Regional District of East Kootenay (RDEK)

Cold Spring Creek Debris Flow Hazard and Risk Assessment

FINAL REPORT

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Executive Summary

A Debris Flow Hazard and Risk Assessment for Cold Spring Creek was prepared on behalf of the Regional District of East Kootenay (RDEK) by Clarke Geoscience Ltd. (CGL), together with Tetra Tech EBA. The project was administered by RDEK and the Ministry of Forests Lands and Natural Resource Operations (MFLNRO) provided technical review of the assessment report.

The Cold Spring Creek watershed is located on the eastern slopes of the Columbia River valley, approximately 100 km north of Cranbrook, B.C. Situated on the coalesced fans of Cold Spring Creek and Fairmont Creek, are approximately 500 residents of the unincorporated community of Fairmont Hot Springs and the Fairmont Hot Springs Resort (FHSR).

The area was impacted by a damaging debris flow on Fairmont Creek on July 15, 2012 and both Fairmont Creek and Cold Spring Creek experienced a high flow event in June 2013 that infilled reservoirs and plugged downstream culverts, causing localized damage.

The objectives of the debris flow hazard and risk assessment are to determine the hazard and risk of future debris flow events on Cold Spring Creek, and to identify practical mitigation measures, if required.

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

- Because of the lack of field-based evidence, large-scale debris flows affecting extensive areas across the Cold Spring Creek fan are considered rare, with a low likelihood of occurrence. Cold Spring Creek is more likely to have a higher frequency of small debris flows, or sediment-laden floods. Sediment and/or debris is more likely to move through the system in a series of small events, rather than few large events.
- The Cold Spring Creek watershed is more prone to sediment-laden floods than it is to debris flows. However, debris flows do occur on steep tributaries and in the upper reaches of the watershed;
- The Cold Spring Creek Dam reservoir became infilled with sediment due to flooding in 2011, 2012 and 2013. Significant sediment infilling prior to 2011 is not documented;
- A hazard and risk assessment predicted debris flow paths and consequences across areas of the fan with the assumption that existing flood protection structures (Cold Spring Creek Dam and RDEK Debris Trap) remain and function as intended;
- Based on the likely composition of future debris flows (i.e. boulder-sized debris flow material and high flow velocities) and the uncertainty regarding channel containment at the fan apex, a high debris flow risk classification is assigned to a small area at the top of the fan in the vicinity of the Cold Spring Creek Dam.
- The risk of impacts due to debris flows to other areas of the fan depends largely on channel constrictions, stream bank weaknesses, and local topography. These areas, identified as having a moderate debris flow risk, would be impacted by a saturated slurry of gravel, cobbles and fine sediments, moving at low velocities.

Mitigation measures could reduce the risk to properties and infrastructure. Recommended mitigation measures include the following:

1. Maintain existing flood protection works (Dam and downstream Bank Protection/Debris Trap);
2. Increase the hydraulic capacity of Reach 3 and replace four culverts (between Fairmont Resort Road and Highway 93/95);
3. Re-establish the Highway 93/95 ditch drainage;
4. Complete a detailed survey and hydraulic capacity assessment of the valley area upstream of the Dam;
5. Develop land-use planning policies; and,
6. Continue to monitor the watershed periodically, roughly every 5 years, to document changes that may affect the potential debris flow hazard.

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1.0 INTRODUCTION AND OBJECTIVES

Clarke Geoscience Ltd. (CGL), together with Tetra Tech EBA, were retained by the Regional District of East Kootenay (RDEK) to prepare the following Cold Spring Creek Debris Flow Hazard and Risk Assessment. The project scope and approach are defined in the proposal to RDEK, dated September 19, 2014.

1.1 BACKGROUND

The Cold Spring Creek watershed has a catchment area of approximately 8 km^2. The watershed is located on the eastern slopes of the Columbia River valley, roughly 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 Cold Spring Creek and Fairmont Creek (Figure 1).

On July 15, 2012 Fairmont Creek experienced a debris flow event that impacted the community of Fairmont Hot Springs. A debris flow hazard and risk assessment report was completed for Fairmont Creek by RDEK following the 2012 event (Clarke Geoscience Ltd., 2013) and work to mitigate the risk to the downstream community is currently underway.

An intense summer rainstorm in June 2013 triggered a high flow event on Cold Spring Creek. The event, likely a sediment-laden flood, filled the reservoir at the Cold Spring Creek dam and also filled the RDEK sediment trap located near the Columbia River downstream.

RDEK recognizes that the Cold Spring Creek watershed is comparable to the Fairmont Creek watershed and is considered to have a similar susceptibility to sediment-laden flood and/or debris flow. Overview assessments of Cold Spring Creek, completed in 2012 and 2013 indicated a potential for debris flows and recommended more detailed assessment to further characterize the risk of debris flows (Clarke Geoscience Ltd. 2012, and 2013).

The debris flow hazard on Cold Spring Creek was identified in the late 1970s at the time of subdivision of the Fairmont Hot Springs Resort. Subdivision approval was contingent on maintaining the Cold Spring Dam, a water retention structure built in the 1980s, as a debris flow protection structure. In addition, flood protection structures, including a riprap lined channel and a debris trap (sediment detention basin), were constructed on the lower part of the fan, as the creek approaches the Columbia River.

1.2 PROJECT OBJECTIVES

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

The overall objectives of the debris flow hazard and risk assessment, as stated in the Request for Proposal, are:

1. Characterize the debris flow and flood hazard on Cold Spring Creek;
2. Determine the qualitative risk of future debris flow and flood events to the existing downstream community and infrastructure;
3. Prepare a hazard and risk map for the fan area; and,
4. Recommend specific risk mitigation measures and associated Class D cost estimates.

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).

The study also references the *Professional Practice Guidelines for Legislated Flood Hazard Assessments in the Changing Climate in B.C.* (APEGBC, 2012). Methods for debris flow hazard analysis used in this report have 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 of the lower fan area of the Fairmont Hot Springs Resort;
- Digital orthophoto overlays (2007) and Google Earth imagery (2012 & 2014);
- 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
    - 1952, Flight line BC1607, No. 61-62
    - 1964, Flight line BC4229, No. 69-75

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

    - 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, RDEK, other professionals and local residents who are familiar with the study area; and,
- Other related technical reports and studies (cited in references).

2.2 FIELD INVESTIGATION

A field investigation was carried out by Ms. Jennifer Clarke, P.Geo., of CGL and Ms. Angela Cormano, RPF, R.P.Bio., of Ecoscape Environmental Consultants Ltd., on October 7-9, 2014, and on November 6, 2014. The field investigation included a foot traverse of Cold Spring Creek, from the mouth at the Columbia River upstream through the middle reaches and into the headwaters. Helicopter overview flight videos obtained in 2012 and 2013 were reviewed to observe channel conditions and sediment sources throughout the watershed and adjacent areas. The fan area was traversed on foot and local site topography and other features were noted and photographed.

In addition, a subsurface investigation, which included eight (8) test pits, was conducted across the fan area. Three samples of buried organic material obtained from test pits were sent to Beta Analytical Laboratory for radiocarbon dating.

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.

The debris flow hazard classification developed for this project is defined in Table 1. The hazard class is based on the anticipated frequency of occurrence and the predicted magnitude, or volume, of a specific debris flow event. The hazard class is equivalent to the likelihood of a debris flow hazard occurrence (P(H)). Higher frequency events tend to be smaller in magnitude, while low frequency events, those events that occur very rarely, are the high magnitude events.

Table 1: Debris Flow Hazard Classification Scheme for Cold Spring Creek (Likelihood of a Debris Flow Hazard, P(H))

		Predicted Magnitude, or Volume of Debris Flow		
		Low	Moderate	High
		1,000 to 20,000 m^3	20,000 to 100,000 m^3	>100,000 m^3
Frequency of Occurrence Or Return Period	Low - More than 10,000 years	LOW	LOW	MODERATE
	Moderate - 500 to 2500 years	LOW	MODERATE	HIGH
	High - 10 to 500 years	MODERATE	HIGH	HIGH

2.3.1 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. In the determination of partial risk, the consequence ratings are equivalent to the likelihood of a certain hazardous event reaching, or affecting, a particular resource (P(S:H). In this case, the resource is the Community of Fairmont Hot Springs, including residences, infrastructure, and human life. The consequence ratings are used to distinguish between events that may be potentially damaging and those that may be life-threatening.

Table 2 Predicted Debris Flow Consequences, or Impact Characteristics for Cold Spring Creek (Likelihood of a debris flow affecting the Community, P(S:H))

Consequence Class	Predicted Debris Flow Impact Characteristics
Low	<u>Flood Zone (Minor Property Damage)</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 (Minor Property Damage, no Structural Damage)</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 (Potential for Structural Damage and Potentially 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

2.3.2 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, qualitative “partial risk” is assessed. Partial risk is expressed as:

$$P(HA) = P(H) \times P(S{:}H)$$

where, partial risk (P(HA)) is the product of the probability of occurrence of a specific hazardous debris flow event (P(H)) and the probability of that debris flow reaching or otherwise affecting the site occupied by a specific element (P(S:H)). (Wise, et al., 2004)

Information regarding the vulnerability of the element is required to estimate “specific risk”, which is not part of this study.

The partial 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 for Cold Spring Creek (P(HA))

		Debris Flow Hazard Class (P(H))		
		Low	**Moderate**	**High**
Debris Flow Consequence (P(S:H)	**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 (as determined using Table 1) and the impact corresponding to each class (as determined using Table 2).

The risk classes are based on, and defined by, the level of acceptable landslide safety, which is discussed in Section 2.3.3.

2.3.3 Level of Landslide Safety

There is no established national level of landslide safety in Canada nor is there a legislated level of acceptable debris flow risk in British Columbia. For the purposes of this assessment, the RDEK has directed the use of the BC Ministry of Transportation and Infrastructure (MOTI) defined levels of acceptable landslide safety. In reference to landslide safety, MOTI includes geohazard events, such as debris flow.

In BC, MOTI provided some guidance with respect to levels of landslide safety (2005). 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. The 1 in 475 year return period event is also referenced in the BC Building Code as a geotechnical design parameter for seismic design.

Risk Class descriptions are summarized in Table 4.

Table 4: Debris Flow Risk Class Descriptions for Cold Spring Creek

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 475 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

The Cold Spring Creek watershed has an area of approximately 8 km^2. Cold Spring Creek is a third-order[2] stream flowing 7.0 km from Fairmont Ridge (elev. 2480 m) to the Columbia River (elev. 820 m). An overview of the watershed is shown in Figure 2. The length of channel from Fairmont Ridge to the fan apex is approximately 5.5 km.

The upper Cold Spring Creek 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 Cold Spring Creek watershed are moderate to steeply sloped (35% to >70%) but appear to be relatively stable, except where the slopes are oversteepened due to bank erosion along the stream channels. The fan of Cold Spring 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 Hot Springs predate the Cold Spring Creek fan, as the fan is a post-glacial feature that has downcut the terrace slopes.

With a relative relief of 1660 m, the Cold Spring Creek watershed has a Melton Ratio[3] of 0.58. 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). Cold Spring 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, such as Cold Spring Creek, 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 BEDROCK GEOLOGY, SOILS AND TERRAIN

The study area is underlain by sedimentary and meta-sedimentary bedrock that ranges in age from Upper Proterozoic to Cambrian-Ordovician (see Figure 3). Geological mapping (from Data BC) of the Stanford Range indicates that massive grey limestone to white dolomite, marble and calcareous sedimentary rock of Cambrian-Ordovician age underlies the lower watershed. Mid-reaches of the watershed are underlain by coarse clastic sedimentary rocks of the Horsethief

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[2] Stream Order is a classification of stream hierarchy that provides an indication of stream size and strength.

[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.

Creek Group. Bedrock geology of the upper watershed is characterized by sequences of dolomite/limestone of the Beaverfoot Formation, and thin exposures of fine clastic sedimentary rocks (mudstone, siltstone and shale) of the McKay Group. Noted in the headwaters of Tributary A of Cold Spring Creek, is a volcaniclastic (laval flow or sill) exposure (see Photo Appendix A). The reddish-coloured rock is rich in base metals (Norford and Cecile, 1994).

From a geotechnical perspective, it is the coarse clastic sedimentary rocks of the Horsethief Creek Group that are relevant to debris flow process in the watershed, as these rocks range in competency from slate or phyllite to metamorphosed pebble conglomerates that degrade to a fine grit. This is a highly erodible bedrock type that weathers to a very fine loose rock. The weathered product of this bedrock constitutes a significant 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. The middle reaches (approximately 600 m in length) of Cold Spring Creek are flanked by steep unstable exposures of phyllite rock.

Soils mapping in the Fairmont Hot Springs 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. In the field, along lower to middle reaches of Cold Spring Creek, thick (10 to 20 m) exposures of consolidated sands and gravels of glaciofluvial origin were observed to lie above the phyllite bedrock.

3.3 STREAM CHANNEL AND FAN MORPHOLOGY

The headwaters of Cold Spring Creek are located in the alpine Fairmont Ridge. Cold Spring Creek has several small contributing tributaries, including one (Tributary A), which has experienced recent debris flow activity that deposited material in the mainstem channel, resulting in an aggraded channel and supplying material that may be mobilized during future high flow events.

A channel profile, shown in Figure 4, illustrates the stream channel gradient from the headwaters down to the Columbia River. 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, which limits the sediment availability. 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 Cold Spring Creek fan is approximately 44 ha (0.44 km^2) in area and has gradients ranging from 8 to 12%, which is similar to the Fairmont Creek fan (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 Cold Spring Creek fan, therefore, is inferred to have been formed at least in part by debris flow processes.

3.4 CLIMATE AND HYDROLOGY

The Cold Spring 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 ^oC, ranging from -7.5 ^oC in January to 18.3 ^oC 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, completed by the Water Management Branch (1984) estimated the 200-year return period instantaneous peak flow on Cold Spring Creek to be 2.52 m^3/s and the maximum daily flow to be 1.95 m^3/s.

More recent analysis of peak flows, completed by Kerr Wood Leidal for the Cold Spring Creek Dam Consequence Assessment (2014), used the unit flood runoff rate of 0.2 $m^3/s/km^2$ to estimate the 100-year return period event to be 1.55 m^3/s. Interpolating between the 100-year flood and the Probable Maximum Flood (PMF), the 1000-year return period flood was estimated to be 7 m^3/s (KWL, 2014).

By comparison, the 1 in 200 year peak instantaneous flow on Fairmont Creek was estimated to be 2.88 m^3/s (Reid Crowther and Partners Ltd., 1994b). Although dated, the 1984 estimates of peak instantaneous flow are considered reasonable. Current practice is to factor extreme stream flood flows by 10 percent to account for climate change (see discussion in section 6.4) (APEGBC, 2012).

To summarize, the key hydrologic parameters for Cold Spring Creek, derived from various sources, are:

Q 100 = 1.55 m^3/s (+10% = 1.71 m^3/s)

Q 200 peak instantaneous flow = 2.52 m^3/s (+10% = 2.77 m^3/s)

Q 1000 = 7 m^3/s

Probable Maximum Flood (PMF) = 73 m^3/s

Debris flood and debris flow peak discharges are known to be much higher, sometimes 20 to 50 times higher, than the peak instantaneous flood flow (Q200) (Jakob and Jordan, 2001). The 2012 Fairmont Creek debris flow assessment estimated a peak debris flow discharge that was 57 times the peak instantaneous flow. In mountainous regions, mass movements such as tributary debris flows, debris slides, landslides, and temporary dam failures have a strong influence on the hydrologic character of a watershed, and results in higher than expected peak flow discharges.

3.5 WATER INTAKE AND DAM STRUCTURES ON COLD SPRING CREEK

There are eleven (11) active water licenses on Cold Spring Creek. However, only one functioning intake was identified on Cold Spring Creek. This is the Fairmont Hot Springs Resort intake, located at approximately 1300 m elevation. There is also a small concrete dam located on Cold Spring Creek at the fan apex at approximately 945 m elevation.

3.5.1 FHSR Water Intake at 1300 m elevation

Fairmont Hot Springs Utilities Ltd. operate the upper water intake structure on Cold Spring Creek. The intake structure was originally built in 1979-1980 as a wooden weir, to service the Fairmont Ski Resort, which opened in 1980. Water is used by the ski lodge, provides water for snow making purposes, and domestic water supply to the FHSR community.

