Kelly Creek Fire
Post Wildfire Hazard Assessment and Partial Risk Analysis

2009 Fire C40429 near Clinton

Prepared for the BC Ministry of Forests and Range

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Executive Summary

Twenty-five (including Pat Martin's assessment) elements (elements are the individual structures or objects that might be damaged) consisting of single structures (or sometimes assemblages of structures) were included in a partial risk analysis for exposure to post-wildfire natural hazards as a result of the Kelly Creek Fire. Thirteen elements are rated as having a high partial risk of being affected by a post wildfire event, eight are moderate and four are low. These partial risk ratings cannot be evaluated in isolation of the individual hazards (degree and type) and exposure conditions. This report details the methodology used to derive these ratings, discusses the limitations to the ratings and briefly discusses other considerations. Recommendations have been included in a separate document. Included maps can be used to identify the locations of the elements at risk. The names and addresses of the owners of the elements at risk are not identified in this report to protect privacy, but may be requested from the Ministry of Forests and Range or the Provincial Emergency Program. The location of the elements at risk is included to help readers determine which properties are being discussed.

Background and Field Reviews

The purpose of this work is to conduct a partial risk analysis to determine the degree to which identified structures (elements) and, to some degree, people around the Kelly Creek Fire are at an elevated hydrogeomorphic risk (general understood by the public as mudflows or flooding) as a natural consequence of the Kelly Creek Fire. The partial risk determination is the product of the probability of occurrence of a specific hazard and the probability of that hazard reaching or otherwise affecting a specific element. Partial risk does not consider the vulnerability or worth of the element, and therefore is not a complete estimate of risk.

This analysis consists of three components. The first is the determination of the probability that a hazard will occur. The second is the determination of the probability that the hazard will spatially affect the element (that the event will hit the structure). In theory Part 2 also includes an assessment of whether the element will be there when the event occurs (temporal probability) but since structures are essentially always there; this can be ignored for structures. People come and go and so risk to people must be modified by their movement. Several of the drainages examined have water intakes on them and these are elements of special concern since they normally have high levels of human activity around them, especially during high water flows. The third component is the combination of the probability of hazard and spatial exposure to determine the partial risk.

Probabilities are typically expressed as a fraction, but in this case the use of single probability fraction would imply a degree of certainty not warranted by the methodology. Therefore the probability of a hazard occurring is discussed as likelihood of occurrence (low, medium and high)

A number of authors contributed to this work. Pat Teti, Research Hydrologist, was initially involved but could not continue with the investigation, but contributed again in edit and review as well as with detailed watershed photography. Pat Martin completed a risk exposure assessment of three elements in the southwest sector of the fire. Doug Nicol was engaged to estimate the spatial probability for the Jesmond Road area and he combined the hazard estimates and spatial probabilities to arrive at a partial risk estimate for the elements considered in the Jesmond Road area. Bill Chapman was the fire analyses team leader, determined the hazard likelihood and compiled the final report. Technical review as well as an airphoto and geomorphological assessment was completed by Tim Giles.

The four main sections of this work are:

1. Hazard Likelihood
2. Spatial Probability
3. Partial Risk Analysis
4. Risk Mitigation

There are also some appendices that contain more detailed information on some topics.

The fire was examined by helicopter on September 11, 2009 by Pat Teti, Regional Research Hydrologist and again on September 16 by Pat and Bill Chapman. This inspection also included a ground inspection of the fire at one location. Pat Teti photographed all the drainages of concern on September 17th. It was not possible to tell the topographic vulnerability with confidence from the air due to tree cover and subtle variation in relief. Doug Nicol was engaged to assess topographical (spatial) vulnerability of the sites and to combine that with the likelihood of an event to determine the partial risk to identified elements. Mr. Nicol's assessment was ground based on October 7th and 8th. Also, the site was ground inspected again by Bill Chapman and Graeme Hope on October 7, 2009 to further assess the intensity of burn. Pat Martin looked at three sites to the south and west of the fire at the request of the fire Incident Commander. His report is attached in Appendix 3 and in it he concludes that the three sets of structures he looked at are at minimal risk because of the topographic situation of the structures.

