SQUAMISH - LILLOOET
REGIONAL DISTRICT

Box 219, 1350 Aster Street,
Pemberton, BC V0N 2L0
Ph. 604-894-6371, 800-298-7753
F: 604-894-6526
info@slrd.bc.ca www.slrd.bc.ca

FOR OFFICE USE ONLY	
Application Fee Paid:	Receipt Number:
Received By:	Date Received:
File Number:	

DEVELOPMENT APPLICATION FORM

Applicants are advised to consult with Planning Staff before submitting a development application.
Development Applications will not be accepted unless they are complete and the required fee and plans are attached. Fees are non-refundable unless otherwise noted.

1. APPLICATION TYPE (S)

(select all application types being applied for)

☑ Zoning Amendment	☐ Development Permit **(specify type below)**
☐ Official Community Plan Amendment	☐ Development Variance Permit
☐ Temporary Use Permit **Specify Term __________ (1-3 year term)**	☐ Covenant Amendment
☐ Temporary Use Permit Renewal **Specify Term __________ (1-3 year term)**	☐ Other (specify)____________________________

DEVELOPMENT PERMIT TYPE

(if applicable, select all development permit types being applied for)

☐ Riparian Protection Development Permit ☐ Wildfire Protection Development Permit ☐ Farming Protection Development Permit (Area D) ☐ Form, Character & Conservation Development Permit (Area D) – applicable for commercial, industrial, multi-family, and intensive residential development	Howe Sound East Development Permits: ☐ Environmental Protection Development Permit ☐ Natural Hazards Protection Development Permit ☐ Slope Stability Protection Development Permit (Britannia North and Oliver's Landing only)
☐ Mount Currie Commercial Development Permit ☐ Bralorne & Gold Bridge Heritage Commercial Development Permit ☐ Upper Bridge River Valley Commercial & Multifamily Residential Form & Character Development Permit	Porteau Cove Development Permits: ☐ Protection of ecosystems and biological diversity ☐ Protection from hazardous conditions ☐ Multi-family and other intensive residential

Sign Notification: Certain applications require that a sign be posted on the property to advise the community of the proposed development, and invite comments and questions. Staff will advise you if a sign is required as part of your application process.

Securities: Development Permits and/or Temporary Use Permits may require a security in the form of an irrevocable letter of credit or bonding, as a condition of the permit.

Delegations: there is an opportunity for any party to speak as a delegation to the SLRD Board on land use and other matters. Delegations will not, however, be allowed once a bylaw has gone before a public hearing.

See the Development Approval Information, Fees and Notification Procedures Bylaw for specific requirements and details.

2. APPLICANT

	Applicant:	Owner: (if different from Applicant)
Name(s):	Robert Taylor	Boulder Creek Power Inc
Mailing Address:	Unit 1100 - 888 Dunsmir St Vancouver, BC V6C 3K4	Unit 1100 - 888 Dunsmir St Vancouver, BC V6C 3K4
Phone:	(Home) 778-873-7685 (Cell)	(Home) 604-633-9990 (Cell)
e-mail:	rtaylor@innergex.com	

3. PROPERTY INFORMATION

Legal Description of Land under Application:

Crown Land Tenure file number 2412750 – THAT PARCEL OR TRACT OF UNSURVEYED CROWN LAND IN THE VICINITY OF BOULDER CREEK TOGETHER WITH UNSURVEYED CROWN FORESHORE OR LAND COVERED BY WATER BEING PART OF THE BED OF BOULDER CREEK ALL WITHIN LILLOOET DISTRICT, CONTAINING 6.78 HECTARES, MORE OR LESS

Civic Address (House No. , Street Name, Community):

Size of Property (Ha):	6.78	*(if applicable, indicate proposed land use)*	
Current Zoning:	Rural Residential 1	Proposed Zoning:	TBD
Current OCP Designation:	Resource Management	Proposed OCP Designation:	N/A

Existing Land Use:

Land is not currently in use. The area was previously used for a temporary construction camp during the construction of the Upper Lillooet River and Boulder Creek Hydroelectric Facilities. The area was reclaimed following decommissioning of the temporary camp.

Description of Proposed Land Use:

(please attach separate pages if necessary)

See attached separate pages for description.

4. AGENT'S AUTHORIZATION

If the applicant is not the registered owner, the owner(s) must complete the owner information and attach a letter of authorization, or complete and sign the following:

As the owner of the land described in this application, I/we hereby authorize

____________________ to act as applicant in regard to this land development application.

Owner Signature Date

Owner Signature Date

5. DECLARATION PURSUANT TO THE *ENVIRONMENTAL MANAGEMENT ACT*

The *Environmental Management Act* requires that a person who knows or reasonably should know that a subject property has been used for a specified industrial or commercial use provide the local government a Site Disclosure Statement when making an application for subdivision, zoning, or a development or building permit (if the development or building activity is likely to disturb the property's soil). The Site Disclosure Statement must be submitted in conjunction with the SLRD Development Application. The following declaration should be completed only after the applicant has reviewed the *Contaminated Sites Regulation Schedule 2 Specified Industrial or Commercial Uses* and determined that the subject property has not been used for the activities described therin.

I, Robert Taylor, hereby acknowledge that *the Environmental Management Act,* 2003, is effective as of March 31st, 2005.

Based on my personal knowledge of the property in question, I do not believe that it is or has been used for any of the Specified Industrial or Commercial Uses specified in Schedule 2 of the Contaminated Sites Regulation. Accordingly, I elect not to provide a Site Disclosure Statement, as outlined in Section 40(1) of the *Environmental Management Act.*

I further acknowledge that this election does not remove any liability, which may otherwise be applicable under the legislation.

Robert Taylor — 2023-11-20

Signature — Date

I, the undersigned, hereby certify that the attached information, provided with respect to this application is full and complete and a true statement of facts, and hereby agree to submit further information as may be deemed necessary for processing the application.

Robert Taylor — 2023-11-20

Signature — Date

6. ADDITIONAL REQUIRED INFORMATION (Please complete checklist)

All applications should be accompanied by the following information:

- ☑ **Application fee(s)** – see Development Approval Information, Fees and Notification Procedures Bylaw 1301-2014
- ☑ **Signed "Declaration Pursuant to the Environmental Management Act"**
- ☑ **Site Plan (drawn to scale and showing the following):**
    - Civic address and full legal description of property
    - Lot dimensions
    - Easements and rights of way on the property
    - Names of roads adjacent to the property
    - Locations and dimensions of **all** existing and proposed buildings and structures
    - Locations of existing wells and septic systems
    - Locations of watercourses, steep banks, and slopes on or adjacent to the property

The following information is required for specific application types as indicated below:

- ☐ **Development Plans** - depending on the specific application, required information may include the following (see s.5.34 & s.5.35 of Development Approval Information, Fees and Notification Procedures Bylaw 1301-2014, as amended for full application requirements):
    - **DEVELOPMENT VARIANCE PERMITS (DVP)** - detailed drawings showing the proposed development and showing the requested variance. This includes building elevations, floor plans, site elevations, etc. that will be attached to the permit.
    - **DEVELOPMENT PERMITS (DP) –** requirements depend on the type of development permit and the guidelines contained within the applicable Official Community Plan (OCP). Please review the applicable Development Permit Area (DPA) guidelines that are outlined in the OCP for the electoral area in which the development is occurring.
        - (Electoral Area A) Upper Bridge River Valley OCP Bylaw No. 608, 1996
        - Electoral Area B OCP Bylaw No. 1073, 2008
        - Electoral Area C OCP Bylaw No. 689, 1999
        - Electoral Area D OCP Bylaw No. 1135-2013
    - ✓ **OCP, ZONING or COVENANT AMENDMENTS** – details with respect to the proposal, including proposed density (number of lots and or dwellings), proposed permitted uses, and any necessary background reports/studies/or additional information to describe the proposal.
    - **TEMPORARY USE PERMITS or RENEWALS** – details with respect to the specific proposed use, the specific duration, and what measures are in place to restore the land following the cessation of the temporary use. Please review the applicable Temporary Use Permit (TUP) guidelines available on the SLRD website:

      https://www.slrd.bc.ca/planning-building/planning-development-services/development-applications-approvals/application-forms-and-guides

Zoning application form section 4 – Description of proposed land use:

- Description of Proposed Land Use (with additional pages) – include number of dwellings and structures, proposed permitted uses, reference to reports, 20-person capacity maximum. Include service details for current location.

  The proposed use is for a residence facility for operators of the Boulder Creek and Upper Lillooet River Hydroelectric Facilities. The current operator residence, located at the Boulder Creek Powerhouse, was selected just after construction of the hydroelectric facilities was completed and was initially concluded to be in an appropriate location. However, after the last few years of operations, we have had some challenges with our limited access to the facilities due to winter access restrictions, but more importantly, summer access restrictions due to flood/landslide hazard risks.

  Services at the current location include electrical (provided by the Boulder Creek Hydroelectric Facility Powerhouse), water (provided by a groundwater well – Conditional Water Licence (Groundwater) 500112)), and septic.

  Studies have concluded that the higher elevation of the original construction camp location is a safer and more appropriate site in the event of landslide activities. A 2016 report, prepared by Knight Piesold Consulting, assessed several options for the operator residence location. The location proposed in this application was determined to be the one with the least risk, from a landslide/flooding perspective. The report has been appended to this zoning amendment application.

  The attached figure shows the current and new operator residence locations. The residence facility will house a maximum capacity of 20 people.