The wooden weir and intake structure was washed out in 2010, resulting in a total loss of water supply. The intake was reconstructed and a new concrete lock-block weir was installed. The current weir structure has been damaged and partially washed out twice since it was installed. The structure now includes a sub-surface infiltration gallery. Water is conveyed by buried pipe downslope parallel to the creek along a 1.7 km long hillside route to a reservoir located below the ski resort at an elevation of approx. 1070 m.

Currently FHSR is making plans to construct groundwater wells to supplement and secure the water supply for the Resort (R. Haworth, personal communication, 2014).

3.5.2 Cold Spring Creek Dam

The Cold Spring Creek dam, located on Cold Spring Creek at the fan apex, is owned and operated by Fairmont Hot Springs Resort. The dam is a concrete gravity structure, constructed in 1980 to provide domestic and irrigation water for the resort community.

The dam is 22 m long along the crest of a concrete retaining wall (crest elevation 944.2 m), and 4.6 m high at the crest of a 3 m wide concrete free-crest ogee overflow spillway (sill elevation 943.4 m) (KWL, 2014). The upstream reservoir has a design capacity of 1,600 m^3. Stored water at the dam is diverted and used for golf course irrigation in the community.

A recent (draft) report by Kerr Wood Leidal (KWL, 2014) proposes to revise the Cold Spring Creek Dam downstream consequence classification from “Very High” to “Significant” Consequence on the basis of a hydrology assessment and modelled inundation mapping, and a detailed dam breach analysis. If revised, according to the BC Dam Safety Act, there would be a reduced frequency of inspection (from weekly to monthly) and the need for a detailed Dam Safety Review would be eliminated.

3.6 WATERSHED AND FAN LAND USE

There are no current commercial forestry operations in the Cold Spring Creek watershed. There are some old (circa late-1960s) overgrown logging roads on the north slopes of the lower watershed that may be associated with historic high-grade logging operations, or possibly mineral exploration and/or recreation access.

The Fairmont Hot Springs Resort Ski Area occupies the mid-elevation ridge between Cold Spring Creek and Fairmont Creek. The Ski Area is a relatively small alpine ski hill serviced by 2 chair lifts. Resort activities that have a potential hydrological effect on Cold Spring Creek include forest clearing, snow making, and road construction.

As mentioned above, FHSR maintains a water intake on Cold Spring Creek, diverting water by buried pipeline along the south side of the creek, traversing steep slopes above the creek, to a reservoir. Pipeline leaks or ruptures may potentially affect slope stability.

On the fan, Cold Spring Creek traverses three golf courses within the Community of Fairmont Hot Springs. These are: the Riverside Golf Course, located on the west side of Highway 93/95, the Creekside Par 9 Golf Course adjacent to the east side of Highway 93/95, and the Mountainside Golf Course.

Situated on the Cold Spring Creek fan are residences and businesses of the unincorporated municipality of Fairmont Hot Springs. The Community is within Electoral Area “F” of the Regional District of East Kootenay.

4.0 FIELD OBSERVATIONS AND AIR PHOTO ASSESSMENT

The following documents the observations and measurements from the field investigation, helicopter overview (2012 and 2013), air photo assessment, and sub-surface investigation. Photographs are provided in Appendix A.

4.1 STREAM CHANNEL CHARACTERISTICS

The Cold Spring Creek mainstem channel was sub-divided into reaches, based on similar gradient, confinement, and character. Reach breaks and noted features are shown on the Watershed Overview Map (Figure 2) and Stream Channel Profile (Figure 4). Stream reaches are described in the following sub-sections.

4.1.1 Headwater Reaches (Reaches 6 and 7)

The high elevation headwater reaches (Reaches 6 and 7) of Cold Spring Creek originate from Fairmont Ridge (elev. 2480 m) and extend down to the FHSR intake structure (elev. 1300 m). The upper reaches combine flows from numerous small first- and second-order drainages, many with undefined or poorly defined channels.

Reaches 6 and 7 are steep bedrock-controlled reaches with a step-pool morphology, and an average gradient greater than 28%. The average bankfull width is 10-12 m and the substrate size is largely boulder, with some cobble-sized material.

Along these upper reaches there are numerous steep tributary channels contributing runoff and sediment to the channel. The upper reaches of Cold Spring Creek have several tributaries with a narrow angle of entry and are considered to have the potential to trigger debris flows on the mainstem. Tributaries with a narrow angle of entry (as opposed to a perpendicular angle of entry) are more likely to trigger debris flows (Jakob, et al., 2000).

At the upper end of Reach 6 there is a relatively active (avalanche/debris flow) tributary joining from the north. This tributary source was identified in previous (2012 & 2013) overview flights. Remnants of a debris jam and accumulated sediment provide evidence of a temporary landslide dam (Photo 33). It is likely that the small landslide debris dam washed out shortly before 2012 (and was perhaps associated with the flood event of 2011).

The upper headwater reaches of Cold Spring Creek represent a snow and debris accumulation zone and gradients are steep enough for debris flow initiation and transport.

4.1.2 Tributary A

Tributary A drains a small sub-alpine catchment area (1.3 km^2) that is characterized as steep and bedrock-controlled. The tributary channel is heavily laden with sediment, with no visible surface water flow at the time of the field assessment. There is evidence that the small catchment has experienced a sediment-laden debris flood, or debris flow, in the past few years.

Tributary A is 2 km long with a steep (>25%) channel gradient and is capable of debris flow initiation and transport. The average channel width at the lower end of the reach is approximately 10-15 m, and the channel depth is approximately 2 m.

Bedrock within the headwaters of Tributary A are characterized as steeply dipping dolomitic carbonate, fine clastic sedimentary, and calcareous sedimentary rock. Reddish-coloured rock, visible in the upper catchment, is a volcaniclastic intrusion (lava flow or sill). There are numerous sources of bedrock instability in the headwaters of this tributary.

Sediment transported from Tributary A has infilled the mainstem channel, resulting in a lack of surface water flow for a distance of approximately 150 m downstream from the confluence. This tributary represents a recent significant source of sediment to the mainstem channel.

4.1.3 Reach 5 between tributary confluence and FHSR Intake

Reach 5 extends downstream from the confluence of Tributary A to the FHSR water intake site (at 1300 m elevation). This reach is characterized as having an average bankfull width of about 15 m (ranges from 8 to 15 m), an average depth of 0.5 to 1.5 m, and a stream gradient ranging from 18 to 22%, with gradient decreasing in a downstream direction.

Reach 5 represents a zone of transition between debris flow transport and debris flow deposition. The channel loses some confinement but is steep enough for most material entrained in a debris flow surge to continue downstream. Several large (1.5 to 2.0 m diameter) boulders that have been transported downstream during previous events are present within this reach. There is also evidence of debris flow levee deposits along the channel, and within-channel deposition has created side channels in some cases.

4.1.4 Reach 4 downstream of FHSR Intake to Cold Spring Dam

This reach extends downstream from the FHSR water intake site (elev. 1300 m) to the Cold Spring Creek Dam (elev. 944 m). Reach 4 is characterized as an aggraded, boulder cascade-pool channel with an average stream gradient of 12-17%, with short steeper (20%) sections. The average bankfull width is much narrower (4 to 6 m) than the upstream reach, and the average bankfull depth is 0.7 to 1.5 m.

Throughout this reach there are many small-sized debris jams and associated stored sediment wedges. Stored sediment is 0.5 to 1.5 m thick, with cobble to boulder sized material. Based on the adjacent mature forest, there is ongoing likelihood of debris jam formation. Debris jams can break down, or can be washed out at high flows, releasing sediment downstream.

Reach 4 downcuts and erodes adjacent valley slopes, which are comprised of erodible phyllite/grit bedrock of the Horsethief Creek Group. Alternating banks of the creek expose high banks of easily eroded material, creating an abundant source of sediment to Cold Spring Creek.

Across the valley bottom, below the apex of the Cold Spring Creek fan and above the Cold Spring Creek Dam, there are levee deposits, indicative of previous debris flow events. The levees, however, are overgrown with mature forest. Examining tree rings from a (already) cut tree and from tree cores obtained using an increment borer, the estimated age of the forest is 70 to 80 years old. This indicates that the levee deposits are at least that old.

Cold Spring Creek flows into the small reservoir above the Dam, where transported sediment forms a delta at the mouth of the reservoir. Sediment that has been previously excavated from the channel and reservoir is piled high within the vicinity of the dam.

4.1.5 Reach 3 below the Cold Spring Dam

Between the Cold Spring Creek Dam (elev. 944 m) and the Columbia River (elev. 806 m), the creek is sub-divided into three reaches based on changes in gradient and channel character. A summary of all culverts along the lower reaches of Cold Spring Creek is presented in Section 4.1.8.

Reach 3 extends downstream from the Dam to Highway 93/95, crossing three roads in between.

Downstream of the Dam, to Fairmont Resort Road (the channel is a relatively natural boulder cascade-pool channel, with an average gradient of approximately 10-15%. Substrates are sand, gravel and cobble sized material. The depth within Reach 3 varies from 1.0 to 2.0 m at the upstream end, to 0.3 to 1.5 m downstream.

The channel is relatively well-incised through the upper part of the reach to Fairway Road. Downstream of Fairway Road, the channel becomes less well-confined and there are frequent large woody debris jams. There is evidence of recent overbank flooding on the left bank, with up to 1.5 m of sediment deposition into the adjacent forest. Deposition from recent flood flows is evident through this lower section of the reach.

Downstream of Hot Springs Road, Cold Spring Creek is characterized as an aggraded channel filled with gravels and fine sands and forming mid-channel bars and sediment wedges (up to 0.3 m thick). There is minor undercutting of the stream banks and the channel substrate is sand, gravel and small cobbles. There is evidence of a small blown out debris jam (and associated 0.6 m thick sediment wedge). Scattered boulders (up to 1.5 m diameter) are also present along this reach.

Due to abundant sediment and woody debris, and a reduced channel depth, the lower end of Reach 3 is considered to have a potential for overbank flooding.

The riparian forest on either side of the creek, provides some latitude for small-scale channel avulsions and flooding. The protective role and function of the riparian forest is emphasized.

Just above the Highway 93/95 culvert, accumulated debris blocks the downstream highway ditch. The downstream highway ditch (0.5 m deep, 3.0 m wide trapezoidal shape), as a result, is not well connected to Cold Spring Creek. Thus, in the event of a culvert blockage on Cold Spring Creek, flows would fill the highway ditch and then overtop onto the highway.

4.1.6 Reach 2 Highway 93/95 downstream to RDEK Debris Trap

Reach 2 of Cold Spring Creek extends downstream from Highway 93/95 to the RDEK debris trap. Downstream of the highway, Cold Spring Creek is a straight constructed channel with riprap armoured banks. The creek passes through two culverts before reaching the RDEK debris trap.

Reach 2 has an average gradient ranging from 6 to 10%, an average bankfull width of 8 m and an average depth of 1.7 to 2.0 m. Substrate materials are cobble-boulder at the top end of the reach, decreasing to gravel-cobble at the lower end, approaching the debris trap.

Stream banks along this reach are armoured with riprap (est. 500 mm diameter; roughly equivalent to 50 kg Class), at a 2H:1V slope. Generally, the right bank appears to be in good condition, with an access trail paralleling the right bank designed for maintenance access. The left bank, however, is often steeper and occasionally undercut. Along the lower section of the reach, where residential properties back onto the creek, the left bank is lacking riparian vegetation, with lawn extending to the edge of the bank. Some sections of the left bank through this section have partial riprap coverage.

Mid-way along Reach 2 there is a widening of the channel. This area is intended to be an intermediate area for debris deposition.

The RDEK Debris Trap:

At the downstream end of Reach 2 there is a debris trap, licensed to and maintained by RDEK. The debris trap is a small pond, with an estimated surface area of 1600 m^2. At an average depth of 0.5 to 1 m, the estimated storage capacity of the debris trap is 800 to 1,600 m^3. Sand, gravel and small cobbles accumulate at the mouth of the pond and sediment is deposited in the pond as the gradient of the channel drops to approximately 1%. Access is very good to the pond, which facilitates maintenance.

As fine-textured sediments (i.e. silts and sands) gradually infill the pond, the pond is periodically cleaned. In July 2012, when Fairmont Creek experienced the debris flow, the debris trap was only partially filled. In the summer of 2013, however, the debris trap completely filled, requiring excavation later that fall.

The debris trap was cleaned in 2011 and in 2013 by RDEK (photos showing the 2011 and 2013 condition are provided in Appendix A). There are no historical records of dates and/or volumes removed from the pond.

4.1.7 Reach 1 downstream of RDEK Debris Trap to the Columbia River

Reach 1 is a very low gradient reach of Cold Spring Creek downstream of the debris trap, connecting with the Columbia River. Downstream of the RDEK debris trap, Cold Spring Creek flows within a 1600 mm culvert (with a manual gate) underneath a maintenance shed, into a pond within the Riverside Golf Course. The pond is a remnant backchannel within the Columbia River floodplain and the pond is connected to the Columbia River by four culverts, two of which are blocked.

Reach 1 lies within the 200-year floodplain of the Columbia River (elevation 804 m a.s.l. [5]).

4.1.8 Culverts along Lower Reaches of Cold Spring Creek

Flowing downstream of the Cold Spring Creek Dam, the creek crosses three local roads above the highway, before reaching Highway 93/95. Below the highway, Cold Spring Creek crosses two roads before reaching the RDEK debris trap, then through another culvert beneath a golf course maintenance building before entering a pond which drains via 4 culverts into the Columbia River. Culvert locations are shown in Figure 5 and characteristics are summarized in Table 5 below. Photographs are provided in Appendix A.

In a report by Reid Crowther (1995) there is a reference to a second culvert, approximately 25 m south of the Hwy 93/95 culvert on Cold Spring Creek. The 1995 report indicates that in the event that the two highway culverts are plugged with debris, that material would overtop the highway and flow down the highway ditch, depositing material along the lower gradient slopes. During the 2014 field program, there was no evidence of this second culvert.

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[5] Ministry of Environment (1978) BC Floodplain Mapping, Columbia River: Columbia Lake to Windermere Lake. Drawing A5286, Sheet 3.

Table 5: Cold Spring Creek Culvert Crossings

Crossing Location	Culvert Size (mm)	Condition
Confluence with Columbia River	4 x 500 mm	2 out of 4 culverts are blocked;
Under Maintenance Building	1600 mm; and a manual gate	Partial accumulation of material at culvert inlet.
Ogilvey Ave.	Arch culvert; 2.2 m wide and 1.1 m high	Partial accumulation at culvert inlet.
Riverview Rd.	1500 mm	Good
Highway 93/95	1500 mm	Partly deformed under highway; Black PVC water tubing inside culvert.
Hot Springs Road	1 x 900 mm 1 x 800 mm 1 x 200 mm road ditch drain	Good
Fairway Road	1 x 900 mm 1 x 1200 mm	Good
Fairmont Resort Rd.	1200 mm	Good

The results of the KWL hydrology study (2014) indicate that culverts are capable of passing the estimated 200-year peak flow, which is designated as a clear water (flood) event with minimal debris bulking. The capacity assessment does not necessarily account for accumulations and potential blockages by sediment and organic debris.

Because a lot of the sediment from the upper watershed is detained at the Dam, mobilized sediment below the Dam is, for the most part, locally derived. For large scale and/or extreme debris flow events that overtop the Dam, it is judged that the culverts below the Dam are unlikely to be able to convey flows with a high sediment load. During debris flow or sediment-laden flood conditions, it is judged that the culverts would likely be blocked and overtopping could occur.

4.2 SUBSURFACE INVESTIGATION

Eight (8) test pits were excavated on the Cold Spring Creek fan in an effort to determine the distribution and return periods of previous debris flows. Test pit locations are shown on Figure 5. Test pit location choices were limited to FHSR property in areas that would least impact resort operations and infrastructure.

Test pits were excavated to approximately 3-4 m depth and the stratigraphy was logged. Photographs are provided in Appendix A and test pit logs are provided in Appendix B. It was noted that no test pits intercepted groundwater.