Part 1
HAZARD LIKELIHOOD

Part 1 Summary
The 2009 Kelly Creek fire was a large fire (21,000 hectares) located in steep and complex terrain to the northwest of Clinton.

Twenty five structures or assemblages of structures (elements) were examined around the periphery of the Kelly Creek Fire (26 drainages potentially affect these structures). Most of the elements are located adjacent to Jesmond Road, but three sets of elements are located on the south or southeast edge of the fire, and three elements are located on the west side of the fire. This portion of the report estimates the incremental post-wildfire likelihood that a flood, debris flow or debris flood (alluvial fan event) will occur in drainages above these structures. Hazards naturally occur on and adjacent to alluvial fans and below steep slopes and this review does not attempt to document or estimate the extent or degree of pre-existing natural hazards. These ratings are used in a partial risk analysis in Part 3 of this report.

This work estimates the incremental post-wildfire likelihood of an event occurring in the individual drainages and by the sites described, in sufficient volume to impinge upon the alluvial fan at the bottom of the drainage. In addition higher than commonly experienced flows can occur in Kostering or Porcupine Creeks which can affect the floodplains on which several sites are located (a floodplain event). Several properties could be susceptible to both alluvial fan and floodplain events.

Sixteen of the sites were rated as having a high likelihood of experiencing an alluvial fan event and three sites were rated as having a medium likelihood and six as low likelihood. The likelihood of an event is not the same as the partial risk discussed in Part 3 and in the executive summary. The partial risk factors in some additional variables like topographic relationship of the structure to the likely pathway of the event. See Table 1 for a summary by drainage (and Appendix 2 for a map showing the drainages). All of the sites that are located in close proximity to Porcupine and Kostering Creeks are determined to have a high likelihood of being affected by greater than normally expected peak flows for the next few years.

Introduction
The intent of this section is to provide an estimation of the likelihood of events occurring on alluvial fans so that they can be used to assess the partial risk.

The Kelly Creek fire was a large fire (21,000 hectares) in steep (20-100% slopes) and complex terrain. Elevations range from about 1100 to 2100 metres. The burn severity was highly variable (Figure 1). Twenty five sites were identified with one or more structures that might potentially be at risk from water, mud or debris flowing from a drainage onto the structure. Various terminologies are used to describe these types of events. Most recent government publications refer to floods, debris floods and debris flows. Snow avalanches were not considered as part of this review. The Part 1 analysis does not attempt to differentiate between these different types of events, but Parts 2 and 3 discuss the relevance of these different types of events to risk. In addition, several structures are located on the flood plains of Kostering and Porcupine Creeks and so could be affected by higher than normal flooding of those creeks.

The Campbell and Tipper 1971 GSC map indicates the presence of Paleozoic Limestone and basaltic flows, Tertiary volcanics (further to the east) , Permian chert, argillite, siltstone and limestone (southwest) and the presence of significant Pleistocene and recent tills and glacial outwash (gravels, clay silts and sands). Some of these outwash deposits were observed alongside the road cuts. The 2005 Massey et al BCGS Geoscience Map 1:1,000,000 compilation notes Quatenary alluvium and glaciofluvial gravels, sand and till, Cenozoic Chilcotin Group (mostly basalts) and Mississippian to Jurassic Cache Creek Complex volcanic, phyllite, chert, schist, sandstone, argillite and marble. The parent material underlying the fire varies significantly but both sides of the fire have soils that are generally loamy to sandy loam in texture with a high proportion of silt or fine sand. Soils in the area of the fire would generally be highly erodible in the right circumstances.

Most of the structures identified were constructed on alluvial fans and/or flood plains located at the bottom of drainages- the fans being preferred habitation locations. Alluvial fans are of particular concern because they are formed by the rapid deposition of sediment resulting from infrequent but catastrophic floods or landslides. Research in BC (Sanborn et al, 2006) has shown that alluvial fan formation is accelerated in association with fires in some parts of BC. For many logical reasons it is reasonable to assume that major deposition on alluvial fans below mountain slopes, is likely and naturally to be accelerated post-fire. The primary effect of fire is to remove the vegetation and organic covering (forest floor or thatch) that has such an important role in preventing erosion and aiding infiltration of water into the soil. The vegetation in the drainages was burned to varying extents and severities with a tendency for more severe burning at higher elevations, south facing slopes and with somewhat lower intensity burning on ridge tops. In many cases the drainages form channels that become increasingly confined by their valley sides in the downslope direction. Wildfires upslope from a fan are therefore expected to increase the likelihood of hazardous events (floods, mudflows, etc).