  The new residence is located on Crown Land Tenure file 2412750, with a legal description of: THAT PARCEL OR TRACT OF UNSURVEYED CROWN LAND IN THE VICINITY OF BOULDER CREEK TOGETHER WITH UNSURVEYED CROWN FORESHORE OR LAND COVERED BY WATER BEING PART OF THE BED OF BOULDER CREEK ALL WITHIN LILLOOET DISTRICT, CONTAINING 6.78 HECTARES, MORE OR LESS. The attached figure shows proposed infrastructure on the site, including approximate dimensions:

  - Six individual trailers (Atco trailer) – two operator residences per unit.
  - Overflow residence –This unit is intended for occasional overflow housing for contractors or visitors completing routine or as-need maintenance activities.
  - Workshop (dome shelter)
  - Electrical equipment (sea can)
  - Water treatment facility (sea can)
  - General storage facility (sea can)

Operator Residence New Location

Legend

- Licence of Occupation - Roadway (F2412753)
- Licence of Occupation - Operator Residence (F2412750)
- Overflow Residence 21m x 17m
- Workshop- 20m x 25m
- Operator's Residence- 60' x 12'
- Storage 8' x 20'
- Electrical 8' x 10'
- Water Treatment System 8' x 10'

1:5,500

0 0.03 0.06 0.11 mi

0 0.04 0.09 0.18 km

Google

October 5, 2016

File No.:VA103-279/5-A.01
Cont. No.:VA15-02653

ISO 9001 - FS 64925
ISO 14001 - EMS 550121
OHSAS 18001 - OHS 550122

Mr. Oliver Robson
Project Manager
Innergex Renewable Energy Inc.
200 - 666 Burrard Street
Vancouver, British Columbia
Canada, V6C 2X8

Dear Oliver,

Re: Upper Lillooet Hydro Project – Proposed Operators Residence - Quantitative Risk Assessment for Natural Terrain Landslide Hazards

1 – INTRODUCTION

The Upper Lillooet Hydro Project, currently under construction, comprises two run-of-the-river facilities – the Upper Lillooet Hydroelectric Facility (HEF) and the Boulder Creek HEF. The project is located approximately 60 to 65 km northwest of Pemberton, BC. The project is to be operated by the Upper Lillooet River Power Limited Partnership (LP) and Boulder Creek Power LP (the Partnerships). The Partnerships propose to develop an Operators Residence at the site. It is assumed that between 3 and 8 people will generally be staying at the residence. It is proposed that the residence remain in use for the full 40-year operational life of the associated hydroelectric facility.

The site is located on the north side of the Mount Meager Volcanic Complex (MMVC). The MMVC comprises weak, highly fractured and hydrothermally altered volcanic rocks that are particularly susceptible to landslides with the possibility of extremely large events (Friele et al., 2008). The landslide hazards at the MMVC are described in detail in the Terrain Hazards Assessment report for the Upper Lillooet HEF (KP, 2011). The principal hazards at the MMVC are edifice (mountain) collapse, large rock avalanches and debris flows, as well as associated river damming and floods and hyper-concentrated flows produced by outbursts of landslide-dammed lakes.

As part of the permitting requirements for the residence, the Squamish and Lillooet Regional District have requested, in line with the requirements of Section 56 of the *Community Charter,* that the permit application needs to be accompanied by a geotechnical report on the landslide hazards that states that the proposed site is ‘safe for the use intended’ with any necessary conditions being stipulated in the report.

Knight Piésold Limited (KP) was requested by the Partnerships to review possible sites for the Operators Residence with respect to the natural terrain landslide risk. Five possible sites were reviewed. A Quantitative Risk Assessment (QRA) was undertaken with respect to the natural terrain landslide hazards. The risk was evaluated with respect to risk tolerance criteria allowing an appropriate site for the Operators Residence to be determined with respect to the natural terrain landslide hazards. This report describes the work that was undertaken to establish an appropriate site for the Operators Residence. The risk assessment methodology used in this assessment is consistent with that used in a previous study undertaken to determine the appropriate site for the project Construction Camp (KP, 2014b).

2 – SITE AND PROJECT DESCRIPTION

The project site is located on the northeast side of the Lillooet River Valley approximately 60 to 65 km northwest of Pemberton, BC. Access to the site is along the existing Lillooet Forest Service Road (FSR). The Upper Lillooet River Valley has a broad base, ranging from approximately 200 m-wide to 700-m wide in the vicinity of the site (Drawing G0005). The valley side slopes are generally moderately steep (50-70% slopes) to Steep (>70% slopes). The intake site of the Upper Lillooet HEF is located at the head of a bedrock canyon approximately 550 m upstream from Keyhole Falls, and approximately 250 m downstream from the confluence of the Upper Lillooet River with Salal Creek. The powerhouse site is located approximately 6 km upstream from the confluence of Meager Creek and the Upper Lillooet River. Boulder Creek joins the Upper Lillooet River approximately 2 Km upstream from the Meager Creek confluence. The Boulder Creek HEF Powerhouse is located at the apex of a fan at the toe of the side slopes of the Lillooet River Valley. The powerhouse site is located approximately 1 km upstream from the confluence of Boulder Creek with the Lillooet River and approximately 40 m above the elevation of the Lillooet River Flood Plain. The Boulder Creek Intake structure is approximately 3 km upstream on Boulder Creek. The Boulder Creek Valley has a steep v-shaped profile, with steep side slopes extending to an elevation of approximately 2,000 m.

The MMVC consists of approximately 20 km^3 of eruptive volcanic rocks with a maximum elevation of approximately 2,700 m above sea level, which have accumulated since the Pliocene some three million years ago. The MMVC is a potentially active volcano. New fumarole activity has been recently noted on the mountain and NRCan circulated a notice about this activity in relation to the probability of volcanic activity (NRCan, 2016). The notice concluded the volcano is not currently exhibiting signs of an imminent volcanic event. During the last eruption of Mount Meager, approximately 2,360 years Before Present (BP), volcanic deposits were laid down in the Upper Lillooet River Valley from a vent on the upper slopes of Plinth Peak. Block and ash avalanche and rock avalanche deposits blocked the Lillooet River Valley to a height of approximately 100 m, forming the paleo-Salal Lake. The dam eventually failed catastrophically causing an outburst flood in the valley below, and leading to the development of Keyhole Falls.

A combination of factors, including the presence of weak volcanic deposits and steep, recently de-glaciated topography combined with a rapid rate of uplift, have resulted in extensive large and frequent landslides on the slopes of the MMVC. Debris flows with an extremely large magnitude (10^8 to 10^9 m^3), but very low frequency (return-period of greater than 1,000 years) are known to have initiated in the MMVC and travelled a considerable distance down the Lillooet River Valley, beyond its confluence with Boulder Creek. The risk of such events needs to be considered in selecting the site of the Operators Residence.

3 – POSSIBLE SITES FOR THE OPERATORS RESIDENCE

The area under consideration for siting the Operators Residence was initially defined by a 2 km buffer around the Boulder Creek Powerhouse site, as shown on Drawing G0005, and then limited to locations on the northeast side of the Upper Lillooet River. Five possible sites (hereafter referred to as Sites A to E) were identified for the Operators Residence, as shown on Drawing G0005. Sites A to D were selected at locations on the lower slopes on the northeast side of the valley that are just over 50 m above the elevation of the adjacent reach of the Upper Lillooet River and adjacent to existing access tracks. Sites A and B are adjacent to access tracks that join the Lillooet FSR upstream from the confluence of Boulder Creek and the Upper Lillooet River. Site C is located adjacent to the Boulder Creek HEF Powerhouse. Site D is located at the toe of the glacial terrace upon which the construction camp is located, and is on the upper part of the Boulder Creek Fan. Site E is within the footprint area of the existing construction camp. The elevation of Site E is between approximately 105 m and 135 m above that of the closest reach of the Upper Lillooet River (520 m asl to 550 m asl, compared to approximately 415 m asl). There are moderately steep to steep slopes to the east (upslope) and to the west (downslope) of Site E (Drawing G0005). These moderately steep to steep slopes are relatively small (approximately 50 m-high on the upslope side and approximately 75 m-high on the downslope side.

4 – AIR PHOTO INTERPRETATION

Air photo interpretation (API) using BC Provincial historic airphotos was undertaken for the 2 km buffer zone. The API involved mapping the terrain hazards from air photos with the aid of a stereoscope. The air photos inspected are detailed in Table 4.1 below:

Table 4.1 Summary of Air Photos Inspected

Reference	Year	Scale	Source
BC 409:53 and 54	1947	Not shown	UBC
BC 4086: 24 to 26	1962	Not shown	UBC
BC 7551: 100 and 101	1973	Not shown	UBC
30BC 79036: 45 and 46	1979	Not shown	UBC
30BC86063: No. 9 and 10	1986	1:15,000	UBC
30BCB90114: No. 160 and 161	1990	Not shown	UBC
30BCC94102: No. 94 and 95	1994	Not shown	UBC
30BCC06169: No. 203 and 204	2006	Not shown	UBC

NOTES:
1. UBC: University of British Columbia.

The landslides mapped are shown on Drawing G0006. The years of the air photos in which the landslides were first identified are highlighted on Drawing G0006. In the mapping, 'recent' landslides that were assessed to have occurred during or shortly before the period of the air photo record are distinguished from older 'ancient' landslides.

5 – LANDSLIDE HAZARDS AFFECTING THE PROPOSED SITES FOR THE OPERATORS RESIDENCE

5.1 HAZARD CLASSIFICATION

Hazards can be expressed qualitatively as well as quantitatively based upon their annual probability of occurrence or expected annual return frequency. Table 5.1 summarizes the adopted classification system for qualitative and quantitative probability estimates of landslide processes (Wise et al., 2004).

Table 5.1 Qualitative and Quantitative Probability Estimates for Landslide Processes

Hazard Likelihood	Expected Annual Probability/Return Frequency
Very High	>1/20
High	1/100 to 1/20
Moderate	1/500 to 1/100
Low	1/2,500 to 1/500
Very Low	<1/2,500

5.2 LANDSLIDES INITIATING IN THE MMVC

5.2.1 General

The landslide types in the MMVC include debris and rock slides, debris flows and rock avalanches. Debris flows and rock avalanches have the longest run-out distances and pose the greatest potential threats to safety. A debris flow is a very rapid to extremely rapid flow of saturated, non-plastic debris in a steep channel. A rock avalanche is an extremely rapid, massive, flow-like motion of fragmented rock from a large rock slide or rock fall (Hungr et al., 2001).