Debris flow deposits and especially debris flood deposits, are similar to, and sometimes difficult to distinguish from, alluvial (flood) deposits. As the proportion of water to sediment is less in a debris flow, a debris flow deposit tends to have a wider gradation, with coarse clasts supported in a fine matrix. The deposit is unsorted and lacks bedding as the mode of deposition is quite rapid. Debris flow deposits are sometimes marked by a buried layer of organics, where previously vegetated areas have been inundated.

Following is a summary of subsurface observations at the test pits:

Test pits 1 and 2 are located at the fan apex, downstream of the Cold Spring Dam but upslope of the Community. The test pits are located within a mature (approximately 70-80 years old) forest.

- Test pit 1 encountered 0.7 m thick debris flow layer below a thin surface layer, characterized as a light-brown matrix-supported gravel and cobble. This unit was separated from the unit below by a layer of buried organics.
- The lower layer is interpreted as being a thick (>1.8 m) layer of colluvium or debris flow origin as it is a coarse unstratified gravel-cobble unit.
- Radiocarbon dating from a sample of material taken from the buried organic layer between the two layers indicates an age of 1280 +/- 30 years BP. *This indicates that the upper debris flow unit is more than a 1200 years old.*
- Test pit 2 had a similar 0.7 m thick unit of light brown unstratified cobbles, with some boulders, with a buried organic layer. The unit was fairly loose.
- Radiocarbon dating from a sample taken at 1.7 m depth proved to be modern age (<100 years old). Based on the proximity to the residential area and an access trail through the forest, it is suspected that the subsurface stratigraphy is disturbed and likely infill material.

Test pits 3 to 7 are located along the south side of Cold Spring Creek, between Fairway Road and the Highway. The test pits are situated upon the mid- to lower-fan

- Test pits 3 to 7 indicated roughly stratified units of bedded silty-sand gravels, with clast size increasing with depth. Some interbedding of clean sands was present. Identification of material genesis is inconclusive, based on the inconsistent bedding and composition.
- The density of units varied from fairly compact to loose.

- Rootlets and small organic fragments were encountered at a variety of depths. However, no distinct buried layers were encountered.
- Radiocarbon dating from an organic sample taken from Test pit 4 at a 3.0 m depth indicated a contemporary age (100 +/- 30 years BP). This was unexpected, given the depth of the sample. Identified units overlaying the buried sample were relatively loose, so it is possible that the area had been disturbed. It is considered unlikely, therefore, that the overlying units are attributed to a flood or debris flow.

Test pit 8 is located below Highway 93/95 on the north side of Cold Spring Creek. It is recognized that the current alignment of Cold Spring Creek is relatively recent, having been straightened and channelized in the late 1970s during the development of the Community. Thus, the stratigraphic sequence in Test pit 8 represents more recent flood and debris flow activity.

- Within Test pit 8 there are approximately four units of sandy-gravel, with buried organic layers between each. The units lack bedding, or are weakly bedded, with few coarse cobbles and boulders.
- No samples of organic material were obtained for radiocarbon dating.
- Tufa rock was encountered at the base of Test pit 8, at a depth of 3.6 m.

By comparison, almost all test pits completed on the mid- to lower Fairmont Creek fan in 2012 encountered a white/yellowish tufa layer within the first metre (range 0.6 m to 0.9 m). Tufa[6], forms where calcium carbonate precipitates from water in a fluvial environment. This reflects the influence of hot thermal spring water on Fairmont Creek, compared to a lack of thermal spring water on Cold Spring Creek.

5.0 HISTORIC FLOOD AND DEBRIS FLOW EVENTS

Debris flow and flood hazard concerns on Cold Spring Creek were recognized in a preliminary assessment by the BC Ministry of Environment (Boyer, 1989). Rationale was provided for the Ministry of Environment decision to require a professional assessment of debris flow hazard on land owned by FHSR as a condition of subdivision approval. A terrain hazard assessment was completed for the FHSR area by Reid Crowther & Partners Ltd. in 1994.

The Cold Spring 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.

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

5.1 THE JULY 2012 DEBRIS FLOW EVENT ON NEARBY FAIRMONT CREEK

On July 15, 2012, a debris flow occurred on Fairmont Creek. The Fairmont Creek watershed is located immediately adjacent to the Cold Spring Creek Watershed. The event on Fairmont Creek 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 on Fairmont Creek washed out the Fairmont Hot Springs source wells and water supply, downstream culverts and bridges, buried the Marble Canyon and inundated the Mountainside Golf Course, including surrounding homes.

Debris flow or flood events did not occur on any creeks adjacent to Fairmont Creek, including Cold Spring Creek. 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).

5.1.1 2012 Fairmont Creek Event Trigger

The 2012 event was triggered shortly after a localized convective storm moved across the area at a time when local snow packs were recording higher than average snow pack depths and when soils were saturated. Snow water equivalent measured on May 15, 2012 at Floe Lake (Stn. 2C14P), north of Fairmont Creek, were 141% of Normal levels (17 year record). 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.

5.1.2 2012 Fairmont Creek Event Magnitude

The July 2012 debris flow magnitude, measured as the volume of material deposited on the fan, was estimated to be 62,000 to 65,000 m^3 (Clarke Geoscience Ltd., 2012) This estimate lies within the predicted size range for a basin this size (Van Dine, 1985).

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. Further downslope, the debris flow composition is gravel to cobble sized and had an approximate depth of 0.5 m. The inundated area included the large golf course pond on Hole 12 of the Mountainside Golf Course, which had an estimated storage capacity of 7,000 m^3.

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 after-flow. The thickness of deposition in this zone ranged from 0.1 to 0.3 m.

5.1.3 2012 Fairmont Creek Debris Flow Frequency

The results of the 2012 debris flow assessment estimate that the return period for hazardous debris flow (classified as an event of a size sufficient to reach the fan) is 25 years.

The investigation estimated that the 2012 event had a return period of approximately 500 years.

5.1.4 2012 Fairmont Creek Debris Flow Peak Flow Estimates

The debris flow peak flow discharge of the July 2012 event, was estimated to be 165 m^3/s, and had an estimated return period of 500 years (Clarke Geoscience Ltd., 2012). The peak debris flow discharge estimate is 85x the estimated 200 year flood flow and 57x the instantaneous peak flow (see Section 3.4).

It is noted that Reid Crowther (1994b) estimated the 1 in 200 yr debris flow discharge to be 120 m^3/s.

5.2 HISTORIC FLOOD AND DEBRIS FLOW EVENTS ON COLD SPRING CREEK

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

The Fairmont Hot Springs area was settled by Europeans at the turn of the Century. In the early 1900s, WH Holland operated a ranch and resort in the area and the original Holland Barn still exists at the north end of the Mountainside Golf Course (mid-fan). There is little, however, in the way of accessible early recorded history as archived newspapers at the Windermere Valley Museum and Archives date to the 1950s.

5.2.1 Historical Air Photo Interpretation

Historical air photos, and more recent Google Earth imagery, document watershed conditions over a period of 69 years, from 1945 to 1991 (air photo) and 2012 and 2014 (Google Earth).

Early air photos (1945 to 1964) indicate that Cold Spring Creek is not well confined across the fan, and that multiple flow paths are possible. Although not well defined, it appears that Cold Spring Creek flows south-west towards the location of the historic Holland barn (shown on Figure 5), across the north end of the Mountainside Golf Course (where there are currently several ponds) and into a gully that incises the glaciolacustrine terrace upslope of the Columbia River.

Visible on the 1964 photos, there is an increase in development associated with the resort, including construction of the Mountainside Golf Course. Logging trails also extend upslope from the valley into the watershed. At this time, it appears that Cold Spring Creek generally follows the same alignment that it does today as it approaches the Highway. Below the highway, there is no visible connection to the Columbia River and the creek likely infiltrates into the ground before reaching the river.

On the 1978 photos, development in the Riverside area below the highway is visible. The road to the Cold Spring Creek Dam site is also visible and clearing is completed for the Fairmont Ski Hill. Due to the small scale and resolution of the 1978 and 1985 air photos, the creek alignment across the fan is difficult to distinguish.

Cold Spring Creek was channelized and straightened downstream of the highway in the mid-1990s when the Riverside residential area became more developed. The channelization work was intended to protect adjacent residential areas from flooding and forms part of the subdivision approval.

Throughout the 69 year period of air photo record, there is no evidence of large-scale debris flow or sediment-laden flood activity on the Cold Spring Creek fan.

5.2.2 Field Indicators of Debris Flow

Field indicators of previous debris flow on the fan were noted during the field investigation. These include:

- Debris flow boulder levee deposits within the forest on the upper part of the fan below the Dam; and,
- Scattered large boulders within the forest on the upper part of the fan and across the residential area of the middle fan.

Above the Dam, and within the valley bottom occupied by Cold Spring Creek, field indicators of debris flow include:

- Debris flow boulder levee deposits;
- Buried soil/organic horizons exposed along the stream banks;
- Scour marks and impact scars on trees; and,
- The presence of boulders much larger than what could be moved by flood flow.

5.2.3 Stratigraphic Evidence of Debris Flow

Results from the subsurface investigation provide evidence of at least one previous debris flow event that affected the upper part (apex) of the fan. Radiocarbon dating indicates that the event is at least 1200 years old.

Downstream, across the middle to lower end of the fan, the stratigraphy is inconclusive with respect to debris flow. It is possible that either these areas were subject to debris flood (sediment-laden flood) or it is possible that historical creek relocation and ground disturbance has obscured the stratigraphic sequence of events.

Based on materials deposited along the creek downstream of the highway, there has likely been 3 to 4 smaller sized flood events (largely confined to the channel, or areas immediately adjacent to the channel) on Cold Spring Creek over the past 50 years.

5.2.4 More Recent Events on Cold Spring Creek

More recently, Cold Spring Creek has experienced flood events that have impacted the Fairmont Hot Springs Community.

In July 2011, an intense rain storm generated a sediment-laden flood (unclear whether it was a debris flow upstream of the Dam) that washed out the wooden weir at the FHSR water intake at 1300 m elevation. The flood event filled the reservoir at the Cold Spring Dam and partially filled the RDEK debris trap, both requiring excavation (Photos 34 and 35). Records of excavated volumes were not available. The FHSR water intake structure had to be reconstructed (Photo 36). The event also blocked culverts across the fan.

In July 2012, as a result of a higher than average snow pack, a late, but rapid, snowmelt, combined with a summer rainstorm and wet antecedent soil conditions, Fairmont Creek experienced a destructive debris flow event. Cold Spring Creek experienced a smaller sized event that led to debris infilling of the Dam reservoir and local flow diversions downstream.

In June 2013, Cold Spring Creek experienced a high flow event as a result of an intense summer rain storm. The closest BC Fire Weather Station at Emily Creek (elev. 1190 m), recorded 105.6 mm rain over a 4 day period. The storm caused problems on streams and rivers throughout the east Kootenays, including Fairmont Creek and Dutch Creek. The event led to debris infilling of the Cold Spring Creek Dam reservoir and the RDEK debris trap (and the channel in between the two). Excavation records from RDEK indicate that 190 dump truck loads of material were removed from the reservoir (estimated volume of 1100 m^3).

To summarize, known historic flood and debris flow events on Cold Spring Creek include:

- 1200 year old debris flow event observed in test pits on upper fan;
- July 2011 – sediment-laden flood; and,
- June 2013 – sediment-laden flood.

6.0 DEBRIS FLOW HAZARD AND RISK ASSESSMENT RESULTS

6.1 DEBRIS FLOW INITIATION POTENTIAL

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

6.1.1 Watershed Characteristics and Stream Geometry

Watershed characteristics that influence the debris flow initiation potential are stream gradient and confinement. The stream channel profile for Cold Spring Creek is shown in Figure 4.

Based on an average stream channel gradient greater than 25%, debris flow initiation is possible within Reaches 6 and 7. These reaches also have several contributing tributaries that are subject to debris flow and debris slides. Where these tributaries or side slopes have the potential to temporarily block the mainstem channel, then there is a potential for debris flow initiation when temporarily stored water is suddenly released.

The upper stream reaches (Reaches 6 and 7) are also well-confined by bedrock-controlled valley side slopes. Further downstream, Reach 5 is moderately confined by valley side slopes. With a wider valley bottom and a reduced channel gradient (18-20%), this reach is considered a zone of debris flow transport.

Between the FHSR Water Intake and the Cold Spring Dam, Reach 4 has an average stream gradient of 12-17%. Based on field observations of numerous debris jams and sediment wedges, this reach is considered a zone of debris flow transport and deposition. Reach 4 is well-confined by adjacent side slopes. These side slopes are steep, undercut in places, and exhibit instability. Sediment delivery to Cold Spring Creek has the potential to temporarily block flow, however, the reach gradient is not steep enough to initiate debris flows.

6.1.2 Sediment Sources and Supply

Significant 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 Cold Spring Creek flow through zones with major sources of sediment. The channel downcuts through sections underlain by easily erodible phyllite bedrock and unconsolidated till deposits.

The investigation found that headwater reaches above approximately 1620 m elevation are bedrock-dominated. Sediment supply along these upper reaches is primarily coarse rock fall debris, and small debris slides and debris flows from first- and second-order tributaries. Because of the bedrock control, the headwater reaches are 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 reaches of Cold Spring Creek, between 940 m and 1620 m elevation, have numerous sediment sources. Numerous small landslides, including small (100-500 m^3) slumps and eroding phyllite bedrock slopes were identified. At least one tributary (such as Tributary A) constitutes a significant sediment supply, and channel bedload deposits represent an abundant sediment supply through Reaches 5 and 6. These reaches have a gradient steep enough to entrain and mobilize debris.

Approximately 900 m upstream of the Dam on the south facing slope above the right bank, there appears to be a large, roughly terraced slope, interpreted to be a large deep-seated relict landslide. The headscarp, situated about 80 metres upslope of the creek at an elevation of approximately 1100 m, was observed during the air photo review. The upper headscarp exposes sandy-gravel glacial till, and the lower scarp adjacent to the creek exposes erodible phyllite bedrock.

The slide feature was inspected by Ministry of Forests Lands and Natural Resource Operations geomorphologist, Peter Jordan in 2012. At that time the 30 m high headscarp, unvegetated due to the south-west aspect, showed no indications of recent movement and was judged to be unlikely to present a hazard of large-scale failure or creek blockage (pers. comm., 2014). Currently there is no instability or bulging at the toe of the slope to suggest recent movement of the slope.

Debris entrainment is the destabilization and transport of unconsolidated material stored within the channel. Entrainment is an important factor for debris flow initiation potential. Within-channel destabilization occurs by the forces imposed by overriding water flow on channel gradients exceeding 10^o (18%). On Cold Spring Creek, this threshold gradient occurs along the mainstem channel upstream of the FHSR intake (elev. 1300 m) up to 1620 m elevation.

Based on the results of this assessment, the middle reaches of Cold Spring Creek are judged to have an abundant sediment supply. The ability for this material to be mobilized and transported down to the fan area is dependent upon downstream channel conditions (gradient and degree of confinement) and the nature of the triggering event.

6.1.3 Potential Triggering Events

Debris flows may be initiated by landslides or debris flows 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. This was considered to be the trigger mechanism for the 2012 Fairmont Creek debris flow.

Unstable and potentially unstable areas in the Cold Spring Creek watershed occur on slopes above the stream. Several tributaries, including Tributary A and a colluvial gully upstream of Tributary A, both enter the mainstem channel at an oblique angle. Both tributaries are significant sources of sediment to the mainstem channel and may prove capable of perpetuating an event downstream.

6.2 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.

It is judged that, based on lack of field-based evidence, large debris flows affecting extensive areas across the Cold Spring Creek fan are rare, with a low likelihood, or probability of occurrence.

Cold Spring Creek is more likely to have a higher frequency of small debris flows, or sediment-laden floods. Sediment and/or debris is more likely to move through the system in a series of small events, rather than few large events.

Along the mainstem channel, the length of stream channel considered to be capable of generating a debris flow was measured to be approximately 1,600 m. The depth of material available for transport within the channel was estimated based on field observations to determine a yield rate. Estimation is difficult and subjective along reaches lacking a shallow, firm substrate. Yield rate and distance were used to estimate the potential volume of material (magnitude) available for a debris flow.