The potential for higher floods on floodplains is more reliably predictable than extreme hydrogeomorphic events on alluvial fan sites. Research results (e.g., Neary et al.) indicate that wildfires can greatly increase peak flows and water yield during the first few years. Dead conifers lose their needles and so intercept less snow. Snow held on tree branches often evaporates or sublimates and dose not contribute to the spring freshet. Dead trees do not transpire and so the soil does not dry out as rapidly after trees are killed and transpiration remains lower until vegetation (trees, shrubs grass, or herbaceous vegetation) regenerates sufficiently. The main component of the flood plain risk is the topographic analysis of structures spatial relationship to potential flood levels. The methodology below focuses on determining the likelihood of events on alluvial fan sites. The flood plain risk is visited again in the "Interpretation" section.

Methodology
Post-wildfire risk analyses are intended to be rapid assessments in order to quickly determine if there are elements at risk that require stakeholder notification or mitigation. As such the assessments are not comprehensive and should be considered as estimates only.

Since the area is so large and complex, it was not feasible to do comprehensive ground based assessment of drainages. Therefore, the determination of the likelihood of hazard rating is derived largely from the USDA methodology called Burned Area Reflectance Classification (BARC). BARC is a satellite-derived map that examines reflectance in some wavelengths (in some versions it may compare reflectance pre and post fire). BARC roughly approximates vegetation burn severity, but with some important caveats. This work was completed by Will Burt, Regional Geomatics Analyst, BCMFR, Nelson. The BARC denotes four classes: high, moderate, low, and unburned. The BARC mapping was ground verified at 4 locations and from Pat Teti's aerial photography. The purpose of the ground verification was to determine if the BARC mapping was accurate and if the BARC classes corresponded closely enough with soil burn severities to serve as a surrogate for soil burn severity. All four ground derived soil burn severities agreed exactly with the BARC burn severities and the photographic verification indicated agreement of about 86%, which is more than adequate for this work.

The photographic verification of the BARC map was achieved by assigning random points in ARCMAP. The points were exported to KML files and Pat Teti's photos were roughly georeferenced around the random point. Some random points did not have high resolution imagery and were discarded. The soil burn severity rating from the photos was based on experience acquired during the ground-truthing. In the end, 29 points were examined and 25 of the points showed agreement between the BARC and the air photo interpretation. With such a high correlation, it was felt that doing further verification was unnecessary and that the BARC ratings corresponded well with soil burn severity. Photos 1 and 2 show examples of the watershed photography.

Many factors affect the likelihood of an event. These include the amount of mineral soil exposed, the erodibility of the soil, collecting area (the size of a patch of ground which is generating flow), channel geometry, water infiltration capacity of the soil (as modified by wetting hysteresis related effects, water repellency and others), slope, flow attenuation and others. Clearly not all variables can be examined in detail on a fire of this size. Many of the variables are of substantially less significance than others. The amount of contiguous bare mineral soil is the most important factor. A few other factors must work in concert with bare mineral soil to precipitate an event. Some slope is necessary, but slope quickly reaches something close to a maximum effect, i.e. the effect of increasing slope on water concentration/ erosive events increases imperceptibly beyond a relatively low gradient in situations where overland flow can be generated. However, in-channel slope does have an influence on the potential for debris flow initiation and transport. Infiltrability varies considerably especially with wetting hysteresis related effects, water repellency and surface plugging. However, the potential range in water input greatly exceeds the normally occurring potential range in infiltrability (especially for the scenario where soil is very dry as in shortly after a fire) and so infiltrability will not often be a deciding factor during very intense precipitation,. In this analysis, we have tried to place more emphasis on the most important variables.

Photo 1- In drainage H2c showing the BARC verification point on a Teti photo.

Photo 2- A mixture of high (left), low and unburned (middle) and medium severity burn (right) based on the visual criteria that were used to verify the BARC Map with Teti photos.