A summary of selected dated 'recent' landslides in the MMVC is presented in Table 5.2 below:

Table 5.2 Selected Dated 'Recent' Landslides in the Mount Meager Volcanic Complex

Location	Landslide Type	Date	Volume (m^3)
Devastation Creek	Debris Flow	October, 1931	$3.0x10^6$
Devastation Glacier	Rock Avalanche	July 22, 1975	$1.2x10^7$
Affliction Creek	Debris Flow	October, 1984	$2.0x10^5$
North slopes of Mount Meager	Rock Avalanche	March or April, 1986	$1.0x10^5$ to $1.0x10^6$
Canyon Creek	Debris Flow	1987	$1.0x10^4$
Boundary Creek	Debris Flow	August, 1987	$5.0x10^4$
Boundary Creek	Debris Flow	September 6, 1988	$5.0x10^3$
No Good Creek	Debris Flow	September 6, 1988	Not known
Boundary Creek	Debris Flow	November 9, 1989	$2.5x10^4$
No Good Creek	Debris Flow	October, 1990	Not known
Canyon Creek	Debris Flow	1990	$2.0x10^4$
Capricorn Creek	Debris Flow	July 29, 1998	$1.2x10^6$
Upper Lillooet River (approximately 1 km upstream from Powerhouse Site)	Debris Flow	September 19, 2009	$1.0x10^4$
Capricorn Creek	Debris Flow	September 19, 2009	$0.5x10^6$
Capricorn Creek	Debris Flow	August 6, 2010	$4.85x10^7$

NOTES:
1. Compiled from Friele et al (2008) and Guthrie et al (2012).

It can be seen from Table 5.2 that the majority of the dated 'recent' landslides are debris flows. The Frequency-Magnitude distribution of volcanic debris flows initiating in the MMVC ranges from debris flows with a volume of $<10^5$ m^3 with return intervals of approximately 5 to 10 years to a maximum credible debris flow of approximately $1.0x10^9$ m^3 with an annual probability in the order of 1:5,000 (Jakob, 1996, Friele et al., 2008).

5.2.2 Landslide Source Zones Upstream from Keyhole Falls

The proposed sites for the Operators Residence are at risk from a large magnitude/low frequency debris flow initiating in the Job Creek or Affliction Creek Catchment of the MMVC and travelling along the Upper Lillooet River drainage line (Drawing G0007). Recent unpublished research work confirms ongoing slope movement on the northwest side of Plinth Peak directed into the Job Creek Catchment (Roberti, 2015). The risk to the proposed building from this specific hazard was mitigated from the outset by only considering sites that are more than 50 m above the elevation of the adjacent reach of the Upper Lillooet River. The required elevation buffer was determined from the results of a published assessment of the maximum credible inundation for a debris flow, undertaken with the semi-empirical *Laharz* Model (Simpson et al., 2006), as described below.

Simpson et al., 2006 modelled the run-out of 10^6 m^3, 10^7 m^3, 10^8 m^3 and 10^9 m^3 debris flows initiating in the Job Creek Catchment. Their inundation map indicates 10^7 m^3, 10^8 m^3 and 10^9 m^3 debris flows could all potentially reach the portion of the Upper Lillooet River Valley where the Operator's Residence is proposed to be located and are, therefore, potentially harmful. Debris flows with a volume in excess of 10^9 m^3 are considered not credible (Friele et al., 2008). The published inundation map (Simpson et al., 2006) indicates that a 10^7 m^3 event could affect about a quarter of the valley floor in the vicinity of the Boulder Creek confluence, and in this assessment it was assumed that the run-out from a 10^7 m^3 event would be largely constrained to the active channel and flood plain of the Upper Lillooet River. The published inundation map (Simpson et al., 2006) indicates a 10^8 m^3 event could affect about half the width of the valley floor in the vicinity of the Boulder Creek Confluence and a 10^9 m^3 event could affect the full width of the valley floor.

At the request of KPL, NRCan provided estimates of the thickness of the 10^7 m^3, 10^8 m^3 and 10^9 m^3 debris flow deposits that were predicted by the 2006 model runs in the vicinity of the Boulder Creek confluence. The values, provided to an estimated accuracy of no more than ±10 m, based upon the accuracy of the output data, are 10 m for the 10^7 m^3 event, 20 m for the 10^8 m^3 event and 50 m for the 10^9 m^3 event. Thus, it was concluded that an elevation buffer of greater than 50 m from the adjacent reach of the Upper Lillooet River is needed to mitigate the risk from landslides originating in the Job Creek and Affliction Creek Catchments.

5.2.3 Landslide Source Zones Downstream from Keyhole Falls

Evans (1987) documented a 500,000 m^3 rock avalanche from the north side of Mount Meager, which occurred in the spring of 1986. During or somewhat after the primary event, debris flow material followed a drainage line and reached the Upper Lillooet River, forming a temporary blockage. The confluence of this tributary drainage line and the Upper Lillooet River is located approximately 1.7 km downstream from the Upper Lillooet HEF Powerhouse Site. Another small debris flow was reported along this same drainage line in July, 2015 (personal communication, Tom Millard, MoFLRO). The 2015 event developed a small fan at the confluence and shifted the main flow of the river towards the east bank. Evans (1987) documented tension cracks upslope from the detachment zone of the 1986 landslide in the ridge that protrudes from the peak of Mount Meager and he estimated that $1x10^7$ m^3 of material could be involved in a future rock avalanche from this area. The risk assessment presented in this report accounts for the possibility of both a rock avalanche and a debris flow initiating in the vicinity of the peak of Mount Meager, followings a similar travel path to the 1986 event, and then travelling along the Upper Lillooet River watercourse (Drawing G0007).

Consideration was given to the possibility of a larger landslide occurring along one of the other MMVC drainage lines in the area downstream from Keyhole Falls. Small ($<10^5$ m^3) debris flows are common in this area. An example of such an event occurred on September 19, 2009 when a small rainstorm triggered a small debris flow with a volume of approximately 10^4 m^3 on the north flank of Plinth Peak. The debris flow reached the Upper Lillooet River approximately 1 km upstream from the powerhouse site. This event does not seem to have blocked the Upper Lillooet River. The air photo record provides evidence of another previous debris flow reaching the river at the same location. The project Terrain Hazards Assessment identified a debris flow in the 1990 air photos on a drainage line that intersects the Upper Lillooet River approximately 250 m downstream from the powerhouse site. The debris flow initiated on a steep gully side slope in the upper part of the catchment and terminated approximately 200 m from the Upper Lillooet River. It was concluded that the landslide run-out path described by Evans (1987) is the critical drainage line run-out path in this area.

Jordan (1994) mapped an area of 'sackung' features on the northeast facing open slopes in the eastern-most portion of the MMVC. This area of distressed terrain, which is approximately 1.5 km-wide, is shown on Drawing G0007. There is potential for a large rock avalanche to initiate in this area and affect the proposed sites for the Operators Residence (Drawing G0007). This specific hazard was also accounted for in the risk assessment.

5.3 HAZARDS OUTSIDE THE MMVC

A large (approximately 800 m wide) alluvial/colluvial fan has developed where Boulder Creek intersects the floor of the Upper Lillooet River Valley (Drawing G0006). Site D is located in the upper part of the fan and Site C is just outside the margin of the fan. A debris flood hazard has been previously identified on the fan (KP, 2011a). In the API undertaken as part of the current assessment, 'recent' debris flood deposits were identified in the vicinity of the active channel in the 1947 air photos and again in the 1986/1990 air photos, as shown on Drawing G0006. The debris flood deposits extend from the apex of the fan to the confluence of Boulder Creek with the Upper Lillooet River. This indicates that debris floods large enough to deposit material all the way to the toe of the fan occur at a frequency of approximately 1:50 years. Smaller events are expected to occur more frequently. Avulsions channels were identified on the north side of Boulder Creek in both the 1947 and 1984 air photos (Drawing G0006).

The debris flood hazard on the Boulder Creek Fan has also been investigated by Golder Associates (2013), who were considering the hazard in relation to a proposed construction camp site adjacent to the Lillooet FSR, on the south side of Boulder Creek. Golder Associates (2013) mapped avulsion channels on the fan and produced an avulsion hazard map for the south part of the fan based upon topographic and vegetative indicators. The fan was subdivided into 'upper' and 'lower' portions and areas of 'Low', 'Moderate' and 'High' hazard were mapped.

The hazard terms used in this previous report were not defined in terms of an anticipated return frequency so the findings can only be used in a qualitative way. Site D is located on the ‘upper’ part of the Boulder Creek Fan, where the hazard was mapped as being ‘low’.

It is interpreted that the debris flood hazard is generally lower on the south side of the Boulder Creek compared to the north side. The reasons for this are that the west-northwest orientation of the modern channel at the apex of the upper fan tends to direct debris flood events away from the south portion, and because the south bank of the current watercourse is deeply incised into the fan deposits protecting the south portion of the fan from channel avulsions. The debris flood hazard at Site D cannot, however, be assumed to be negligible since significant aggradation of the channel bed can occur over time (as an example, approximately 2 to 5 m of aggradation occurred locally on the South Creek Fan, approximately 23 km to the southeast, during a debris flood event in the fall of 2015), which would reduce the natural protection afforded by the south bank of Boulder Creek.

Two debris flows were identified in the API along ephemeral drainage courses in the slopes on the northeast side of the Upper Lillooet Valley. One occurred in a forest clear-cut and was observed in the 1994 air photos and the other, which was identified in the 1990 air photos, initiated along a forestry access track (Drawing G0006). Both of the debris flows were relatively small having a travel distance of approximately 250 to 300 m. The debris flow hazard is judged to be ‘low’ along these drainage lines now that the areas have been re-vegetated.

There is natural terrain with slope angles in excess of 60% in the vicinity of the site of the proposed Operators Residence (Drawing G0005). Consideration was given to the open slope debris slide hazard in the areas of moderately steep to steep terrain immediately upslope from the sites considered. No landslides were identified in these areas in the historic air photo interpretation. The open slope debris slide hazard is judged to be ‘moderate’ in these areas.

5.4 OTHER HAZARDS

Landslide debris dam outburst flood hazards also need to be accounted for in considering possible sites for the Operators Residence. Such hazards have been identified in the Meager Creek, Salal Creek and Boulder Creek Catchments (KP, 2011). The process of only considering sites for the Operators Residence that are situated at least 50 m above the adjacent reach of the Upper Lillooet River served to mitigate the risk from landslide debris dam outburst floods along the MMVC drainage lines.