Research by Busslinger (2010) found that average yield rates, for streams in the West Kootenays were 2-3 m^3/m, compared to 12-23 m^3/m in the Queen Charlotte Islands. The debris flow assessment on Gar Creek, which experienced a damaging landslide and debris flow in 2012, determined the yield rate to be 9 m^3/m (Nicol, et al. 2013). The Fairmont Creek debris flow assessment determined the yield rate to be 15 m^3/m (Clarke Geoscience, 2012).

Based on the similarity between the two watersheds, a yield rate of 15 m^3/m is used to estimate the potential debris flow magnitude Cold Spring Creek. Along a 1600 m long section of Cold Spring Creek, the volume of a potential debris flow is 24,000 m^3.

By 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).

Based on the hazard classification scheme outlined in Section 2.3.1, the debris flow magnitude and frequency assessment analysis is summarized here. Areas affected by the corresponding debris flow hazard classification are shown in Figure 5:

- The upper part of the fan, in close proximity of the Dam, is rated MODERATE hazard because of the potential for a moderate sized debris flow event (20,000 to 100,000 m^3) and a moderate frequency of occurrence (500 to 2500 year return period). The reservoir is not sufficient to provide full protection for larger sized events, so some nearby areas are subject to a MODERATE hazard;
- Areas adjacent to the channel downstream of the Dam and along relict channels and/or areas of low topographic relief that may be affected by channel diversions, are rated MODERATE hazard. The hazard rating is assigned due to the potential of being affected by a lower magnitude event (based on an estimated debris flow magnitude less than 20,000 m^3) and a high frequency of occurrence (based on a return period less than 2500 years);
- Downstream of the highway, only areas immediately adjacent to the channel are rated MODERATE hazard. The downstream reaches are potentially subject to low magnitude events (1,000 to 20,000 m^3) occurring at a high frequency (10 to 500 years). It is assumed that the channel remains appropriately sized and sufficiently armoured to contain the majority of the flow volume during one of these events;
- Areas of the Cold Spring Creek fan upstream of the highway and along a relict channel downstream of the highway are rated LOW debris flow hazard. These areas may experience low magnitude events very infrequently (return period greater than every 2500 years). These identified areas are potentially affected by channel avulsion, or diversion of flows to the north side of the valley, upstream of the Dam. The hazard condition in this area depends largely on the channel capacity, and as the channel becomes infilled with sediment, the channel becomes less capable of containing large sediment-laden flows, or debris flows.

6.3 RISK ANALYSIS RESULTS

6.3.1 Elements at Risk

The elements at risk from a debris flow event on Cold Spring Creek are situated on the fan as delineated on Figure 6 and include the following:

- Fairmont Hot Springs Resort Water Intake structure at 1300 m elevation;
- Cold Spring Creek Dam at 940 m elevation;
- Numerous (approx. 100) single-family dwellings;

- Fairmont Hot Springs business district (grocery, restaurants, businesses, gas station);
- Approximately 500 residents live in the Fairmont Hot Springs community, but the population greatly increases in the summer due to tourism;
- The north end of the Mountainside Golf Course and Creekside Golf Course and associated infrastructure;
- Highway 93/95; and
- The only access to the main buildings of the Fairmont Hot Springs Resort (Fairmont Resort Road).

6.3.2 Risk Analysis and Mapping

The results of the qualitative risk analysis provide an indication of predicted debris flow impacts across the fan. The debris flow risk assessment results are shown on the Risk Map, provided as Figure 6. The risk zones delineated on the map define zones of approximately equal debris flow composition, depth and velocity (estimated using professional judgement). The results indicate that limited areas of the fan are susceptible to impacts from debris flows. Risk zones, shown in Figure 6, are described as follows:

High Risk Areas

High risk areas are classified as occurring within the direct impact zone of a debris flow. High risk zones are subject to rapidly-moving, high discharge debris flows. Material transported includes large boulders and woody debris. This zone includes areas mapped as moderate hazard on the upper fan of Cold Spring Creek, just downstream of the fan apex. At the downstream end of this zone, at approximately Fairmont Resort Road, the composition of debris flow is expected to change based on a loss of channel confinement and decrease in slope. By the time a large event reaches this point, the larger boulder sized material will deposit, with smaller sized material continuing down slope along preferential pathways.

Moderate Risk Areas

Moderate risk areas, or the indirect impact zone, includes areas at the mid to lower parts of the fan. Specifically, these are areas adjacent to Cold Spring Creek from Fairmont Resort Road downstream to the RDEK debris trap. Moderate risk zones are those areas mapped as moderate hazard because of the higher frequency of smaller scale events, or the lower frequency of large scale events. Within the zone, areas are subject to indirect impacts from debris flow or debris flood events. Through these areas, lower peak flows would be expected, so lower impacts are also expected. Debris, comprised of gravel to cobble-sized material and smaller woody debris, may still inundate or bury areas and objects. Judgement was used to delineate areas based on topography, and the presence of drainage structures that are prone to blockage. Areas classified as moderate hazard are based on an interpretation of how debris flow surges will follow the slope.

Low Risk Areas

The low risk zone, or flood zone, includes areas that may potentially experience flooding due to debris flow. Transported material is fine-grained (muddy) and is mostly a "nuisance" for clean up after an event. These areas interpreted as low risk 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 the Community is considered very important.

6.4 CLIMATE CHANGE AND LAND SURFACE CHANGE CONSIDERATIONS

The results of the debris flow risk assessment represent a snapshot in time, based on conditions observed at the time of the assessment (2014). 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, 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 Cold Spring 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 Cold Spring 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.

7.0 DEBRIS FLOW RISK MITIGATION RECOMMENDATIONS

The results of the debris flow hazard and risk assessment indicate that portions of the Cold Spring Creek fan are at risk from damaging debris flow events. Based on the results of the risk assessment, recommended options for debris flow risk mitigation are identified below.

7.1 EXISTING FLOOD PROTECTION STRUCTURES

Flood protection structures were established on Cold Spring Creek in the mid-1990s when that portion of the Community was subdivided. These include: the Cold Spring Dam, and a 484 m long armoured channel and debris trap downstream of the highway in the Riverside area. Both are listed in the provincial Flood Protection Structural Works database and are regulated structures as defined in the *Dike Maintenance Act.*

Reid Crowther (1995) indicated the possibility that a sufficiently large debris flow would overcome the channel at the highway. A deflector berm was recommended to direct flows back into the channel or road ditch. There is currently no evidence of a deflection berm south of Cold Spring Creek on the downstream side of the highway. An unfinished residential development is currently situated where the berm would have been located. It is possible that the deflector berm was removed during development activities on the property and not reconstructed.

The Cold Spring Dam is owned by, and the responsibility of, Fairmont Hot Springs Resort Ltd. (Dam File No. D330122-00). The reservoir at the Cold Spring Dam, although not designed to be a debris flow protection structure, functions to detain approximately 1,500 to 2,000 m^3 of sediment (when cleared).

The hazard assessment takes into consideration and assumes the ongoing protective role of the Cold Spring Creek Dam. The dam is expected to detain sediment from smaller-sized events, which would normally proceed downstream onto the fan area if it weren't there. It is judged, however, that the Dam will not be able to detain the largest events on Cold Spring Creek and that in the event of a large event (i.e. any event that exceeds the storage capacity of the reservoir at the time of occurrence), that the Dam would be overtopped by material and sediment-laden flows. It is also unclear whether the structural integrity of the dam is sufficient to withstand impact by large (>1.5 m diameter) boulders, should they be transported downstream to the dam by debris flow.

The armoured channel and debris trap on lower Cold Spring Creek are the responsibility of the RDEK Service Area. The registered portion of Cold Spring Creek is 484 m long, and consists of a riprap-lined channel, with adjacent machine access. The associated debris trap has an estimated storage capacity of 800 to 1,600 m^3. RDEK is responsible for inspection and maintenance activities.

The Cold Spring Creek fan lies within a Service Area, which was first established in 1996 to provide a means of providing operational maintenance of the flood and debris control works. RDEK recently expanded the Service Area to incorporate areas affected by Fairmont Creek and Cold Spring Creek (RDEK – Fairmont Flood and Landslide Service Establishment Bylaw No. 1208, 1996 – Amendment Bylaw No 1, 2014).

In the 1996 Service Area document, the works reference the dam site and the constructed channel in the Riverside area. Maintenance activities, budgeted at $5,000 per year (1996 dollars), include:

- annual inspection and reporting of the protective works; and,
- debris clean out every 5 to 7 years.

7.2 RECOMMENDATION 1 - MAINTAIN THE EXISTING FLOOD PROTECTION WORKS

The Cold Spring Creek hazard and risk assessment was completed on the assumption that the existing flood protection structures would continue to function. Thus, it is recommended that inspection and maintenance activities continue on at least an annual basis.

The only Dam inspection report on file with the Ministry of Forests Lands and Natural Resource Operations was completed in 1999 by Cochrane Engineering. Recommended maintenance activities based on the results of their visual inspection of the Cold Spring Dam are to:

- Replace backfill along the downstream face of the dam that was possibly eroded when flood flows overtopped the dam crest.
- Remove accumulated debris in the reservoir that would be part of an ongoing maintenance program. (The inspection report did not provide an estimate of reservoir storage capacity.)

Although a cross-sectional survey of the channel above the dam was not provided, the 1999 Cochrane Engineering report indicated that the potential for channel avulsion above the dam is low due to downcutting of the channel.

The RDEK submits inspection reports to the Inspection of Dikes on an annual basis for the 484 m long section of bank protection and debris trap located downstream of the highway. Inspection reports from 2011, 2012 and 2013 were obtained from the RDEK. The reports indicate that the channel has remained stable, and has functioned as designed. Ongoing maintenance and inspection is recommended.

With respect to the missing berm on the south side of Cold Spring Creek, it is judged that, based on the current channel condition and the results of the debris flow hazard assessment, a deflector berm in this location is not considered to be necessary.

7.2.1 Recommended Inspection, Maintenance and Assessment Activities at Cold Spring Dam

Based on the required ongoing protective role to be provided by the existing structures, a more formalized inspection, monitoring and reporting program is recommended.

Inspection activities at the Cold Spring Creek Dam shall be completed at least once per year in the spring. Inspections shall be documented in written and photographic form, and shall include the following components:

- Inspect the condition of the concrete spillway and determine whether there has been a loss of fill indicated by erosion at the toe below the downstream face of the dam;
- Inspect the reservoir and determine the degree of infilling. Estimate the approximate depth of water in the reservoir and measure the length and width of the reservoir using a laser range finder to determine the approximate storage volume;
- Walk at least 100 m upstream from the mouth of the reservoir to assess the degree of channel infilling and to measure the streambank height to determine the potential for streambank overtopping; and,
- Retain records of excavated volumes and material gradations.

Maintenance activities at the Cold Spring Dam shall include addressing any deficiencies or issues identified in the inspection. Inspection and maintenance activities shall also be completed after any flood event that has resulted in overtopping of the dam crest. Maintenance activities will include excavating any sediment from the reservoir such that reservoir storage capacity is maximized.

Although it is not formally addressed in the Canadian Dam Association or BC Dam Safety Guidelines, it is also recommended that the Dam Consequence Assessment be reconsidered to account for the results of this assessment. The consequence classification and associated dam safety program should consider the protective role being offered by the Dam. Any future dam safety work should also address the structural integrity of the dam when subject to impact by boulders and large woody debris entrained in a debris flow.

7.2.2 Recommended Inspection and Maintenance Activities at the RDEK Channel and Debris Trap

Inspection and maintenance activities at RDEK Channel and Debris Trap shall continue to be completed once per year in the spring. Inspections shall be documented in written and photographic form, and shall include the following:

- Inspect the condition of the channel, upstream of the debris trap, to determine whether there has been a loss of armour or whether infilled sediment has reduced the capacity of the channel;

- Inspect the debris trap and determine the degree of infilling. Estimate the approximate depth of water in the debris trap and measure the length and width of the debris trap using a laser range finder to determine the approximate storage volume; and,
- Inspect the channel downstream of the debris trap to determine whether sediment is restricting flow into the culvert and through the channel connecting to the Columbia River.

7.2.3 Document Storage and Retention

It is recommended that annual inspection and monitoring reports be continue to be produced and kept in a central file with the RDEK, such that documents lie within the public realm. RDEK is well suited to integrate the monitoring, inspection and maintenance activities on both structures.

Table 6: Estimated Costs for Inspection, Maintenance and Assessment of the Cold Spring Creek Dam and RDEK Channel and Debris Trap

Design and Construction	Unit	Quantity	Unit Cost	Total
Dam Consequence Review	l.s.	1	$20,000	$20,000
Contingency			10%	$2,000
		TOTAL		$22,000

Annual Maintenance	Unit	Quantity	Unit Cost	Total
Inspection and monitoring		every year	$2,500	$2,500
Material clean out		every 5 years	$20,000	$4,000
		TOTAL	**$22,500**	**$6,500**

7.3 RECOMMENDATION 2 – INCREASE CAPACITY OF REACH 3

The results of the debris flow hazard assessment indicate that, while the culverts along Reach 3 of Cold Spring Creek are capable of passing the 200-year flood flow, they are likely unable to convey flows with any significant sediment load. In July 2012, flooding impacts on the Fairmont Creek fan occurred in areas where culverts were overwhelmed or plugged. In 2012 and in 2013, high flow events on Cold Spring Creek plugged culverts and caused localized road damage. The lack of maintenance of drainage structures affected the manner in which areas were inundated during these flood events and the same type of impact is likely to occur on Cold Spring Creek in the future.

Because of the likelihood for sediment-laden flooding on lower Cold Spring Creek, replacement of the four (4) culverts above the highway is recommended.

It is also recommended that a cross-section and longitudinal survey of Reach 3 of Cold Spring Creek be completed. This would also include sections of the adjacent riparian corridor. Based on observed infilling and debris jams there is the potential for overbank flooding and/or avulsion. This potential for flooding increases the risk of inundation and damage to adjacent properties and to the highway.

For other areas on the Cold Spring Creek fan, regular inspection and maintenance of culverts and ditches is recommended to ensure that culvert entrances are not blocked and are able to perform intended. Culverts and ditches located on private land are the responsibility of the land owner. Otherwise, the inspection and maintenance of culverts owned by MOTI are the responsibility of the roads maintenance contractor.

Table 7: Estimated Costs for Assessing the Channel Capacity and Replacing Four Culverts on Cold Spring Creek (Reach 3)

Design and Construction	Unit	Quantity	Unit Cost	Total
Hydraulic capacity survey and design engineering	l.s.	1	$25,000	$25,000
General costs (bonding/mob/permits/ environmental)	l.s.	1	$5,000	$5,000
Supply and install culvert (800 mm diam CSP)*	Lin. M	16	$350	$5,600
Supply and Install riprap**	m^3	25	$300	$7,500
Engineering and Management			15%	$3,500
Contingency			10%	$4,600
		TOTAL		**$51,200**

Annual Maintenance

	Unit	Quantity	Unit Cost	Total
Inspection and monitoring		every year	$2,000	$2,000
Material clean out		every 5 years	$10,000	$2,000
		TOTAL	**$12,000**	**$4,000**

* -To be confirmed during design

** - Based on 2013 Alberta Unit Price Average Report

7.4 RECOMMENDATION 3 – RE-ESTABLISH HIGHWAY DITCH DRAINAGE

Results of the field investigation found that the highway ditch downstream of the Cold Spring Creek culvert (on the east side of the highway) was partially blocked. There is also no sign of a second downstream culvert. It was neither observed in the field, nor indicated on the MOTI infrastructure database. There is, however, a culvert approximately 250 m downstream but not well connected by the highway ditch. This culvert is thought to be a remnant of a relict drainage channel across the Creekside Golf Course.

To reduce the likelihood for overtopping of the highway, it is recommended that the eastern highway ditch be re-established to effectively convey overflows from Cold Spring Creek. The base of the ditch should be raised above the base of Cold Spring Creek such that only extreme high flows are diverted before overtopping the highway.

Based on the location and presence of development on the west side of the highway, it is not considered necessary to install a secondary culvert below the highway. Nor is it considered necessary to re-establish the missing deflection berm.