The major factors of importance are the area of exposed mineral soil, for which BARC burn intensity is used as a proxy and the collecting area (which is the burn patch size with a 1:1 equivalence for high intensity burn and 1:5 equivalence for moderate burns). Light burns and non-burned areas are presumed to not collect. Light burns typically have forest floor in place and are often quickly covered by needles falling from dead trees with unburned canopies- which greatly reduce the potential to generate overland flow. Small collecting areas may generate flow, but it is presumed that the potential to initiate an event will be attenuated to a large degree by surrounding non-collecting areas. The smaller the collecting area and the larger the non-collecting proportion of the drainage, the higher the probability that flow will be attenuated. Collecting areas below some threshold size cannot generate enough flow to be of concern but the threshold is situation specific. Multiple small collecting areas could also work in concert to generate high flows, but if they constitute a small proportion of a bigger area, the potential for flow attenuation is high. The critical sizes for counting collecting areas have been set at 1 ha for High intensity burns and 5 ha for Medium intensity burns. A burn severity index for erosion is calculated as follows:

Burn Severity Index for Erosion = (∑High Burn Intensity Collecting Areas>1ha + ∑Medium Intensity Collecting areas>5 ha)/Drainage Area*100

The event "Likelihood" rating is **Low<10**
Medium ≥10<30
High>30

Table 1 shows the Likelihood rating by drainage (Appendix 2 is a map showing the drainage location more clearly). The location of the various drainages listed in Table 1 is shown below in Map 1. A larger paper or electronic version of the map is available for closer scrutiny.

The areas of different burn intensity polygons in the various drainages were determined in Arcmap. The drainages were mapped by Pat Teti and Doug Nicol from TRIM data and were not field verified so should be considered approximate.

Meaning of Likelihood Ratings
The likelihood of significant overland flow generation is considered as follows:

- Low means significant post wildfire generated overland flow will not take place even with quite extraordinary precipitation/melt conditions
- Moderate means that a sustained rainfall with intensity of 25 mm/day for a day or more will initiate significant overland flow, especially if the soil is dry. Intense short duration events could also initiate overland flow, but the probability of rainfalls of sufficient intensity to initiate overland flow on moderately rated sites is so low that it is discounted.

- High means that significant overland flow will occur as for the medium likelihood or also with a rainfall of 10 to 15 mm in a short time (20mm/hour for 30 min or 3mm/hour for 3.3 hours or 1mm/hour for ten hours), whether the soil is wet or dry.

The likelihood of an event occurring due to the generated overland flow depends on the type of event considered and the geomorphic drainage characteristics. For simplicity the ratings above were generally used to correlate to event likelihood i.e. if sufficient overland flow could be generated it was generally assumed that an event would be triggered.

Hazard Uncertainties

The Kelly Creek Fire is very large, unevenly burned and covers complex terrain. This makes it impractical to become too specific in this analysis. However, two primary factors determine the probability of an event and these are the presence of collecting areas of bare or near bare soil sufficiently large to generate dangerous flow and an intensity of rainfall or runoff to generate a dangerous flow volume from that size of collecting area. There are numerous burned collecting areas in the Kelly Creek Fire that could generate dangerous flows in gullies and on fans during precipitation or snowmelt events that are likely to occur every year. Because much of the burn is at high elevation, there isn't data available for potential precipitation rates for those areas and people in the valley bottoms may not be aware of precipitation intensities at higher elevations. Therefore, in the event of any unusually intense rainfall or snowmelt at the valley bottom level, great caution must be used on and around the Kelly Creek Fire and this vigilance should be followed for a few years after the fire in spite of anything that might be contained in this report.