6 – QUANTITATIVE RISK ASSESSMENT

6.1 ASSUMPTIONS

The main assumptions for the assessment are detailed below:

- The risk assessment is limited to the expected times that workers will be staying at the Operators Residence. The variable landslide-related risks that workers will face during their daily working hours are to be managed by a site-specific operational plan (KP, 2016). It is assumed that a higher risk tolerance applies to the day-to-day operations and environmental monitoring activities compared to residency at the proposed facility.
- In consideration of the MMVC hazards, the assessment does not include for the possibility of a very large landslide or edifice collapse occurring on the east flank of Mount Meager as a result of volcanic activity. The MMVC last erupted approximately 2,400 years ago and the volcano may be considered active. The acceptance of a very low probability of the proposed facility being affected by future volcanic activity at the MMVC is implied. A volcanic eruption is typically preceded by a period of increased earthquake activity. Earthquake activity in BC is monitored by the Pacific Geosciences Centre. It is assumed, therefore, that there is a mechanism in place for providing warning of a possible eruption and facilitating a timely evacuation. NRCan’s recent notice in response to new fumarole activity demonstrates their active monitoring work.

6.2 METHODOLOGY

Quantitative Risk Assessment (QRA) is a systematic process involving risk analysis and risk evaluation. The QRA methodology used in this study follows established industry practice and the results are reliant upon judgment. Particular reference is made to QRA's undertaken for the project construction camp (KP, 2014b) and for the provincial campsite, situated close to the confluence of Meager Creek with the Upper Lillooet River (Cordilleran Geoscience, 2011).

Risk is assessed in terms of both individual risk and societal (group) risk. Individual risk is calculated using the following equation:

$$R = P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V$$

Where:

- R is the risk (annual probability of loss of life of an individual)
- $P_{(H)}$ is the annual probability of the hazardous event
- $P_{(S:H)}$ is an estimate of the probability that a hazardous event will reach or otherwise affect the site of the element at risk (spatial probability)
- $P_{(T:S)}$ is an estimate of the probability that the element at risk will be at the site when a hazardous event occurs (temporal probability), and
- V is an estimate of the vulnerability of the element at risk (probability of loss of life of the individual given the impact).

Societal risk is a measure of the overall risk to the population and takes into account the number of individuals that may be exposed to the risk and the aversion to multiple fatalities. Societal risk estimates are presented on graphs, referred to as 'F-N curves', which plot 'F', the cumulative frequency of N or more fatalities per year vs. 'N', the number of fatalities. F is the cumulative sum of $P_{(H)}*P_{(S:H)}*P_{(T:S)}$ for all the potentially harmful events once they have been ordered by decreasing value of N. N is calculated by multiplying the number of people at risk by their vulnerability. The graph is sub-divided into four areas representing:

- UNACCEPTABLE risk
- Tolerable risk, which should be reduced further, if practicable, according to the 'As Low As Reasonably Practicable (ALARP) principle'
- Risk that is considered BROADLY ACCEPTABLE, and
- A region of low probability but with the potential for >1,000 fatalities that requires INTENSE SCRUTINY.

In this assessment, the risk was calculated for lower and upper residency estimates of 4 and 8 people, respectively. In each case, lower and upper-bound F-N curves were generated based upon assessed ranges of $P_{(S:H)}$ and V.

Risk guidelines, which establish the maximum allowable risk as the tolerable risk or required 'level of landslide safety', are used to evaluate the risk. At present, there is no provincial or federal legislation addressing levels of landslide safety. Overviews of 'levels of landslide safety' adopted by a few local jurisdictions in BC in relation to residential development are presented in Porter and Morgenstern (2012) and Appendix C of APEGBC, 2010. Of particular note is the 1973 'Berger Ruling', which set a precedent of a 'level of landslide safety' at an annual probability of less than 1:10,000 for a major landslide event affecting a residential development.

Risk guidelines relating to the individual risk from landslides have been developed in Hong Kong, Australia and by the District of North Vancouver, BC. Such guidelines set limits on individual risk for the most vulnerable people affected by the landslide hazard, as follows:

Table 6.1 Example Landslide Risk Guidelines for Individual Risk

Type of Development	Maximum Allowable Individual Risk
New	$1x10^{-5}$ (1:100,000)
Existing	$1x10^{-4}$ (1:10,000)

NOTES:
1. Risk refers to the likelihood of a fatality per annum.

It is also necessary in these jurisdictions to evaluate the group or societal risk by preparing an F-N plot, and development might be approved if it can be demonstrated that risks fall in the ALARP or BROADLY ACCEPTABLE regions of the plot. These individual risk threshold and F-N plot criteria were adopted in this study in order to establish a site for the Operators Residence that is 'safe for the use intended'.

6.3 HAZARD CHARACTERIZATION

Three Specific MMVC landslide hazards have been identified that pose a risk to the sites being considered for the Operator's residence:

- A rock avalanche initiating in the summit area of Mount Meager
- A rock avalanche initiating within the area of 'sackung' terrain on the northeast-facing slopes upslope from the Upper Lillooet River close to its confluence with Meager Creek; and
- A debris flow initiating at the peak of Mount Meager.

Maximum credible events were determined for these landslide hazards. In the case of a landslide initiating at the summit of Mount Meager, the source area dimensions of the maximum credible event were estimated to be 550 m-wide x 500 m-long. An average thickness of 75 m was assumed considering that the lateral shear surfaces of the 2010 landslide, which initiated at the secondary peak of Mount Meager, were estimated to be approximately 70 m-high (Gutherie et al., 2012). These dimensions yield an approximate volume of 20M m^3. A larger maximum credible volume of $5x10^7$ m^3 was estimated for a debris flow initiating at the peak of Mount Meager in order to account for possible entrainment along the travel path. The area of 'sackung' terrain on the northeast-facing slopes upslope from the Upper Lillooet River close to its confluence with Meager Creek does not extend upslope to a peak or ridgeline. The average slope angle in this area is approximately 40º, compared to approximately 50º in the peak area of Mount Meager. A smaller average thickness of 20 m was estimated for the maximum credible event based on these observations. The plan dimensions of the maximum credible event were estimated to be approximately 1,100 m-wide X 400 m-long based on the mapped extent of the 'sackung' features. These dimensions yield an approximate volume of 10M m^3.

Debris floods along Boulder Creek pose an additional risk to Site D. Site D is located on the upper part of the Boulder Creek Fan, where the hazard has previously been described as 'low' (Golder Associates, 2013). In the upper part of the fan, the south bank of Boulder Creek is deeply incised (approximately 15 m) into the ancient fan deposits and it is interpreted that the Upper Fan area on the south side of the creek is outside the run-out area of the 1:1,000 year event. Site D is nonetheless considered to be at risk from the maximum credible (1:10,000 year) event.

6.4 RISK ANALYSIS

Consideration was first given to the risk posed to the five possible sites from a debris flow initiating at the peak of Mount Meager. The travel distance from the peak of Mount Meager varies from approximately 6.5 km to 8.0 km. A debris flow run-out analysis undertaken for the Upper Lillooet HEF Intake structure (KP,2014,a) showed a $1x10^7$ m^3 landslide initiating in the Job Creek Catchment (at a lower elevation than the peak of Mount Meager) is estimated to travel approximately 7.5 km. The maximum credible event debris flow from the peak of Mount Meager is therefore expected to travel further downstream on the Upper Lillooet River drainage line than all five of the proposed sites. The maximum credible event volume is broadly similar to that of the 2010 Capricorn Creek Debris Flow. The 2010 landslide formed an approximately 30 to 50 m thick deposit at the confluence of

Capricorn Creek with Meager Creek, which is located approximately 7.5 km along its travel path. However, the 2010 landslide ran-up approximately 270 m in elevation on the opposing side of the Meager Creek Valley before carrying on down the watercourse. Based upon this review of previous studies, the 50 m elevation buffer from the adjacent reach of the Upper Lillooet River is judged to be sufficient to effectively mitigate the risk of a debris flow initiating at the peak of Mount Meager for the proposed sites with the exception of Site A. Site A is judged to be too close to the confluence of the travel path with the Upper Lillooet River to be clear of the potential run-up zone, and was consequently concluded to be inappropriate for the proposed development.

A QRA was completed for Sites B, C, D and E with respect to the identified specific rock avalanche hazards initiating at the peak of Mount Meager and at the area of 'sackung' terrain. Both rock avalanche hazards were estimated to have an annual probability of occurrence of 1:10,000 (or less) since, while they are deemed credible, comparable magnitude events are not known to have occurred at these sites throughout the approximate 10,000 year time period since de-glaciation.

The spatial probability was assessed using a graphical plot of tan (Angle of Reach) verses rock avalanche volume presented in Scheidegger (1973). The ranges of tan(Angle of Reach) values for the volumes of the two maximum credible events under consideration were determined, and assuming a normal data distribution, the 95th percentile was determined (95% of the angle of reach data for the subject landslide volume being larger than this value) as being representative of the Maximum Credible Event. Using this method, a Maximum Credible Event Angle of Reach (AoR) value of 13º (tanAoR= 0.23) was determined for a rock avalanche initiating at the peak of Mount Meager and a Maximum Credible Event AoR value of 15º (tanAoR= 0.27) was determined for a rock avalanche initiating in the area of 'sackung' terrain. The predicted maximum extent of debris run-out for a rock avalanche initiating in the area of 'sackung' terrain, assuming an angle of reach value of 15º, is shown on Drawing G0007. This line was developed by simply projecting lines directly down slope from the sides of the assumed source zone at an angle of 15º below the horizontal until they intersected the slope on the north side of the valley. It is anticipated that the subject rock avalanche would demonstrate significant debris spreading and the length of slope affected by debris on the north side of the Upper Lillooet River would be significantly greater than the source zone width.

The mean AoR value predicted for a $1x10^7$ m^3 landslide by the Scheidegger (1973) dataset was compared to the value derived from the Corominas (1996) dataset. The mean angle of reach value from the Scheidegger (1973) data set is similar to the Corominas (1996) value for 'obstructed' rock falls and rock avalanches - 22º compared to 21.5º. The 'obstructed' travel path data set is considered to be appropriate for comparison since the subject travel paths intersect the floor of the Upper Lillooet Valley.