Table 8: Estimated Costs for Re-establishing Highway Ditch Drainage

Design and Construction	Unit	Quantity	Unit Cost	Total
Hydraulic capacity survey and design engineering (part of Reach 3 assessment)	l.s.	1	$5,000	$5,000
General costs (bonding/mob/permits/ environmental)	l.s.	1	$1,500	$1,500
Excavate material	Lin. M	10	$350	$3,500
Supply and Install riprap	m^3	10	$300	$3,000
Engineering and Management			15%	$1,500
Contingency			10%	$1,500
		TOTAL		**$16,000**

Annual Maintenance

	Unit	Quantity	Unit Cost	Total
Inspection and monitoring		every year	$1,000	$1,000
Material clean out		every 5 years	$2,500	$500
		TOTAL	**$3,500**	**$1,500**

7.5 RECOMMENDATION 4 – CONDUCT A DETAILED SURVEY OF THE VALLEY AREA UPSTREAM OF THE DAM

There is evidence of historic debris flow within vicinity of the Dam and within the valley bottom upstream of the Dam. These include debris flow levee deposits, buried soil horizons exposed in the stream banks, and incongruous large boulders. The area lies within a mature (>70 year old) forest, which suggests a low frequency of debris flow occurrence. Downcutting of the channel along the reach just below the fan apex may have reduced the potential for avulsion at the top of the fan. To better understand this risk to the upper fan area, further assessment is recommended.

Further assessment in the 1 km^2 area within the vicinity of the Dam and immediately upstream of the Dam may be conducted by LiDAR survey. LiDAR, is a remote sensing technology that measures laser-generated reflected light to map physical features to create very high resolution digital elevation maps. Use of LiDAR increases the ability to detect subtle topographic features beneath the vegetative canopy.

More detailed analysis of the ground surface in the area, combined with a hydraulic capacity study, would enable a more precise determination of avulsion potential and whether the channel is able to convey floods or debris flows through to the Dam.

A quote for Lidar mapping was provided by Mr. Glenn Granger of Eagle Mapping Ltd., based in Port Coquitlam, BC (www.eaglemapping.com). The quote is based on providing airborne acquired mapping with a point density of 8 points/m^2, providing bare earth digital elevation model, showing 1 m contours and an option to provide digital orthophotography with 10 cm resolution. Costs shown in Table 9 assume both lidar and orthophotography as a stand-alone project. Costs are reduced if the project is not time-sensitive and can be combined with other projects in the area.

Table 9: Estimated Costs for Detailed LiDAR Survey and Assessment of Channel Capacity at the Fan Apex

Design and Construction	Unit	Quantity	Unit Cost	Total
LiDAR mapping and digital orthophotography of 1 km^2 area*	l.s.	1	$12,000	$12,000
Interpretation of lidar and hydraulic capacity assessment	l.s.	1	$15,000	$15,000
		TOTAL		**$27,000**

* - costs provided for a stand-alone project by Eagle Mapping Ltd. (GST not included). Costs are reduced for Lidar only, or if combined with other projects.

7.6 RECOMMENDATION 5 – LAND USE PLANNING POLICIES

There are limited opportunities for land use planning as a risk mitigation tool on the Cold Spring Creek fan as it is already developed. Land use planning measures could, however, be considered for new development applications on existing properties and in conjunction with the recommended measures listed above to minimize risk. These include:

- Establish a Development Permit (DP) Area on the Cold Spring Creek fan (as shown on Figure 6). 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 there is no risk of increasing hazard to neighbouring properties;

- 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.

7.7 OTHER RECOMMENDATIONS

Other recommendations that arise from the assessment include:

- Periodic inspection of the Cold Spring Creek channel upstream of the Dam 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. This review should be completed every 5 years, or after a significant (i.e. damaging) flood event.

8.0 SUMMARY AND CONCLUSIONS

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

- The Cold Spring Creek watershed is more prone to sediment-laden floods than it is to debris flow. However, debris flows do occur on steep tributaries and in the upper reaches of the watershed;
- Potentially hazardous debris flows and sediment-laden floods occur relatively frequently but do not necessarily extend down the fan past the Cold Spring Creek Dam;
- The Cold Spring Creek Dam reservoir has infilled with sediment due to flooding in 2011, 2012 and 2013. Significant infilling is not documented prior to 2011;

- A hazard and risk assessment predicted flow paths and predicted consequences across areas of the fan with the assumption that existing flood protection structures (Cold Spring Creek Dam and RDEK Debris Trap) remain and function as intended;
- Based on the likely composition of future debris flows, boulder-sized debris flow material and high flow velocities, a high risk classification is assigned to a small area at the top of the fan in the vicinity of the Cold Spring Creek Dam.
- 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 formalized inspection and maintenance program of existing protective structures, replacement of culverts above the highway, and re-establishing the overflow ditch at the highway, could reduce the risk to properties and infrastructure.

9.0 CLOSURE AND REPORT LIMITATIONS

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, information from air photos, and information available at the time of report preparation. 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 damages, if any, suffered by any third party as a result of decisions made or actions based, or lack thereof, on this report.

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

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10.0 REFERENCES

APEGBC. 2010. Guidelines for Legislated Landslide Assessments for Proposed Residential Development in British Columbia. Association of Professional Engineers and Geoscientists of British Columbia. Vancouver, BC.

APEGBC. 2012. Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC. Association of Professional Engineers and Geoscientists of British Columbia. Vancouver, BC.

BC Ministry of Transportation (MOT). 2005. Guide to Rural Subdivision Approvals, Sections 2.3.1.06 and 2.3.1.07.

BC Soil Survey. 1988. Soils of the East Kootenay Map Area. Soil Survey Report #20, Canal Flats 82J/SW, 1:100 000 scale. Victoria, BC.

Boyer, D. 1989. Debris Torrent Concerns Cold Spring and Fairmont Creeks. B.C. Water Management Branch. Nelson, BC.

Busslinger, M. 2010. Emperical rules for debris flow travel distance: A comparison of Field Data. M.A.Sc. Thesis, Department of Engineering. University of British Columbia, Vancouver, BC.

Cochrane Engineering. 1999. Flood Protection Works Inspection – Cold Spring Creek at the Water Supply Dam. File 35329. Letter to Fairmont Hot Springs Resort Ltd. Dated Aug. 18, 1999. Calgary, AB.

Cochrane Engineering. 1999. Flood Protection Works Inspection – Cold Spring Creek Downstream of Highway 93. File 35329. Letter to Fairmont Hot Springs Resort Ltd. Dated Aug. 18, 1999. Calgary, AB.

Fairmont Hot Springs Community Association. 2012. Report prepared for the B.C. Ministry of Transportation. Dated October 17, 2012. Fairmont Hot Springs, BC.

Haughton, D.R. 1978. Geological Hazards and Geology of the South Columbia River Valley (Edgewater to Canal Flats), British Columbia. Ministry of Highways and Public Works, Geotechnical and Materials Branch, Victoria, BC.

Henderson, G.G.L. 1954. Geological Map of the Stanford Range. B.C. Department of Mines. Bulletin #35. Victoria, BC.

Huebl, J. and G. Fiebiger. 2005. Debris-flow mitigation measures. In: Debris-flow hazards and related phenomena. M. Jakob and O. Hungr (eds.). Praxis. Springer. Berlin.

Hungr, O., Morgan, G.C. and Kellerhals, R. 1984. Quantitative analysis of debris torrent hazards for design of remedial measures. Canadian Geotechnical Journal. No. 21, pp. 663-667.

Hungr, O., D.F. VanDine and D.R. Lister. 1987. Debris flow defenses in British Columbia. Geological Society of America. Reviews in Engineering Geology. Vol. 7, pp. 201-222.

Jackson, L.E., Kostachuk, R.A. and G.M. MacDonald. 1987. Identification of debris flow hazard on alluvial fans in the Canadian Rocky Mountains. In: J.E. Costa and G.Z. Wieczorek (eds.), Debris Flows/Avalanches: Process, Recognition and Mitigation (Reviews in Engineering Geology No. V11). Geological Society of America. Boulder, CO.

Jakob, M. 2005. Debris-flow hazard analysis. In: Debris-flow Hazards and Related Phenomena. M. Jakob and O. Hungr (eds.). Praxis. Springer. Berlin.

Jakob, M., D. Anderson, T. Fuller, O. Hungr, and D. Ayotte. 2000. An unusually large debris flow at Hummingbird Creek, Mara Lake, British Columbia. Canadian Geotechnical Journal. Vol. 37, pp. 1109-1125.

Jakob, M. and P. Jordan. 2001. Design flood estimates in mountain streams – the need for a geomorphic approach. Can. J. Civ. Eng. Vol 28, pp. 425 – 439.

Jordan, P. 2012. The Testalinden Creek debris flow of 2010 near Oliver, British Columbia. In: Proceedings of the International Symposium on Landslides. Banff, AB.

Kerr Wood Leidal. 2012. Technical Memorandum. Fairmont Creek Flood Recovery Assessment. File 257.009-300. Prepared for the Regional District of East Kootenay. Vernon, BC.

Kerr Wood Leidal. 2014. DRAFT Cold Spring Creek Consequence Assessment. KWL Project 3331.001. Dated: June 20, 2014. Prepared for Fairmont Hot Springs Resort Ltd. Vernon, BC.

Ministry of Water Land and Air Protection. 2004. Flood Hazard Area Land Use Management Guidelines. Guidance For Selection of Qualified Professionals and Preparation of Flood Hazard Assessment Reports. Victoria, BC.

Nicol, D., P. Jordan, D. Boyer, D. Yonin. 2013. Johnson's Landing Landslide Hazard and Risk Assessment. Prepared for the District of Central Kootenay. Nelson, BC.

Norford, B.S. and M.P. Cecile. 1994. Cambrian and Ordovician volcanic rocks in the McKay Group and Beaverfoot Formation, western ranges of the Rocky Mountains, south-eastern BC. Current Research 1994-B. Geological Survey of Canada, pp. 83-90.

Reid Crowther & Partners Ltd. 1993. Coldspring Creek Diversion Stage 2. Prepared for Fairmont Hot Springs Resort Ltd. File 23849-C00-4. Calgary, AB.

Reid Crowther & Partners Ltd. 1994a. Fairmont Hot Springs Resort Area Terrain Hazard Assessment (DRAFT). Prepared for Fairmont Hot Springs Resort Ltd. File 23849-3. Calgary, AB.

Reid Crowther & Partners Ltd. 1994b. Fairmont Hot Springs Resort Area Fairmont Creek Debris Control Design. Prepared for Fairmont Hot Springs Resort Ltd. File 23849-4. Calgary, AB.

Reid Crowther & Partners Ltd. 1995. Fairmont Hot Springs Resort Area – Coldspring Creek – Highway 93 Crossing. Prepared for Fairmont Hot Springs Resort Ltd. File 23849-c01-4. Calgary, AB.

Ryder, J. and T. Rollerson. 1977. Terrain Inventory Mapping – Mount Abruzi, Fairmont Hot Springs, BC. Scale 1:50 000, downloaded from iMAP BC.

Schnorbus, M., K. Bennett, and A. Werner. 2010a. Quantifying the Water Resource Impacts of Mountain Pine Beetle and Associated Salvage Harvest Operations Across a Range of Watershed Scales: Hydrologic Modelling of the Fraser River basin. Information Report: BC-X-423, Natural Resources Canada, Canadian Forestry Service, Pacific Forestry Centre, Victoria, British Columbia, 64 pp.

Van Dine, D.F. 1985. Debris flows and debris torrents in the Southern Canadian cordillera. Canadian Geotechnical Journal. Vol. 22, pp. 44-68.

Van Dine, D.F. 1996. Debris flow control structures for forest engineering. B.C. Ministry of Forests Research Branch. Working Paper 08/1996. Victoria, BC.

Wilford, D.J., M.E. Sakals, J.L. Innes, R.C. Sidle, and W.A. Bergerund. 2004. Recognition of debris flow, debris flood and flood hazard through watershed morphometrics. Landslides. Springer-Verlag. pp. 61-66.

Wise, M.P., G.D. Moore, and D.F. VanDine (editors). 2004. Landslide Risk Case Studies in Forest Development Planning and Operations. B.C. Ministry of Forests, Research Branch, Land Management Handbook No. 56. Victoria, B.C

11.0 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 saturated non-plastic debris, including mud, soil, rock, and woody debris 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.

Debris Flood: a very rapid, surging flow of water, heavily charged with debris. Compared with a debris flow, a debris flood is more fluid, containing more water than debris.

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 potential harm—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.

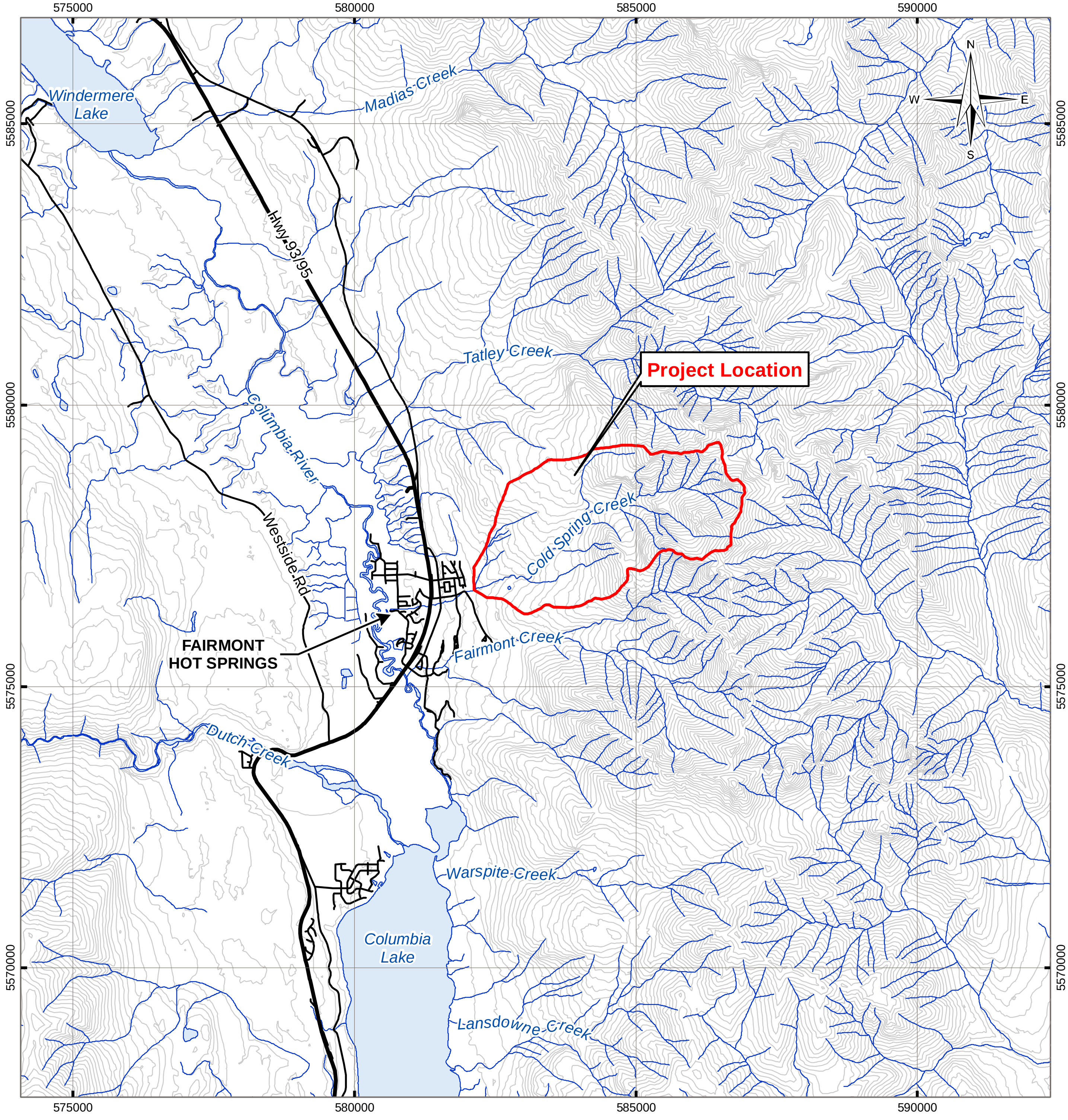
Stakeholders are any individual, group, or organization able to affect, be affected by, or believe they might be affected by, a decision or activity. Note that decision-makers are stakeholders (CSA 1997).

