, soil, rock, and water that moves rapidly downslope with tremendous force. Debris flows are capable of moving very fast, at speeds reaching 100 mph, and can transport very large (more than 1 m diameter) boulders. Debris flow deposits can have a consistency similar to pancake batter. Debris flows are a hazardous geological process based on the destructive potential and the fact that they can occur suddenly without significant warning.

Non-Standard Flooding And Erosion Areas (NSFEA): Areas where standard flood proofing conditions are not adequate to provide the necessary level of protection against flooding, erosion and/or debris flow. NSFEA includes: alluvial fans, debris flow fans and floodway areas subject to flooding and erosion hazards which require special flooding and erosion precautions.

Hazard is a source of potential harm, or a situation with a potential for causing harm, in terms of human injury; damage to property, the environment, and other things of value; or some combination of these (CSA 1997). With respect to landslide risk management, the landslide is the source of potentialharm—it is the hazard. A future landslide that has no harmful potential is not a hazard, but is simply a natural geological or geomorphological process or feature.

Hazard Analyses, P(H), estimate the probability of occurrence of a specific hazardous landslide. Although an element is identified in the analysis of P(H), its relevant nature and characteristics are not considered. In other words, P(H) does not consider the following factors: the probability of the landslide reaching or otherwise affecting the site occupied by the element; the probability of the element being at that site at the time of the landslide; the vulnerability of the element; and the worth of the element. These other factors are discussed in Section 3.5. Therefore, P(H) is a measure of hazard and not risk, because it does not consider the effects, or potential effects, of the landslide on the element.

Consequence is the effect on human well-being, property, the environment, or other things of value; or a combination of these (adapted from CSA 1997). Consequence of a landslide must consider where and when the landslide occurs in relation to the elements and the vulnerability of the elements. A number of different components combine to form consequence – spatial probability (potential of landslide to reach site occupied by element), temporal probability (potential for mobile element to be at a affected site at the time the event occurs), and vulnerability (a measure of robustness of the element and its exposure to the landslide).

Elements of social, environmental, and economic value (or simply elements) are humans, property, the environment, and other things of value, or some combination of these that are put at risk (adapted from CSA 1997). The B.C. Ministry of Forests (2002) lists potential elements as human life and bodily harm, public and private property (including building, structure, land, resources, recreational site, and cultural heritage feature), transportation system/corridor, utility and utility corridor, domestic water supply, fish habitat, wildlife (non-fish) habitat and migration, visual resource, and timber. When elements are known to be at risk, they are referred to as **elements at risk** (or again simply elements).

Probability of landslide occurrence is an estimate of the chance for a landslide to occur. An estimate of probability is expressed quantitatively, using a number between 0 (a landslide will not occur) and 1 (a landslide will certainly occur). The term likelihood is used to provide a qualitative estimate of probability, referred to as a probability rating. Likelihood estimates are typically expressed using relative qualitative terms, such as very low to very high or very unlikely to almost certain. Qualitative terms must be defined to avoid ambiguity.

Risk is the chance of injury or loss as defined as a measure of the probability and the consequence of an adverse effect to health, property, the environment, or other things of value (adapted from CSA 1997).

Partial Risk, P(HA), is the product of the probability of occurrence of a specific hazardous landslide and the probability of that landslide reaching or otherwise affecting the site occupied by a specific element. This is also referred to in this handbook as the probability of a specific hazardous affecting landslide. Partial risk does not consider the vulnerability of the element, and therefore is not a complete estimate of risk. Information regarding the vulnerability of the element is required to estimate specific risk.

Stakeholders are any individual, group, or organization able to affect, be affected by, or believe they might be affected by, a decision or activity. Note that decision-makers are stakeholders (CSA 1997).

Residual risk is the risk remaining after all risk control strategies have been applied (CSA 1997).

Acceptable risk is a risk for which, for the purposes of life or work, stakeholders are prepared to accept "as is," and for which no risk control is needed. Stakeholders do not generally consider expenditure in further reducing such risks as justifiable (adapted from AGS 2000). Different stakeholders can have differing levels of acceptable risk, and in such situations establishing explicit thresholds of acceptable risk can facilitate discussion and consensus among stakeholders.

Tolerable risk is a risk that stakeholders are willing to live with so as to secure certain net benefits, knowing that the risk is being properly controlled, kept under review, and further reduced as and when possible. In some situations, risk may be tolerated because the stakeholders cannot afford to reduce risk even though they recognize that it is not properly controlled (adapted from AGS 2000). Tolerable risks exceed established or acceptable thresholds of risk.