Spatial probability values were estimated for the proposed Operators Residence sites in a qualitative manner by comparing the angular elevations from the rock avalanche source zones to the proposed sites to the respective Maximum Credible Event AoR values. Consideration was given to factors that could attenuate the run-out of a landslide following the subject travel paths to the proposed sites. The factors considered included the required angular deviation in plan that a landslide would need to have in order to affect the site, the required elevation gain from the floor of the Upper Lillooet River Valley to the site, and, in the cases of Sites D and E, the influence of the Boulder Creek Canyon in limiting debris runout. The estimated spatial probability values are summarized in Tables 6.2 and 6.3 below:

Table 6.2 Estimated Spatial Probability Values for a Rock Avalanche initiating at Mount Meager

Site	Tan (Angular Elevation from Source Area to Site)	Estimated Tan (Angle of Reach) of Maximum Credible Event	Required deviation of landslide travel path for it to reach the site (°)(Note 1)	Required elevation gain from the floor of the Upper Lillooet River Valley (m)	Estimated Spatial Probability
B	0.28	0.23	20	40	0.6 to 0.7
C	0.28	0.23	25	35	0.5 to 0.6
D	0.26	0.23	32	30	0.2 to 0.3
E	0.24	0.23	33	100	0.05 to 0.1

NOTES:

1. Angle between the travel direction at the confluence of the tributary drainage line and the Upper Lillooet River and the trajectory line from the confluence to the proposed site for the residence.

Table 6.3 Estimated Spatial Probability Values for a Rock Avalanche initiating in the area of 'Sackung' Terrain

Site	Tan (Angular Elevation from Source Area to Site)	Estimated Tan (Angle of Reach) of Maximum Credible Event	Required deviation of landslide travel path for it to reach the site (°) (Note 1)	Required elevation gain from the floor of the Upper Lillooet River Valley (m)	Estimated Spatial Probability
B	0.30	0.27	32	55	0.7 to 0.8
C	0.28	0.27	46	50	0.5 to 0.6
D	0.26	0.27	62	45	0.1 to 0.2
E	0.23	0.27	63	115	0.05 to 0.1

NOTES:

1. Angle between the travel direction and the trajectory line from the confluence with the Upper Lillooet River to the proposed site for the residence.

The temporal probability reflects the maximum proportion of time individuals are expected to be resident at the building outside of working hours. The plant operators are expected to spend the most amount of time on site. It is assumed that the individuals operating the plant will be on site permanently for 6 months of the year and will be on site for approximately a third of the rest of the year and while they are on site they will spend approximately 50% of each full day at the Operators Residence (as described in Section 6.1, it is assumed that for the remaining 50% of the day, the subject individuals will be at work at the hydroelectric facility with the risk being managed by an Operational Landslide Risk Management Plan). The temporal probability for these individuals is therefore approximately 0.33. It is understood that the Operators Residence will occasionally be used as a 'refuge' during normal working hours when the Landslide Risk Management Plan requires work to 'Shutdown'. This occupancy, which occurs during normal work hours, is part of the mitigation measures pertaining to the operational Landslide Risk Management Plan and is therefore not classed as residency.

The vulnerability is defined as the probability of an individual losing their life if subject to a given landslide hazard. Vulnerability is based solely upon judgement. Vulnerability estimates depend upon the scale and type of the landslide hazard, the predicted landslide velocity and depth (Jacob et al, 2012), and the level of protection that the proposed Operators Residence could provide. It was assumed that the Operators Residence will comprise an elevated wood frame structure. There is considerable uncertainty (particularly in the absence of run-out modelling) regarding the expected landslide velocities and landslide debris depths along the run-out paths. Furthermore, landslides impart both static and dynamic loads, which are difficult to predict. Ranges of vulnerability factors were adopted in order to reflect these uncertainties. Rock Avalanches can be extremely destructive and the locations at which a rock avalanche could destroy a wood frame structure is expected to be very close to the end of the run-out path. Upper-bound vulnerability values of 1.0 were therefore selected for all of the proposed sites. Lower-bound vulnerability values were assessed based upon the positions of the sites relative to the assessed extents of debris run-out for the Maximum Credible Events. The estimated vulnerability values are summarized in Table 6.4 below.

Table 6.4 Estimated Vulnerability Values for Specific Hazards

Site	Vulnerability	
	Rock Avalanche initiating at Mount Meager	Rock Avalanche initiating in the area of 'Sackung' Terrain
B	0.95 to 1.0	0.95 to 1.0
C	0.95 to 1.0	0.9 to 1.0
D	0.9 to 1.0	0.85 to 1.0
E	0.85 to 1.0	0.8 to 1.0

The QRA for Site D also incorporated the risk from a debris flood along Boulder Creek. The south bank of Boulder Creek is incised about 15 m into the upper part of the fan (Golder Associates, 2013). It is interpreted that this provides natural protection to Site D with respect to the 1:1,000 year debris flood event although this part of the fan would still be at risk from the maximum credible (1:10,000 year) event.

The Personal Individual Risk (PIR) was calculated for Sites B to E with respect to the two specific rock avalanche hazards identified. For Site D, The PIR calculation also included the Maximum Credible Debris Flood Event along Boulder Creek. The PIR with respect to the debris flood hazard along Boulder Creek was found to be approximately 1.07×10^{-5} (1:93,250). For each site, the total PIR was calculated by adding the values for the different hazards.

The aggregated PIR values are presented in Table 6.5 below:

Table 6.5 Aggregated Personal Individual Risk Values

Site	Personal Individual Risk	
	Range	Mean
B	4.08×10^{-5} to 4.95×10^{-5} (1: 24,500 to 1: 20,200)	4.52×10^{-5} (1:22,150)
C	3.06×10^{-5} to 3.96×10^{-5} (1:32,700 to 1:25,250)	3.51×10^{-5} (1:28,500)
D	1.70×10^{-5} to 2.97×10^{-5} (1:58,800 to 1:33,700)	2.34×10^{-5} (1:42,800)
E	2.72×10^{-6} to 6.60×10^{-6} (1:367,650 to 1:151,500)	4.66×10^{-6} (1:214,600)

6.5 RISK EVALUATION

The adopted risk guidelines require the individual risk to be less than 1:100,000 in the case of new development; therefore, only Site E meets the required risk tolerance threshold for individual risk. The results of the group risk assessment are presented in Figure 1. For each site, lower-bound and upper-bound curves were generated in order to account for the lower and upper occupancy predictions of 3 and 8 people, respectively. It can be seen in Figure 1 that Sites B to D span across the ALARP Zone with Site B being closest to the boundary with the UNACCEPTABLE Zone and Site D being close to the boundary with the BROADLY ACCEPTABLE ZONE. Site E intersects the boundary between the ALARP Zone and the BROADLY ACCEPTABLE ZONE. Considering the results of the group risk evaluation, it is recommended that ongoing inspection monitoring of the landslide hazard zones be undertaken throughout the life of the proposed residence. It is considered that this monitoring requirement can be fulfilled by annual helicopter reconnaissance of the source zones, which is required as part of the operational Landslide Risk Management Plan for the hydropower facility.

6.6 CONSIDERATION OF OPEN SLOPE LANDSLIDE RISK AT SITE E

Consideration was given to the open slope debris slide risk from the areas of moderately steep to steep terrain adjacent to the north part of the Site E. No landslides were identified in these areas in the API, and the hazard is judged to be 'low' with an expected annual frequency of less than 1/500.

The empirical relationship for translational slides published by Corominas (1996) was used to assess the run-out of a debris slide initiating at the crest of the upslope area of steep terrain, approximately 35 m above the Site E terrace. The Corominas (1996) run-out relationships use the 'Angle of Reach', measured from the crest of the hypothetical landslide source area to the toe of the debris trail. A landslide volume of 500 m^3 was assumed based upon the relatively small-size of the natural slope. The corresponding 'Angle of Reach' from the Corominas (1996) run-out relationship is 24°. The maximum run-out extent for this 'angle of reach' value is approximately 25 m from the toe of the moderately steep to steep slope. It is recommended, therefore, that any occupied structures be set-back a minimum of 25 m from the toe of the moderately steep to steep natural slopes (as shown on Drawing G0008) in order to mitigate the debris slide risk. It is also considered necessary to implement a set-back distance from the crest of the downslope area of moderately steep to steep terrain in the northwest part of the site. A minimum set-back distance of 10 m is considered to be sufficient as the estimated annual landslide frequency is less than 1/500 on the subject slopes and a landslide would be expected to have a relatively small size (<500 m^3). It is recommended, therefore, that occupied structures be set-back at least 10 m from the crest of the moderately steep to steep slopes in this area, as shown on Drawing G0008.

6.7 CHANGED CONDITIONS

Jordan (1994) noted more 'recent' landslides have been observed on the south side of the MMVC than the north and attributed this to there being greater glacial coverage on the north side. If this observation and reasoning are correct then landslide activity on the north side of the massif may be expected to increase with ongoing glacial retreat. However, the finding could also be a reflection of there being less human presence on the north side of the MMVC and therefore a poorer observation record of past events.

Rapid glacier recession (Koch et al, 2009; Scheiffer et al, 2007) will lead to an increased probability of large rock avalanches from areas of glacially debuttressed slopes (Holm, 2004).

The following climate changes can be reasonably expected at the site:

- The average annual precipitation is expected to increase and rainstorms are expected to generate higher peak flows along the drainage channels due to increased storm precipitation intensities (Jacob and Lambert, 2009).
- An earlier spring freshet.
- Warmer winters with a higher incidence of rain-on-snow events and more extreme rainfall events (Whitfield et. al. 2002, 2003).
- Increases in temperature and summer droughts. The Baseline Hydrology Report for the Project (KP, 2011b) predicted a mean annual temperature increase of 0.04 ºC based upon an analysis of temperature records for Whistler. This translates to an increase of 1.6 ºC during the 40 year design-life.
- Increased incidences of lightning strikes and wildfires (BC, 2007). Wildfire can cause significant changes to soil and bedrock physical properties as well as loss of vegetation cover and forest floor material. These changes in hydrological and geotechnical conditions can result in increased incidences of landslides, as discussed in Jacob and Hungr (2005). The site experienced an extensive wildfire in the summer of 2015. A post-wildfire Landslide Risk Management Plan was developed (KP, 2015a). The study identified the development of water-repellent soils in some parts of the site although the affected locations are not in the vicinity of the sites being considered for the Operator's Residence. The Site was affected by an 'Extreme Hazard Level' rainstorm on September 19 and 20, 2015. This rainstorm triggered two debris flows and an avulsion of North Creek that affected the access route to the site but did not trigger any landslides in the burnt terrain in the vicinity of the five sites under consideration for the Operators Residence.