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.

FIGURES



LEGEND

- Cold Spring Creek Watershed
- Highway
- Other Road
- Contour (40 m)
- Watercourse
- Waterbody

NOTES
Base data source:
CanVec (1:50,000)
Watershed from DataBC

STATUS
ISSUED FOR REVIEW

COLD SPRING CREEK

Project Location Map

PROJECTION UTM Zone 11	**DATUM** NAD83	**CLIENT** RDEK

Scale: 1:100,000
2 1 0 2
Kilometres

FILE NO.
K13103363-01_Figure01_Site.mxd

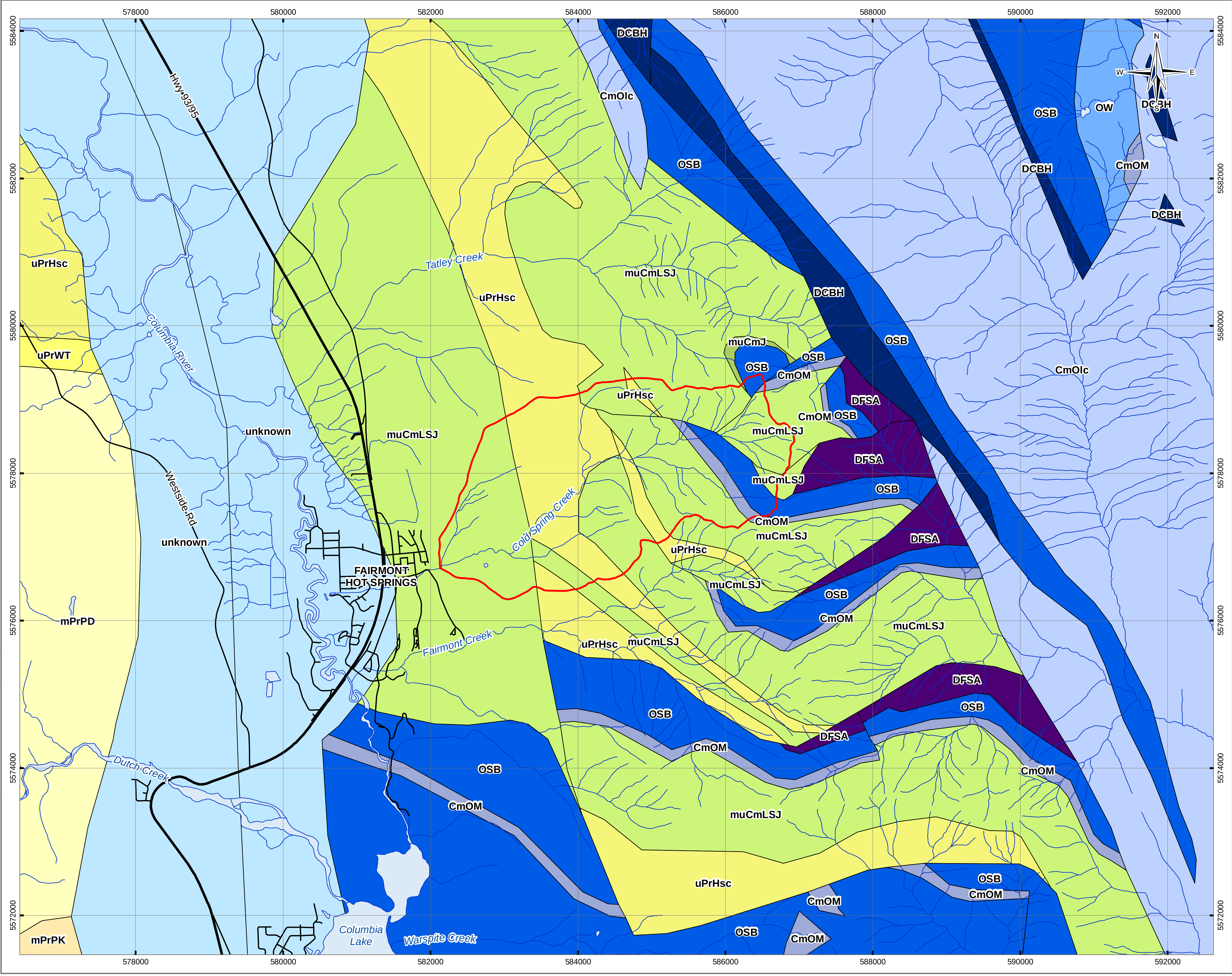
PROJECT NO.	**DWN**	**CKD**	**APVD**	**REV**
K13103363-01	SL	MEZ	JC	0

OFFICE	**DATE**
Tt EBA-VANC	December 11, 2014

TETRA TECH

Figure 1

Q:\Vancouver\GIS\ENGINEERING\K131\K13103363-01_ColdSpring\Maps\K13103363-01_Figure01_Site.mxd modified 12/11/2014 by stephanie.leusink



LEGEND

- Cold Spring Creek Watershed
- Highway
- Other Road
- Watercourse
- Waterbody

Bedrock Geology

- DCBH - Paleozoic - Cedared, Burnais and Harrogate Formations dolomitic carbonate rocks
- DFSA - Paleozoic - Fairholme Group - Sassenach and Alexo Formations limestone, slate, siltstone, argillite
- OSB - Paleozoic - Beaverfoot Formation dolomitic carbonate rocks
- OW - Paleozoic - Mount Wilson, Skoki, Tipperary, Glenogle, Survey Peak and Lyell Formations undivided sedimentary rocks
- CmOlc - Paleozoic - Unnamed limestone, slate, siltstone, argillite
- CmOM - Paleozoic - McKay Group mudstone, siltstone, shale fine clastic sedimentary rocks
- muCmJ - Paleozoic - Jubilee Formation dolomitic carbonate rocks
- muCmLSJ - Paleozoic - Lyell, Sullivan or Jubilee Formations limestone, marble, calcareous sedimentary rocks
- mPrPD - Proterozoic - Purcell Supergroup - Dutch Creek Formation undivided sedimentary rocks
- mPrPK - Proterozoic - Purcell Supergroup - Kitchener Formation dolomitic carbonate rocks
- uPrHsc - Proterozoic - Horsethief Creek Group coarse clastic sedimentary rocks
- uPrWT - Proterozoic - Windermere Supergroup - Toby Formation conglomerate, coarse clastic sedimentary rocks
- unknown - Age Unknown -

NOTES

Base data source:
BC Digital Geology Data, Release 1.0, January 2005.
CanVec (1:50,000)

STATUS
ISSUED FOR REVIEW

COLD SPRING CREEK

Bedrock Geology

PROJECTION	DATUM	CLIENT
UTM Zone 11	NAD83	RDEK

Scale: 1:50,000

1 0.5 0 1

Kilometres

TETRA TECH EBA

FILE NO.
K13103363-01_Figure02_Geology.mxd

PROJECT NO.	DWN	CKD	APVD	REV
K13103363-01	SL	MEZ	JC	0

OFFICE	DATE
Tt EBA-VANC	December 11, 2014

Figure 2

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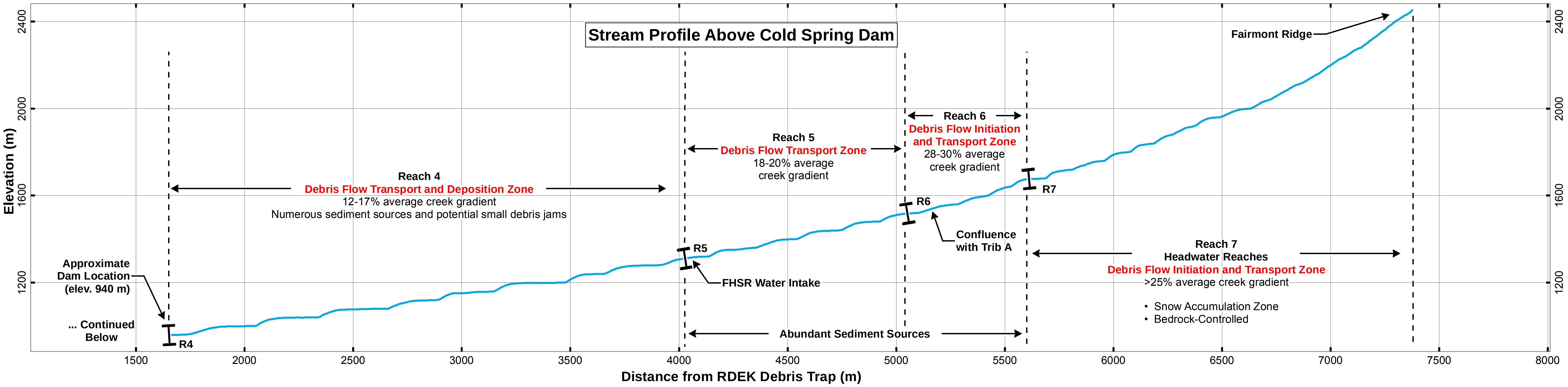

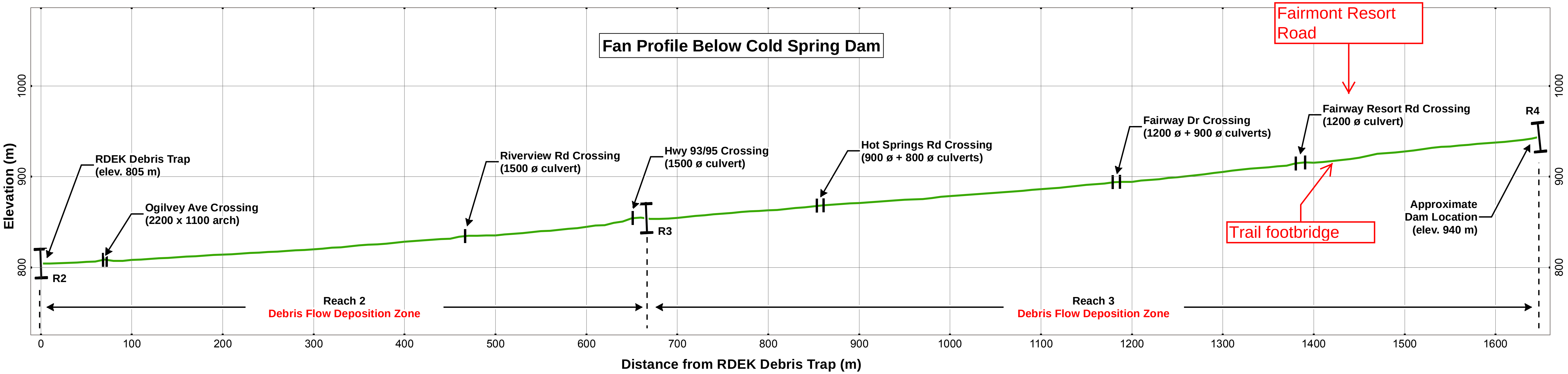

LEGEND

- ⊢⊣ Reach Break (RX)
- ― Stream Profile (CanVec)
- ― Fan Profile (FHSR)

NOTES

1. Columbia River 200-year Flood Construction Level = 804.0 m (Ministry of Environment, 1978).
2. Stream Profile based on CanVec (1:50,000) data.
3. Fan Profile based on CAD data provided by FHSR.

STATUS
FOR INTERNAL USE ONLY

COLD SPRING CREEK

Cold Spring Creek
Stream Channel Profile

PROJECTION	DATUM	CLIENT
N/A	N/A	RDEK

FILE NO.
K13103363-01_Figure03_StreamProfile.mxd

PROJECT NO.	DWN	CKD	APVD	REV
K13103363-01	SL	MEZ	JC	0

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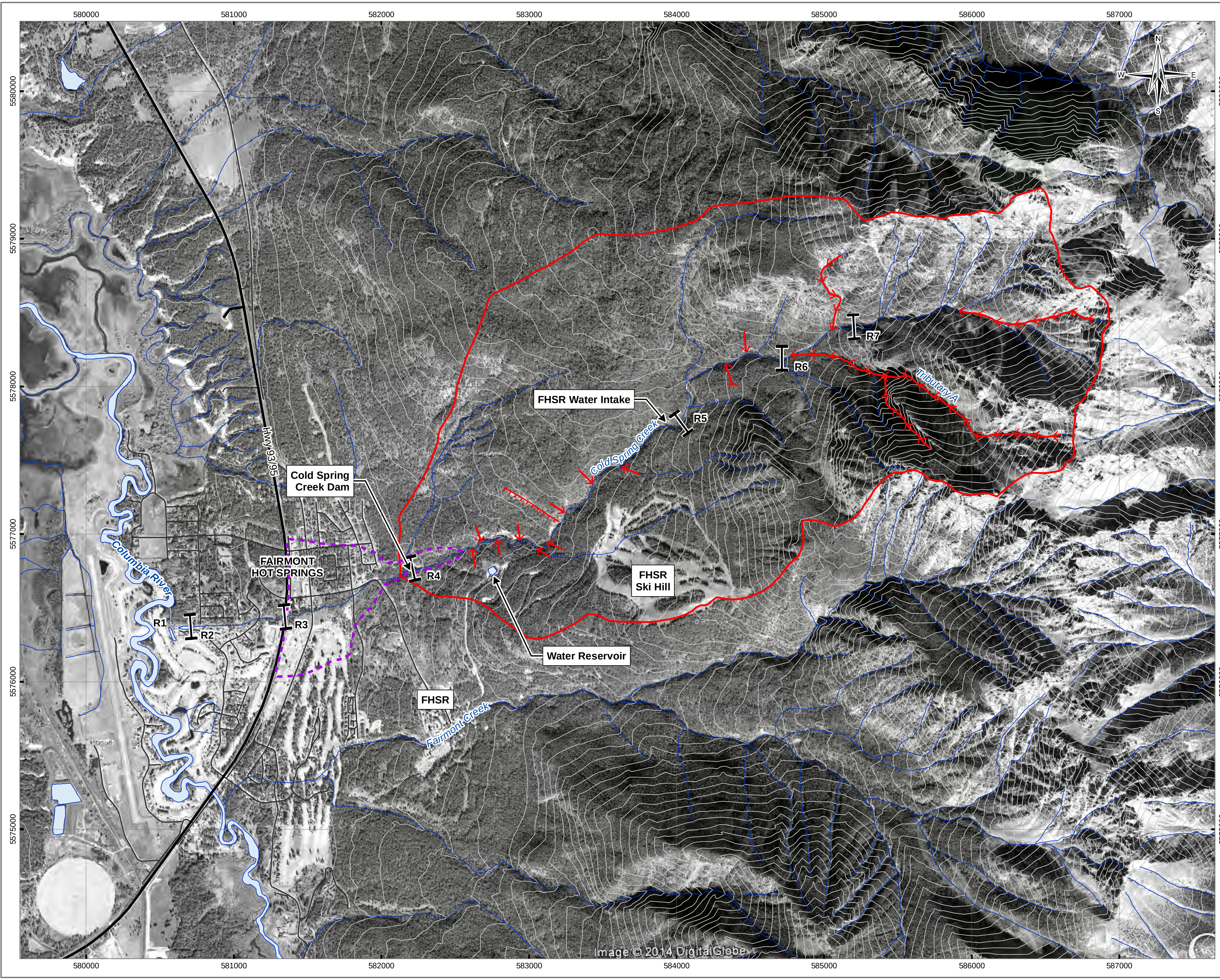
DATE
December 11, 2014

TETRA TECH EBA

Figure 3

Q:\Vancouver\GIS\ENGINEERING\K131\K13103363-01_ColdSpring\Maps\K13103363-01_Figure03_StreamProfile.mxd modified 12/11/2014 by stephanie.leusink



Q:\Vancouver\GIS\ENGINEERING\K131\K13103363-01_ColdSpringMaps\K13103363-01_Figure04_Watershed.mxd modified 12/11/2014 by stephanie.leusink

LEGEND

- Reach Break (RX)
- Stream Connection to the Columbia River (approx.)
- Sediment Sources (Landslides, Debris Flows and Exposed Bank Slopes)
- Scarp of Large Relict Landslide
- Cold Spring Creek Fan (approx.)
- Cold Spring Creek Watershed
- Highway
- Other Road
- Contour (40 m)
- Watercourse
- Waterbody

NOTES
Base data source:
CanVec (1:50,000)
Watershed from DataBC
Imagery from Google; Digital Globe (2012)

STATUS
ISSUED FOR REVIEW

COLD SPRING CREEK

Watershed Overview

PROJECTION UTM Zone 11
DATUM NAD83
CLIENT RDEK

Scale: 1:25,000
400 200 0 400
Metres

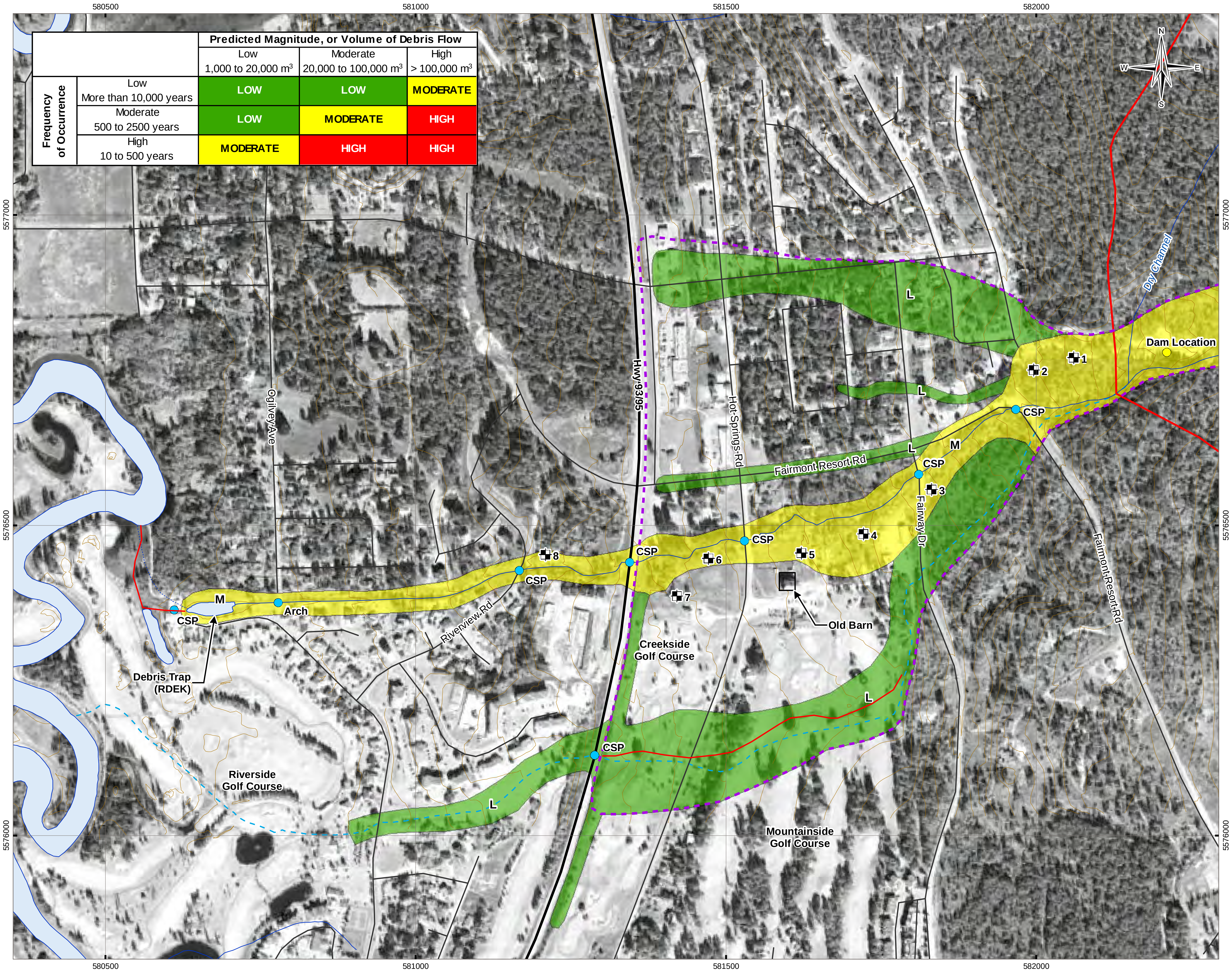
TETRA TECH EBA

FILE NO.
K13103363-01_Figure04_Watershed.mxd

PROJECT NO.	DWN	CKD	APVD	REV
K13103363-01	SL	MEZ	JC	0

OFFICE Tt EBA-VANC
DATE December 11, 2014

Figure 4



		Predicted Magnitude, or Volume of Debris Flow		
		Low 1,000 to 20,000 m³	Moderate 20,000 to 100,000 m³	High > 100,000 m³
Frequency of Occurrence	Low More than 10,000 years	LOW	LOW	MODERATE
	Moderate 500 to 2500 years	LOW	MODERATE	HIGH
	High 10 to 500 years	MODERATE	HIGH	HIGH

LEGEND

- Test Pit
- ● Culvert (type)
- **CSP** Corrugated Steel Pipe
- Cold Spring Creek Fan (approx.)
- Stream Connection to the Columbia River (approx.)
- Approximate Location of Relict Drainage Channel (not currently visible)
- Cold Spring Creek Watershed

Debris Flow Hazard Classification

- 🟩 Low (L)
- 🟨 Moderate (M)
- 🟥 High (H)
- Highway
- Other Road
- FHSR Contour (5 m)
- Watercourse
- Waterbody

NOTES

1. The FHSR CAD data was received in local coordinates and manually shifted to the correct area in UTM coordinates; there may be some error in the data due to this shift.

Base data source:
FHSR (5 m contours)
CanVec (1:50,000)
Watershed from DataBC
Imagery from Google; DigitalGlobe (2012)

STATUS
ISSUED FOR REVIEW

COLD SPRING CREEK

Debris Flow Hazard Assessment

PROJECTION UTM Zone 11
DATUM NAD83
CLIENT RDEK

Scale: 1:6,000
100 50 0 100
Metres

TETRA TECH EBA

FILE NO. K13103363-01_Figure05_Hazard.mxd

PROJECT NO.	DWN	CKD	APVD	REV
K13103363-01	SL	MEZ	JC	0

OFFICE Tt EBA-VANC
DATE December 11, 2014

Figure 5

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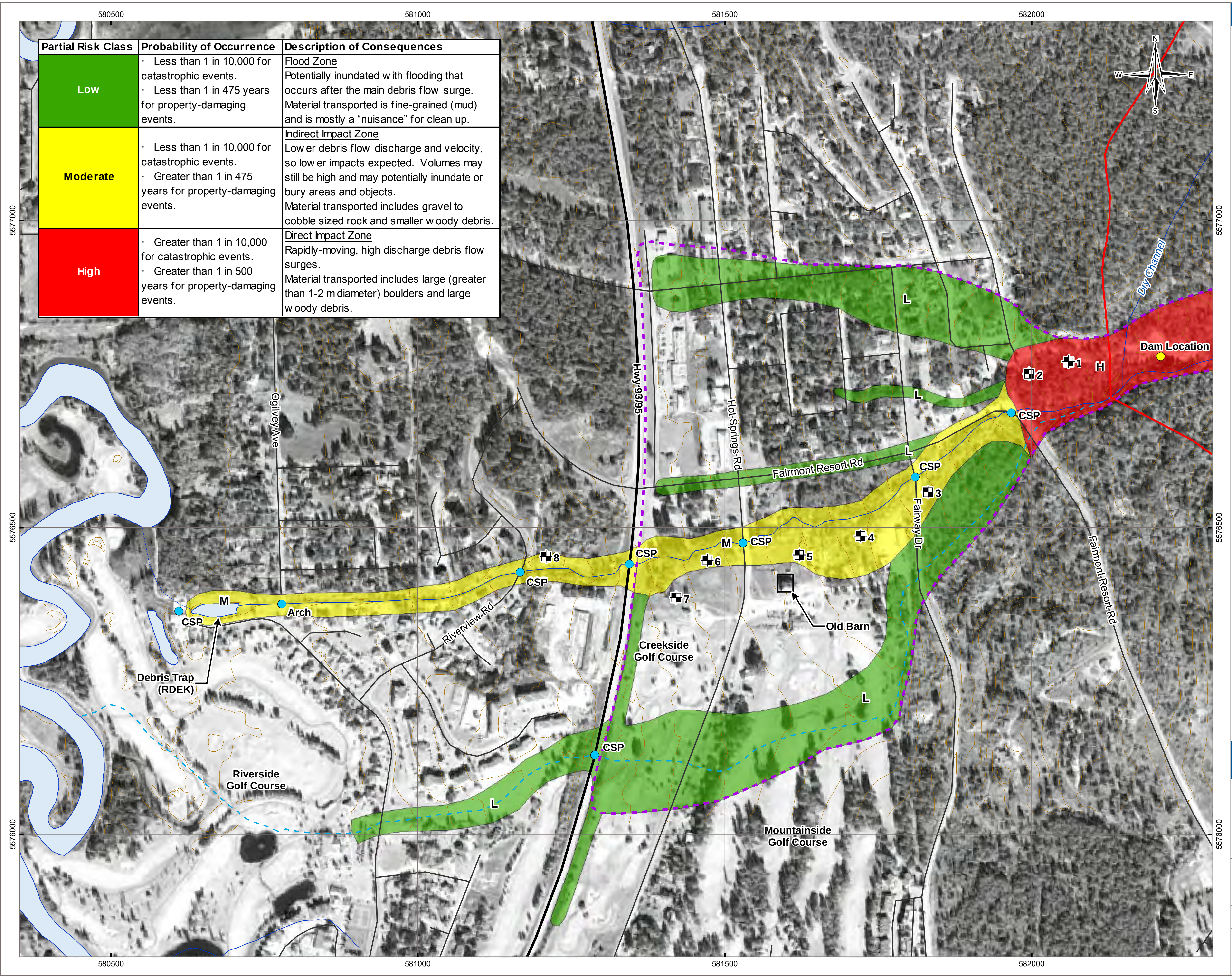

Partial Risk Class	Probability of Occurrence	Description of Consequences
Low	· Less than 1 in 10,000 for catastrophic events. · Less than 1 in 475 years for property-damaging events.	Flood Zone Potentially inundated with flooding that occurs after the main debris flow surge. Material transported is fine-grained (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.

LEGEND

✚	Test Pit
●	Culvert (type)
CSP	Corrugated Steel Pipe
- - -	Cold Spring Creek Fan (approx.)
······	Stream Connection to the Columbia River (approx.)
- - -	Approximate Location of Relict Drainage Channel (not currently visible)
◯	Cold Spring Creek Watershed

Debris Flow Risk Classification

🟩	Low (L)
🟨	Moderate (M)
🟥	High (H)
━	Highway
─	Other Road
∼	FHSR Contour (5 m)
∼	Watercourse
▨	Waterbody

NOTES
1. The FHSR CAD data was received in local coordinates and manually shifted to the correct area in UTM coordinates; there may be some error in the data due to this shift.

Base data source:
FHSR (5 m contours)
CanVec (1:50,000)
Watershed from DataBC
Imagery from Google; DigitalGlobe (2012)

STATUS
ISSUED FOR REVIEW

COLD SPRING CREEK

Debris Flow Risk Assessment

PROJECTION	DATUM	CLIENT
UTM Zone 11	NAD83	RDEK

Scale: 1:6,000
100 50 0 100
Metres

FILE NO.
K13103363-01_Figure06_Risk.mxd

TETRA TECH EBA

PROJECT NO.	DWN	CKD	APVD	REV
K13103363-01	SL	MEZ	JC	0

OFFICE	DATE
Tt EBA-VANC	December 11, 2014

Figure 6

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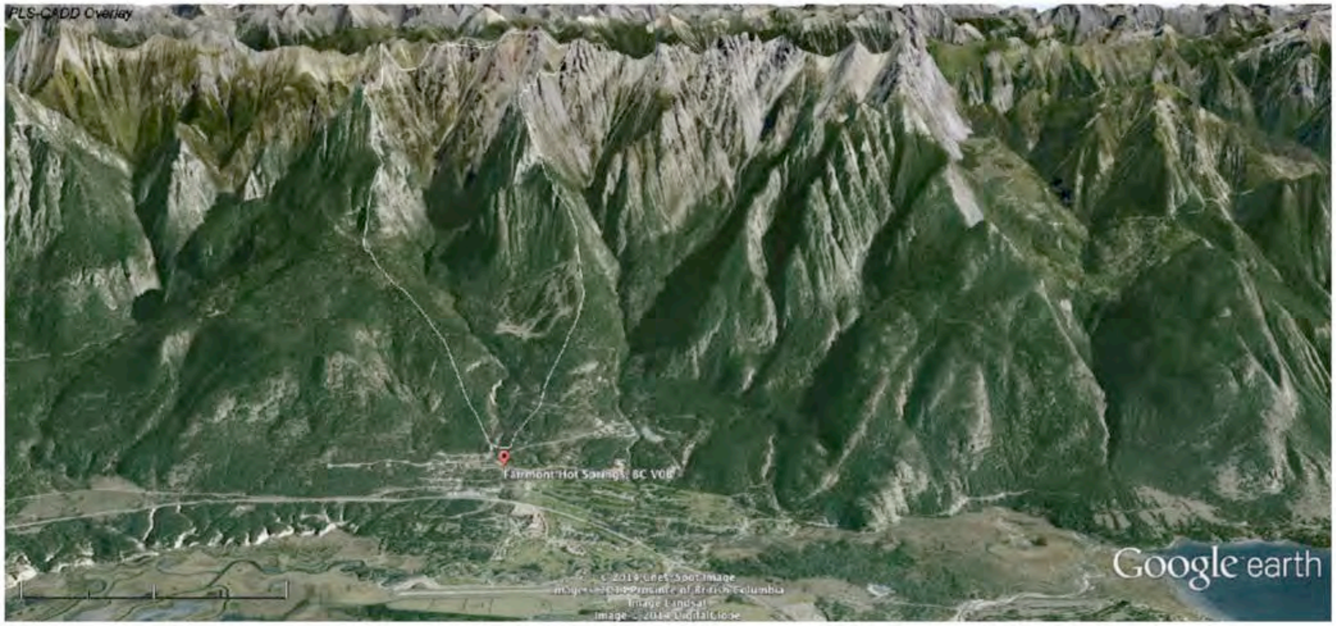
APPENDIX A

PHOTOGRAPHS

Appendix A – Photographs (obtained Oct. 7-9, 2014 and Nov. 6, 2014)

View of Cold Spring Creek Watershed. Historic Holland Barn in foreground.

View of Tributary A headwaters. Note reddish volcaniclastic exposure and steeply dipping bedrock. (google earth imagery)



View of Cold Spring Creek Watershed (outlined) from the west (google earth imagery)

Appendix A – Photographs (obtained Oct. 7-9, 2014 and Nov. 6, 2014)

Photo 1: Culvert (1600 mm) and gate at outlet of RDEK Debris Trap (towards Columbia River)

Photo 3: Inlet to RDEK Debris Trap

Photo 2: RDEK Debris Trap

Photo 4: Cold Spring Creek, Reach 2. Constructed channel, view upstream of Debris Trap

Appendix A – Photographs (obtained Oct. 7-9, 2014 and Nov. 6, 2014)

Photo 5: Cold Spring Creek, Reach 2. Constructed intermediate debris detention area.

Photo 6: Cold Spring Creek, Reach 2. View downstream from Riverview Rd.

Photo 7: View upstream through Hwy 93/95 Culvert. Note deformation and water lines.

Photo 8: Inlet of Hwy 93/95 Culvert (1500 mm)

Appendix A – Photographs (obtained Oct. 7-9, 2014 and Nov. 6, 2014)


Photo 9: Highway ditch on east side. Downstream of Cold Spring Creek.


Photo 10: Reach 3. Small debris jams and lack of channel confinement.


Photo 11: Reach 3. Inlet of culverts (900 mm & 800 mm) at Hot Springs Rd.


Photo 12: Reach 3. View upstream. Note overbank flood deposits.