The predicted climate changes are expected to result in increased landslide hazards in the relatively near future (Jakob and Lambert, 2009). However, countering the notion that landslide activity may increase is the observation that landslide activity exponentially declines following a severe disturbance, such as after continental scale deglaciation (Friele et al., 2008) or a volcanic eruption (Major et al. 2000), both of which apply to the MMVC.

7 – DISCUSSION AND CONCLUSIONS

The natural terrain landslide hazard and risk were assessed for five possible sites (Sites A to E) for the Operators Residence for the Upper Lillooet Hydro Project. A Quantitative Risk Assessment was undertaken and the risk from the identified hazards was evaluated with respect to adopted risk tolerance criteria for individual and group risk.

Site E, the site of the existing construction camp, is the only one that meets the adopted risk tolerance criteria for individual risk. Site E can also be considered to meet the criteria for group risk on the basis that the F-N curve intersects the boundary between the ALARP Zone and the BROADLY ACCEPTABLE ZONE. Considering the results of the group risk evaluation, it is recommended that ongoing inspection monitoring of the landslide hazard zones be undertaken throughout the life of the proposed residence. It is considered that this monitoring requirement can be fulfilled by annual helicopter reconnaissance of the source zones, which is required as part of the operational Landslide Risk Management Plan for the hydropower facility. As described in Section 6.6, set-backs should be established from the moderately steep slopes adjacent to Site E. Accounting for these requirements, it is concluded in relation to the adopted landslide risk tolerance criteria that Site E is 'safe for the use intended'.

There is a possibility of debris from a very large landslide in the MMVC blocking and flooding the access road to the site and cutting off access to the Operators Residence. Access may also be cut-off as a result of non-MMVC landslides or snow avalanches. It is known, from the preliminary geotechnical assessment undertaken for the proposed transmission line (KP, 2010) that additional landslide and snow avalanche hazards affect the portion of the Lillooet FSR that forms the access route to the site. In September 2015, access to the site was cut-off by two debris flows and the avulsion of North Creek. Allowance should therefore be made for the possibility of the residence occasionally being cut-off as a result of the Lillooet FSR being affected by a landslide, snow avalanche or flooding. A helipad should be maintained adjacent to the residence to facilitate access and egress to and from the site in such an event.

Different conclusions may be appropriate if there are changes to the proposed occupancy of the facility or if new scientific information regarding the hazards affecting the site comes to light either from academic research or from ongoing monitoring inspections during the operational life of the project.

Please do not hesitate to contact the undersigned should you have any questions regarding the findings of this assessment or require any additional information.

Yours truly,
KNIGHT PIESOLD LTD.

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Approval that this document adheres to Knight Piésold Quality Systems: SRM

Attachments:

Drawing G0005 Rev 0	Site Map
Drawing G0006 Rev 0	Terrain Hazards Identified within 2 km Buffer from Boulder Creek HEF Powerhouse
Drawing G0007 Rev 0	Landslide Hazards in the Mount Meager Volcanic Complex that affect the sites
Drawing G0008 Rev 0	Recommended Set-backs for Occupied Structures at Site E
Figure 1 Rev 0	F-N Plot for Natural Terrain Landslide Hazards

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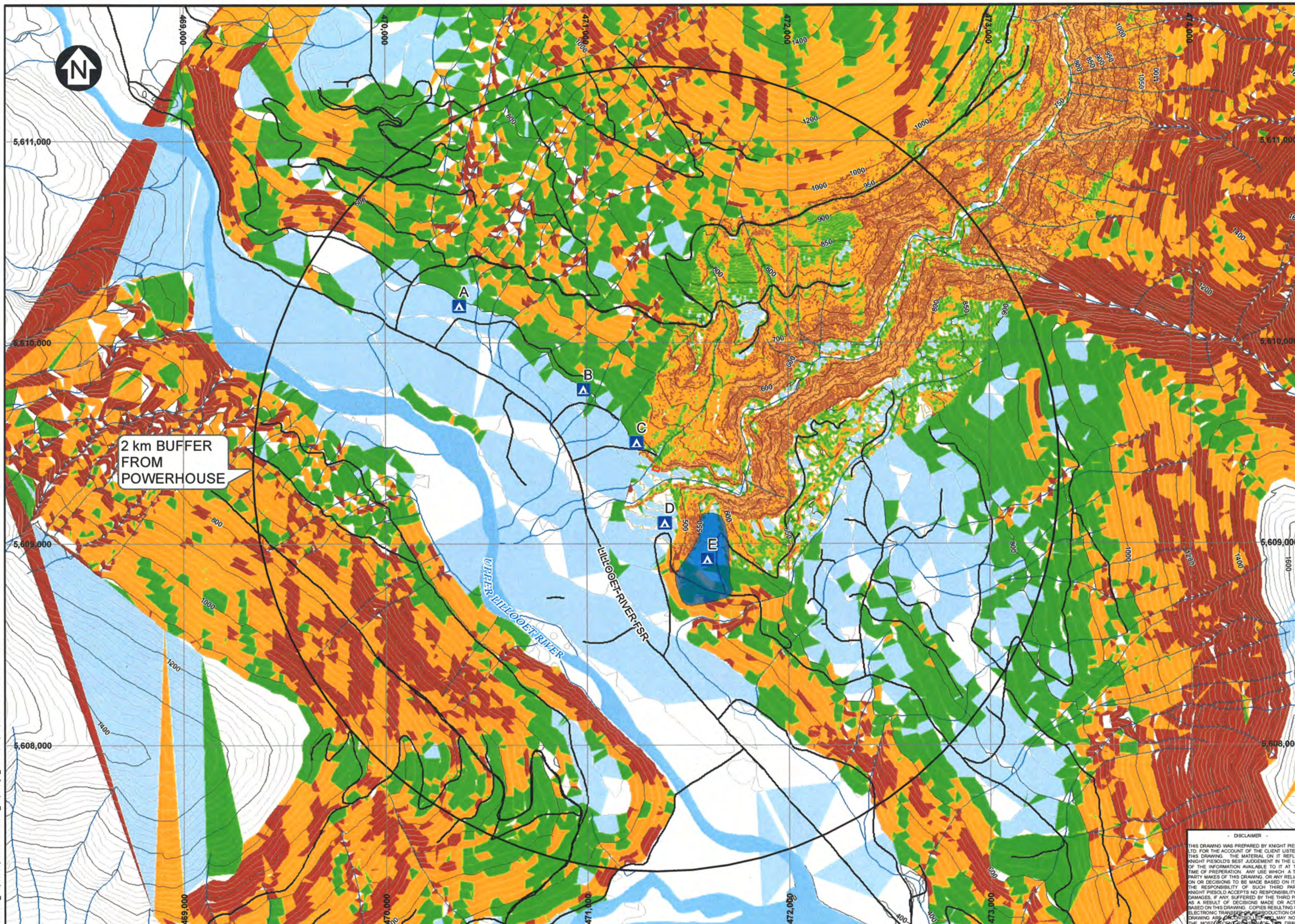

LEGEND:

PROPOSED FACILITIES

- POSSIBLE SITE FOR OPERATOR'S RESIDENCE
- CONTOUR (50 m) - LiDAR
- CONTOUR (5 m) - LiDAR
- CONTOUR (100 m) - TRIM
- BC Roads (Scale 1:50,000)
- CONTOUR (20 m) - TRIM
- ROAD
- TRIBUTARY
- RIVER
- BOULDER CREEK HEF POWERHOUSE
- CONSTRUCTION CAMP

SLOPE ANGLE

- 0 - 5% (PLAIN: 0 - 3 DEGREES)
- 6 - 26% (GENTLE: 3 - 15 DEGREES)
- 27 - 49% (MODERATE: 15 - 26 DEGREES)
- 50 - 70% (MODERATELY STEEP: 26 - 35 DEGREES)
- >70% (STEEP: >35 DEGREES)

NOTES:

1. BASE MAP: TRIM AND LIDAR CONTOURS.
2. COORDINATE SYSTEM IS IN METRES. COORDINATE SYSTEM: NAD 1983 UTM ZONE 10N.
3. THIS FIGURE IS PRODUCED AT A NOMINAL SCALE OF 1:20,000 FOR 11x17 (TABLOID) PAPER. ACTUAL SCALE MAY DIFFER ACCORDING TO CHANGES IN PRINTER SETTINGS OR PRINTED PAPER SIZE.

SCALE 100 50 0 100 200 300 400 500 Meters

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Knight Piésold CONSULTING

UPPER LILLOOET RIVER AND BOULDER CREEK POWER LIMITED PARTNERSHIPS

UPPER LILLOOET HYDRO PROJECT

PROPOSED OPERATOR'S RESIDENCE SITE MAP

PROFESSIONAL ENGINEER — PROVINCE OF BRITISH COLUMBIA — J. E. HALEY # 33730 — Oct. 5th 2016 — J. Haley

P/A NO.	DRAWING NO.	REVISION
VA103-279/05	G0005	0

REV	DATE	DESCRIPTION	DESIGNED	DRAWN	REVIEWED	APPROVED
0	12SEP'16	ISSUED FOR INFORMATION	KK	CAC	J.H	SRM

REVISIONS

DRG. NO.	DESCRIPTION

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REV	DATE	DESCRIPTION	DESIGNED	DRAWN	REVIEWED	APPROVED

REVISIONS

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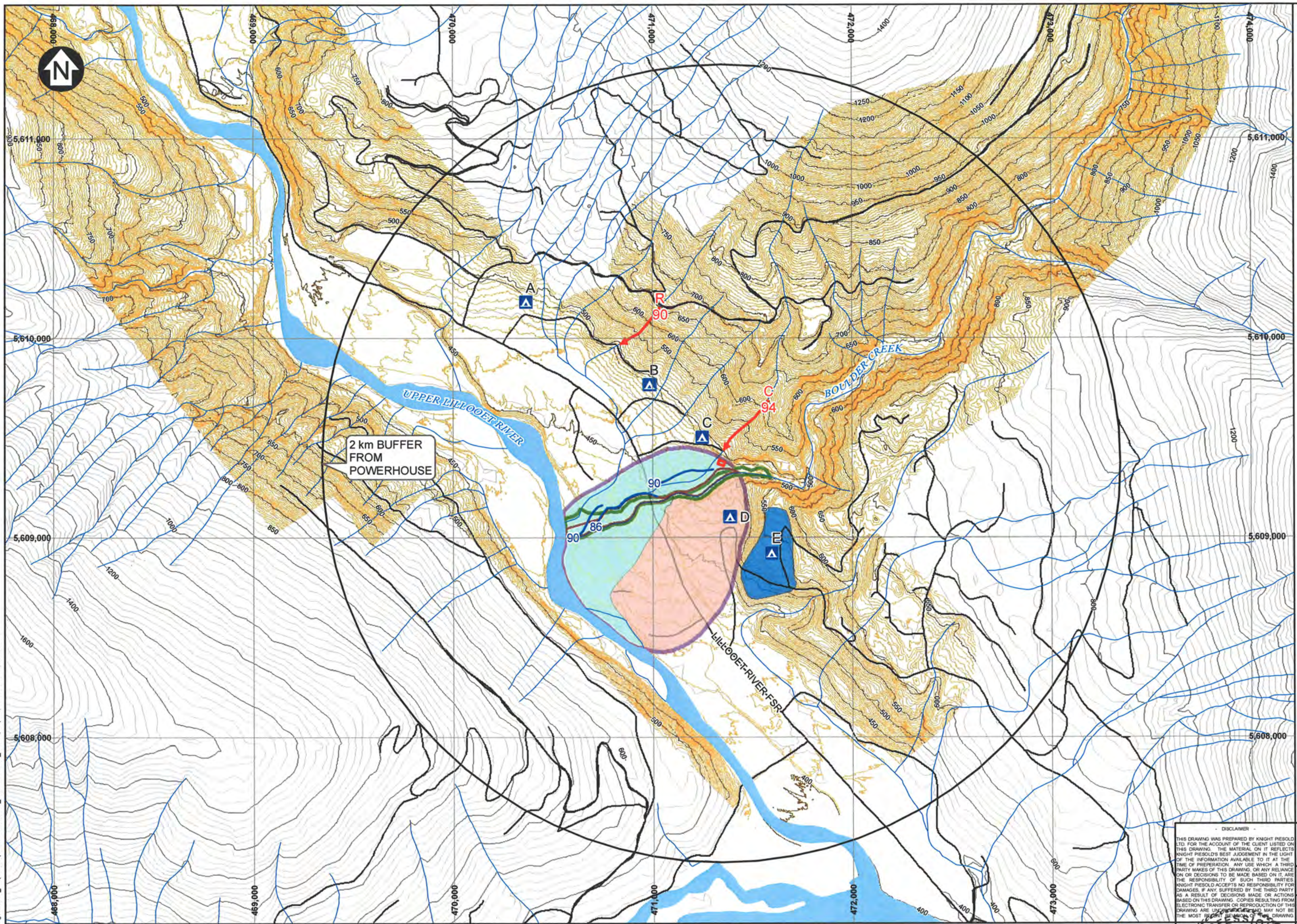

LEGEND:

- CONTOUR (50 m) - LiDAR
- CONTOUR (5 m) - LiDAR
- CONTOUR (100 m) - TRIM
- CONTOUR (20 m) - TRIM
- ROAD
- TRIBUTARY
- RIVER

FACILITIES

- BOULDER CREEK HEF POWERHOUSE
- POSSIBLE SITE FOR OPERATOR'S RESIDENCE
- CONSTRUCTION CAMP

TERRAIN HAZARDS

- BOULDER CREEK FAN
- LOWER FAN
- UPPER FAN
- PRE-1947 DEBRIS FLOOD DEPOSIT
- PRE-1986 DEBRIS FLOOD DEPOSIT
- AVULSION CHANNEL
- RECENT DEBRIS FLOW (R: LANDSLIDE INITIATED ALONG ROAD/TRACK; C: LANDSLIDE INITIATED IN CLEARCUT)

NOTES:

1. BASE MAP: TRIM AND LIDAR CONTOURS.
2. COORDINATE SYSTEM IS IN METRES. COORDINATE SYSTEM: NAD 1983 UTM ZONE 10N.
3. THIS FIGURE IS PRODUCED AT A NOMINAL SCALE OF 1:20,000 FOR 11x17 (TABLOID) PAPER. ACTUAL SCALE MAY DIFFER ACCORDING TO CHANGES IN PRINTER SETTINGS OR PRINTED PAPER SIZE.
4. 90 - YEAR OF AIR PHOTOS ON WHICH FEATURE WAS FIRST IDENTIFIED.

SCALE 100 50 0 100 200 300 400 500 Meters

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PROFESSIONAL ENGINEER — PROVINCE OF BRITISH COLUMBIA — J. E. HALEY # 33730

Oct. 5th 2016 J. Haley

Knight Piésold CONSULTING

UPPER LILLOOET RIVER AND BOULDER CREEK POWER LIMITED PARTNERSHIPS

UPPER LILLOOET HYDRO PROJECT

PROPOSED OPERATOR'S RESIDENCE TERRAIN HAZARDS IDENTIFIED WITHIN 2KM BUFFER FROM BOULDER CREEK HEF POWERHOUSE

P/A NO.	DRAWING NO.	REVISION
VA103-279/05	G0006	0

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REVISIONS

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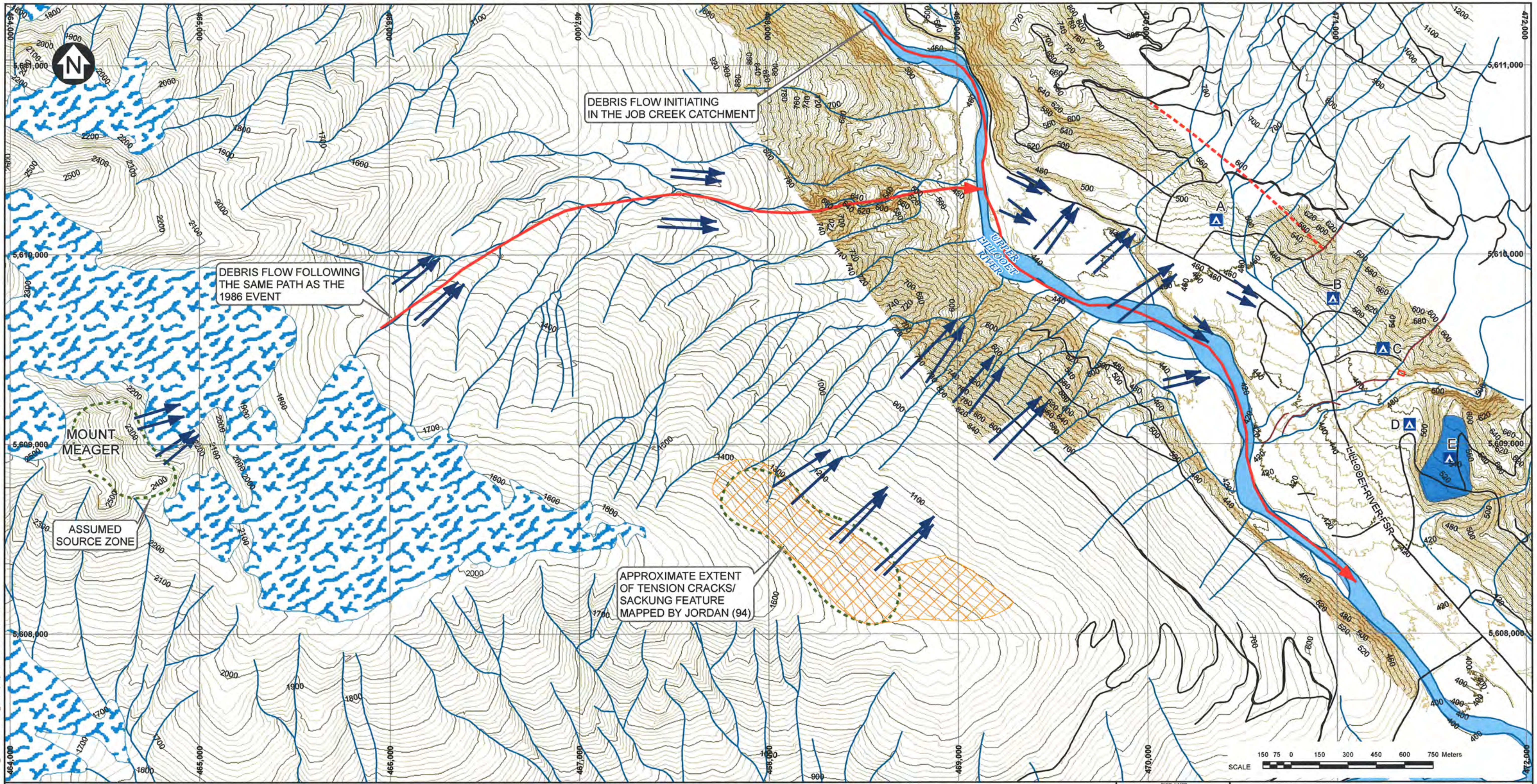

LEGEND

GENERAL

- ROAD
- RIVER
- GLACIER
- 20M LIDAR/100M TRIM CONTOUR
- 5M LIDAR /20M TRIM CONTOUR

FACILITIES

- BOULDER CREEK HEF POWERHOUSE
- POSSIBLE SITE FOR OPERATOR'S RESIDENCE
- CONSTRUCTION CAMP

MMVC TERRAIN HAZARDS

- TENSION CRACKS/SACKUNG
- ROCK AVALANCHE
- POSSIBLE DEBRIS FLOW RUN-OUT PATH
- PREDICTED RUN-OUT FOR A ROCK AVALANCHE WITH 15 DEGREE TRAVEL ANGLE

NOTES:

1. BASE MAP: TRIM AND LIDAR CONTOURS.
2. COORDINATE SYSTEM IS IN METRES. COORDINATE SYSTEM: NAD 1983 UTM ZONE 10N.
3. THIS FIGURE IS PRODUCED AT A NOMINAL SCALE OF 1:20,000 FOR 11x17 (TABLOID) PAPER. ACTUAL SCALE MAY DIFFER ACCORDING TO CHANGES IN PRINTER SETTINGS OR PRINTED PAPER SIZE.
4. CONTOUR INTERVAL IS 5M IN THE LIDAR AREA AND 20M OUTSIDE OF LIDAR ZONE.