Appendix A – Photographs (obtained Oct. 7-9, 2014 and Nov. 6, 2014)

Photo 13: Reach 3. Inlet of culverts (1200 mm & 900 mm) at Fairway Road.

Photo 15: View of scattered boulders in forest at upper end of Cold Spring Creek fan

Photo 14: Reach 3. Inlet of culvert (1200 mm) at Fairmont Resort Rd.

Photo 16: One of several scattered large boulders at upper end of fan

Appendix A – Photographs (obtained Oct. 7-9, 2014 and Nov. 6, 2014)

Photo 17: Reach 3. Footbridge for hiking trail just upstream of Fairmont Resort Rd.

Photo 18: Downstream face of Cold Spring Creek Dam

Appendix A – Photographs (obtained Oct. 7-9, 2014 and Nov. 6, 2014)

Photo 19: Cold Spring Creek Dam reservoir

Photo 20: Downstream view of Cold Spring Creek Dam reservoir. Excavated material on right

Photo 21: Reach 4. Note debris levee and size of boulders transported by Cold Spring Creek

Appendix A – Photographs (obtained Oct. 7-9, 2014 and Nov. 6, 2014)

Photo 22: Reach 4. Shallow gradient reach (12-17%) with debris deposition.

Photo 23: Reach 4. Example of erodible phyllite bedrock along stream bank.

Photo 24: Reach 4. Example of small debris jams and upstream sediment wedges.

Photo 25: Downstream face of FHSR Water Intake Weir

Appendix A – Photographs (obtained Oct. 7-9, 2014 and Nov. 6, 2014)

Photo 26: FHSR Water Intake infiltration gallery

Photo 28: Reach 5. Note overbank sediment deposition.

Photo 27: Reach 5. View upstream. Gradients of 18-20%, with abundant stored sediment in channel.

Photo 29: Reach 5. Note impact damage on trees.

Appendix A – Photographs (obtained Oct. 7-9, 2014 and Nov. 6, 2014)

Photo 30: Reach 6. View upstream of abundant stored sediment (streamflow is subsurface)

Photo 32: View down debris flow/debris slide gully at confluence with Reach 6

Photo 31: Tributary A. View upstream of abundant stored sediment (flow is subsurface)

Photo 33: Evidence of small landslide debris dam at the base of gully shown in Photo 32

Photo 34: Sediment infilling of Cold Spring Dam reservoir after flood event in 2011 (photo from RDEK)

Photo 35: Sediment infilling of lower debris trap on Cold Spring Creek after flood event in 2011 (photo from RDEK)

Photo 36: Reconstruction of FHSR Weir on Cold Spring Creek after 2011 event (exact date of photo unknown) (photo from RDEK)

APPENDIX B

TEST PIT LOGS

CLIENT:

RDEK

BOREHOLE LOG: TP14-01

PROJECT: Cold Spring Creek Debris Flow Assessment	PROJECT NO: 704-K13103363-01
LOCATION: Fairmont Hot Springs, BC	ELEVATION:
NORTHING: 5576771.95 EASTING: 582121.32	ZONE: 11

Depth (m)	SOIL DESCRIPTION	GRAPHICAL LEGEND	SAMPLE TYPE	SAMPLE NUMBER	CLASSIFICATION TESTS PLASTIC M.C. LIQUID 10 20 30 40	IN-SITU SHEAR VANE TEST REMOULDED (kPa) PEAK (kPa) 40 80 120 160 SCALA PENETROMETER Blows Per 50mm Penetration 3 6 9 12	Depth (ft)
	Topsoil and organics, sandy loam						
	Silty sand GRAVEL (light brown colour) - interpreted as fill						
	Root layer (organics)						
1	silty sand GRAVEL and COBBLE, matrix-supported sub-rounded to sub-angular clasts (0.3-0.4 m size)						
	Root layer (buried organics), dark Brown, decomposed		▬	TP1			
2	Silty sand, GRAVEL and COBBLE, increasing in size, lack of bedding, sub-rounded clasts						5
3	End of Testpit						

TETRA TECH EBA

CONTRACTOR: Tanner Daviduke	COMPLETION DEPTH: 3m
DRILLING RIG TYPE: Rubber Tired Backhoe	STARTED: 11/6/2014
LOGGED BY: JC	COMPLETED: 11/6/2014
REVIEWED BY: LAM	Page 1 of 1

CLIENT:

RDEK

BOREHOLE LOG: TP14-02

PROJECT: Cold Spring Creek Debris Flow Assessment
PROJECT NO: 704-K13103363-01
LOCATION: Fairmont Hot Springs, BC
ELEVATION:
NORTHING: 5576748.69
EASTING: 582055.84
ZONE: 11

Depth (m)	SOIL DESCRIPTION	GRAPHICAL LEGEND	SAMPLE TYPE	SAMPLE NUMBER	CLASSIFICATION TESTS PLASTIC M.C. LIQUID 10 20 30 40	IN-SITU SHEAR VANE TEST REMOULDED (kPa) PEAK (kPa) 40 80 120 160 SCALA PENETROMETER Blows Per 50mm Penetration 3 6 9 12	Depth (ft)
	Topsoil and organics, dark Brown sandy loam						
	Silty sand GRAVEL, (light brown colour), fairly compact - interpreted as fill						
	Thin root layer (organics)						
1	Sandy (trace silt) COBBLE, with some boulders, lack of bedding, fairly loose, sub-rounded to sub-angular clasts						5
	Thin root layer (buried organics), dark brown, slight clayey component		▆	TP2			
2	Sandy (trace silt) COBBLE-BOULDER, loose						
3							10
	End of Testpit						

TETRA TECH EBA

CONTRACTOR: Tanner Daviduke
COMPLETION DEPTH: 3.2m
DRILLING RIG TYPE: Rubber Tired Backhoe
STARTED: 11/6/2014
LOGGED BY: JC
COMPLETED: 11/6/2014
REVIEWED BY: LAM

CLIENT: RDEK	# BOREHOLE LOG: TP14-03	
	PROJECT: Cold Spring Creek Debris Flow Assessment	PROJECT NO: 704-K13103363-01
	LOCATION: Fairmont Hot Springs, BC	ELEVATION:
	NORTHING: 5576558.47 / EASTING: 581901.19	ZONE: 11

Depth (m)	SOIL DESCRIPTION	GRAPHICAL LEGEND	CLASSIFICATION TESTS PLASTIC M.C. LIQUID 10 20 30 40	IN-SITU SHEAR VANE TEST REMOULDED (kPa) PEAK (kPa) 40 80 120 160 SCALA PENETROMETER Blows Per 50mm Penetration 3 6 9 12	Depth (ft)
	Topsoil and organics, dark brown sandy loam				
	Silty LOAM, some gravel, faint bedding (light brown colour)				
	Silty SAND and GRAVEL, lack of bedding, more dense				
1					
	Silty sand GRAVEL and COBBLE, with some boulders, fairly dense				
					5
	COBBLES (reddish brown colour), indistinct boundaries				
2					
	COBBLES (dark brown colour)				
3					
					10
	End of Testpit				

TETRA TECH EBA

CONTRACTOR: Tanner Daviduke	COMPLETION DEPTH: 3.2m
DRILLING RIG TYPE: Rubber Tired Backhoe	STARTED: 11/6/2014
LOGGED BY: JC	COMPLETED: 11/6/2014
REVIEWED BY: LAM	Page 1 of 1

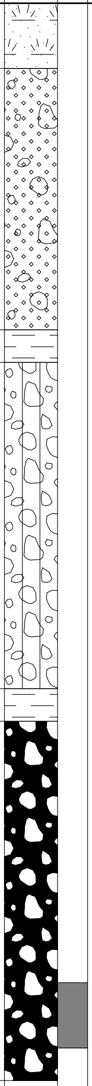
2012 - BH/TP WITH SHEAR VANE OR SCALA FAIRMONT HOT SPRINGS.GPJ EBA.GDT 14/12/16

CLIENT:

RDEK

BOREHOLE LOG: TP14-04

PROJECT: Cold Spring Creek Debris Flow Assessment
PROJECT NO: 704-K13103363-01
LOCATION: Fairmont Hot Springs, BC
ELEVATION:
NORTHING: 5576475.27
EASTING: 581794.92
ZONE: 11



Depth (m)	SOIL DESCRIPTION	GRAPHICAL LEGEND	SAMPLE TYPE	SAMPLE NUMBER	CLASSIFICATION TESTS PLASTIC M.C. LIQUID 10 20 30 40	IN-SITU SHEAR VANE TEST REMOULDED (kPa) PEAK (kPa) 40 80 120 160 SCALA PENETROMETER Blows Per 50mm Penetration 3 6 9 12	Depth (ft)
	Topsoil and organics, dark brown sandy loam						
	Silty SAND and sub-angular GRAVEL, faint bedding (thin organic layers buried within)						
1	SILT and organics (roots)						
2	Silty sand GRAVEL, with some boulders, loose (collapses easily)						5
	SILT and organics (roots)						
3	COBBLES and boulders (up to 1.0 m diameter), organics visible at bottom of testpit (yellow discolouration on roots sampled)		▨	TP4			10
	End of Testpit						

TETRA TECH EBA

CONTRACTOR: Tanner Daviduke
COMPLETION DEPTH: 3.3m
DRILLING RIG TYPE: Rubber Tired Backhoe
STARTED: 11/6/2014
LOGGED BY: JC
COMPLETED: 11/6/2014
REVIEWED BY: LAM
Page 1 of 1

CLIENT:

RDEK

BOREHOLE LOG: TP14-05

PROJECT: Cold Spring Creek Debris Flow Assessment

PROJECT NO: 704-K13103363-01

LOCATION: Fairmont Hot Springs, BC

ELEVATION:

NORTHING: 5576458.76

EASTING: 581685.43

ZONE: 11

Depth (m)	SOIL DESCRIPTION	GRAPHICAL LEGEND	CLASSIFICATION TESTS PLASTIC M.C. LIQUID 10 20 30 40	IN-SITU SHEAR VANE TEST REMOULDED (kPa) PEAK (kPa) 40 80 120 160 SCALA PENETROMETER Blows Per 50mm Penetration 3 6 9 12	Depth (ft)
	Topsoil and organics, dark brown sandy loam				
	Sandy-gravel FILL	▨			
1	Silty sand and GRAVEL, interbedded fine root laters, fairly dense, light brown colour				
	Silty sand GRAVEL and COBBLE, dense				
2	Gravel and COBBLE, fine roots at 1.4 m and 2.4 m				5
3	Sandy (trace silt) GRAVEL and COBBLE, few boulders				10
	End of Testpit				

2012 - BH/TP WITH SHEAR VANE OR SCALA FAIRMONT HOT SPRINGS.GPJ EBA.GDT 14/12/16

TETRA TECH EBA

CONTRACTOR: Tanner Daviduke

COMPLETION DEPTH: 3.8m

DRILLING RIG TYPE: Rubber Tired Backhoe

STARTED: 11/6/2014

LOGGED BY: JC

COMPLETED: 11/6/2014

REVIEWED BY: LAM

CLIENT:

RDEK

BOREHOLE LOG: TP14-06

PROJECT: Cold Spring Creek Debris Flow Assessment

PROJECT NO: 704-K13103363-01

LOCATION: Fairmont Hot Springs, BC

ELEVATION:

NORTHING: 5576449.55

EASTING: 581549.14

ZONE: 11

Depth (m)	SOIL DESCRIPTION	GRAPHICAL LEGEND	CLASSIFICATION TESTS PLASTIC M.C. LIQUID 10 20 30 40	IN-SITU SHEAR VANE TEST REMOULDED (kPa) PEAK (kPa) 40 80 120 160 SCALA PENETROMETER Blows Per 50mm Penetration 3 6 9 12	Depth (ft)
	Topsoil and organics, dark brown sandy loam				
	Sandy-GRAVEL fill				
	Sandy-GRAVEL fill, grey to light brown colour				
1	Silty-sand gravel and COBBLES, matrix-supported clasts, light brown colour, fairly dense, distinct bottom boundary				
	Inter-bedded SANDS (alluvial)				
	Sandy (trace silt) GRAVEL and COBBLE, few boulders, indistinct boundary at bottom				5
2	Sandy (trace silt) GRAVEL and COBBLE, few boulders (no organics visible)				
3					10
	End of Testpit				

TETRA TECH EBA

CONTRACTOR: Tanner Daviduke

COMPLETION DEPTH: 3.7m

DRILLING RIG TYPE: Rubber Tired Backhoe

STARTED: 11/6/2014

LOGGED BY: JC

COMPLETED: 11/6/2014

REVIEWED BY: LAM

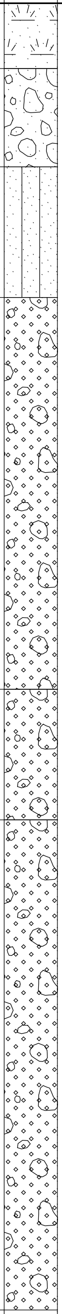
CLIENT:

RDEK

BOREHOLE LOG: TP14-07

PROJECT: Cold Spring Creek Debris Flow Assessment	PROJECT NO: 704-K13103363-01
LOCATION: Fairmont Hot Springs, BC	ELEVATION:
NORTHING: 5576427.84 / EASTING: 581503.4	ZONE: 11

Depth (m)	SOIL DESCRIPTION	GRAPHICAL LEGEND	CLASSIFICATION TESTS PLASTIC M.C. LIQUID 10 20 30 40	IN-SITU SHEAR VANE TEST REMOULDED (kPa) PEAK (kPa) 40 80 120 160 SCALA PENETROMETER Blows Per 50mm Penetration 3 6 9 12	Depth (ft)
	Topsoil and organics, dark brown sandy loam				
	Weakly bedded sandy-GRAVEL, some fine roots at 0.5 m				
	Weakly bedded silty SAND, few gravel clasts, fine roots at 0.9 m				
1	Silty SAND and GRAVEL with small cobbles, loose, lack of matrix.				5
2	Thin clayey SILT lenses inter-bedded with SANDS and GRAVELS				
3	Silty SAND and GRAVEL with small cobbles, loose, lack of bedding,				10
4	End of Tespit				



TETRA TECH EBA

CONTRACTOR: Tanner Daviduke	COMPLETION DEPTH: 4m
DRILLING RIG TYPE: Rubber Tired Backhoe	STARTED: 11/6/2014
LOGGED BY: JC	COMPLETED: 11/6/2014
REVIEWED BY: LAM	Page 1 of 1

2012 - BH/TP WITH SHEAR VANE OR SCALA FAIRMONT HOT SPRINGS.GPJ EBA.GDT 14/12/16

CLIENT:

RDEK

BOREHOLE LOG: TP14-08

PROJECT: Cold Spring Creek Debris Flow Assessment	PROJECT NO: 704-K13103363-01
LOCATION: Fairmont Hot Springs, BC	ELEVATION:
NORTHING: 5576464.05 EASTING: 581286.73	ZONE: 11

Depth (m)	SOIL DESCRIPTION	GRAPHICAL LEGEND	CLASSIFICATION TESTS PLASTIC M.C. LIQUID 10 20 30 40	IN-SITU SHEAR VANE TEST REMOULDED (kPa) PEAK (kPa) 40 80 120 160 SCALA PENETROMETER Blows Per 50mm Penetration 3 6 9 12	Depth (ft)
	Topsoil and organics, dark brown sandy loam				
	Sandy GRAVEL, light grey colour, evidence of buried trees (possibly fill material)				
1	Organic root layer (buried)				
	Sandy GRAVEL, some cobble, well graded, weakly bedded, organics visible at 1.6 m.				5
2	SAND and GRAVEL, lack of bedding				
	Root layer (buried) - unable to obtain sample				
3	Sub-rounded to sub-angular SAND and GRAVEL, lack of bedding				10
	Tufa rock encountered at base of testpit				
	End of Testpit				

TETRA TECH EBA

CONTRACTOR: Tanner Daviduke	COMPLETION DEPTH: 3.65m
DRILLING RIG TYPE: Rubber Tired Backhoe	STARTED: 11/6/2014
LOGGED BY: JC	COMPLETED: 11/6/2014
REVIEWED BY: LAM	Page 1 of 1