DRG. NO.	DESCRIPTION
REFERENCE DRAWINGS	

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PROFESSIONAL ENGINEER
PROVINCE OF BRITISH COLUMBIA
J. E. HALEY
33730
Oct. 5th 2016
J. Haley

Knight Piésold
CONSULTING

UPPER LILLOOET RIVER AND BOULDER CREEK POWER LIMITED PARTNERSHIPS

UPPER LILLOOET HYDRO PROJECT

PROPOSED OPERATORS RESIDENCE LANDSLIDE HAZARDS IN THE MOUNT MEAGER VOLCANIC COMPLEX THAT AFFECT THE SITES

P/A NO.	DRAWING NO.	REVISION
VA103-279/5	G0007	0

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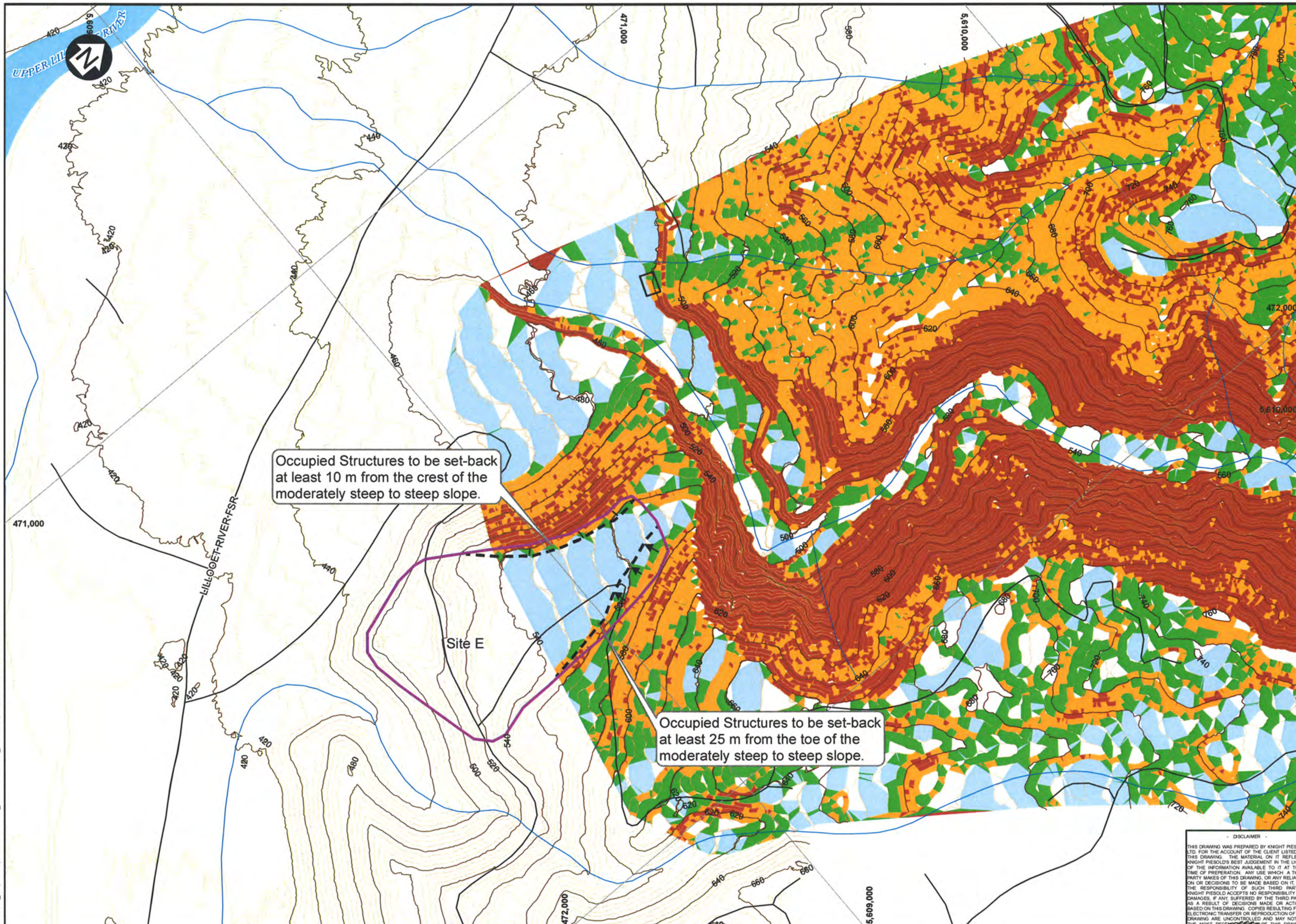

LEGEND:

- ROAD
- RIVER
- 20M LIDAR CONTOUR
- 5M LIDAR CONTOUR

SLOPE ANGLE

- 0 - 5% (PLAIN: 0 - 3 DEGREES)
- 6 - 26% (GENTLE: 3 - 15 DEGREES)
- 27 - 49% (MODERATE: 15 - 26 DEGREES)
- 50 - 70% (MODERATELY STEEP: 26 - 35 DEGREES)
- >70% (STEEP: >35 DEGREES)

NOTES:

1. BASE MAP: LIDAR CONTOURS AND SLOPE ANGLE.
2. COORDINATE SYSTEM IS IN METRES. COORDINATE SYSTEM: NAD 1983 UTM ZONE 10N.
3. THIS FIGURE IS PRODUCED AT A NOMINAL SCALE OF 1:6,000 FOR 11x17 (TABLOID) PAPER. ACTUAL SCALE MAY DIFFER ACCORDING TO CHANGES IN PRINTER SETTINGS OR PRINTED PAPER SIZE.

SCALE 50 25 0 50 100 150 200 250 Meters

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UPPER LILLOOET RIVER AND BOULDER CREEK POWER LIMITED PARTNERSHIPS

UPPER LILLOOET HYDRO PROJECT

PROPOSED OPERATOR'S RESIDENCE RECOMMENDED SET-BACKS FOR OCCUPIED STRUCTURES AT SITE E

PROFESSIONAL ENGINEER PROVINCE OF BRITISH COLUMBIA J. E. HALEY # 33730

Oct 5th, 2016 J. Haley

P/A NO.	DRAWING NO.	REVISION
VA103-279/05	G0008	0

REFERENCE DRAWINGS

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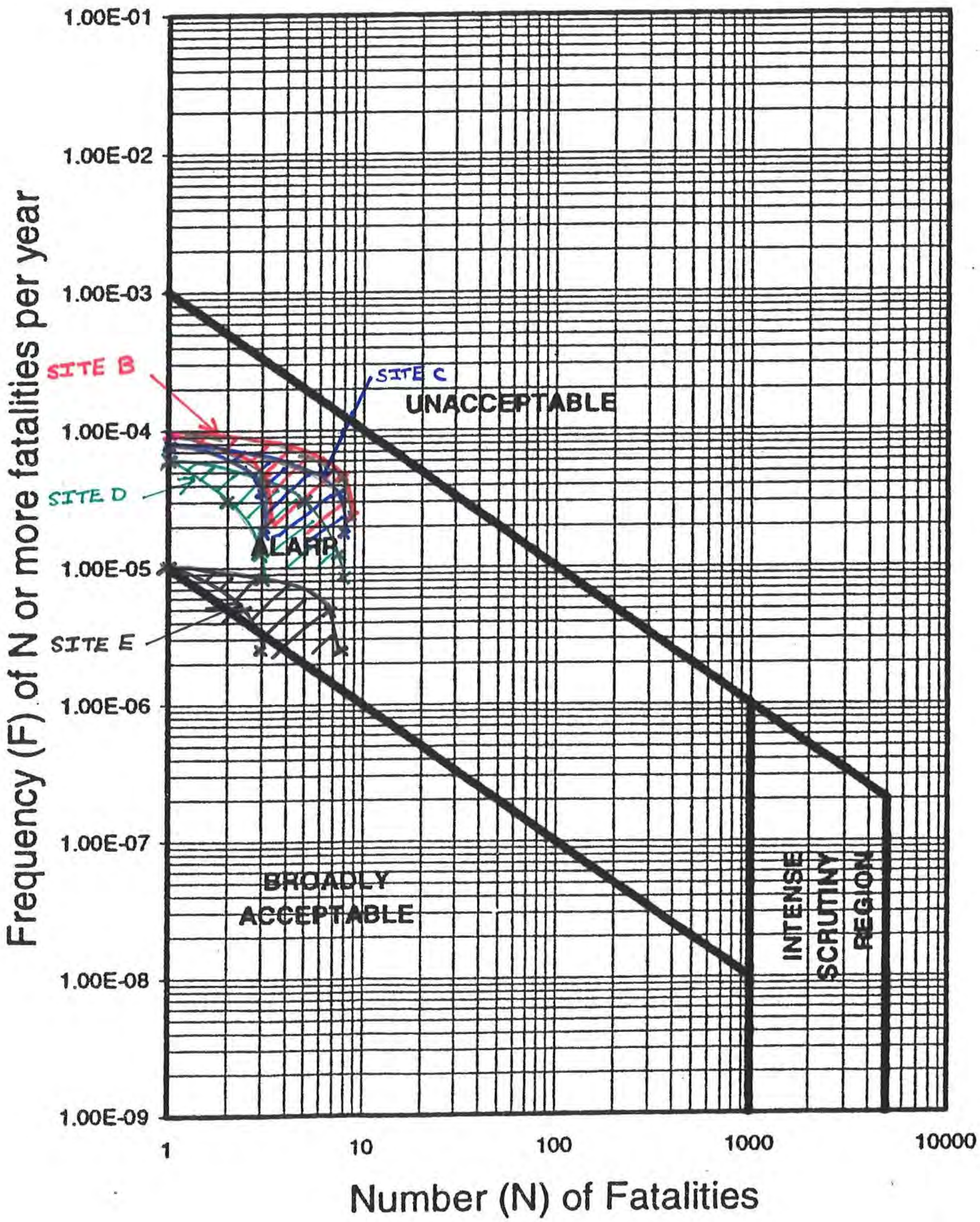

UPPER LILLOOET RIVER AND BOULDER CREEK POWER LIMITED PARTNERSHIPS

UPPER LILLOOET HYDRO PROJECT

PROPOSED OPERATORS RESIDENCE: F-N PLOT FOR NATURALTERRAIN LANDSLIDE HAZARDS

Knight Piésold CONSULTING

P/A NO.	REF. NO.
VA103-279/5	VA15-02653

FIGURE 1 REV 0

REV	DATE	DESCRIPTION	PREP'D	CHK'D	APP'D
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