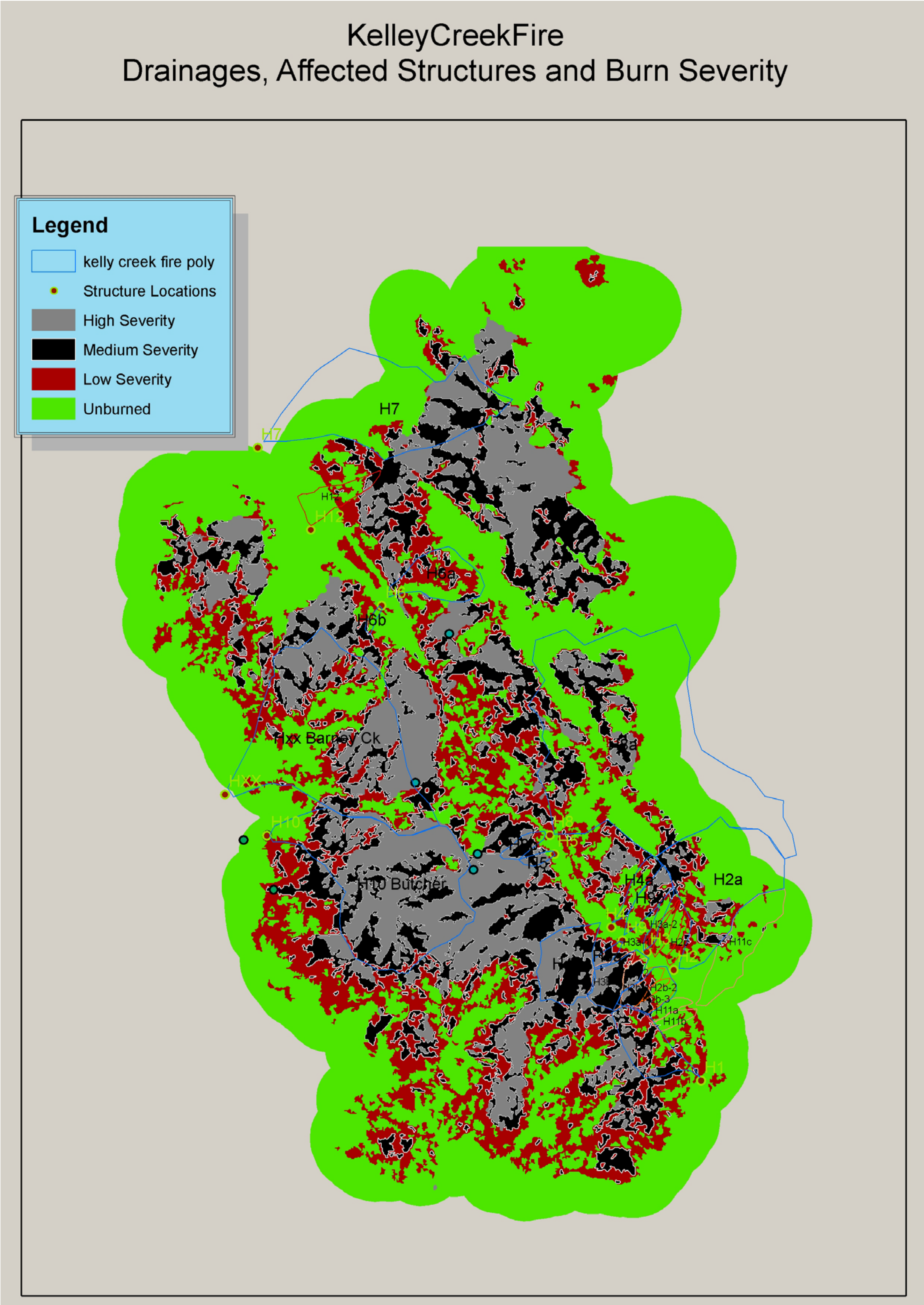
Table 1

Alluvial Fan Event Likelihood Rating by Drainage

Drainage	Drainage Area	Burn Severity Index	Likelihood
H1	202	53	High
H2a	612	17	Medium
H2b-1	49	62	high
H2b-2	13	<1	low
H2b-3	36	31	high
H2c	23	<1	low
H3a-1	12	<1	low
H3a-2	27	<1	low
H3b-1	104	94	high
H3b-2	32	83	high
H4a	59	14	Medium
H4b	257	93	high
H5	20	83	High
H6a	221	6	low
H6b	12	<1	low
H7	815	38	High
H8a	2045	21	Medium
H8b	41	80	high
H9a	22	74	high
H9b	86	38	high
H10 Butcher Creek	1260	86	High
H11a	33	<1	low
H11b	32	<1	low
H11c	235	<1	low
H12	111	9	Low
Hxx Barney Creek	1553	41	High

Table 1 contains more information than the likelihood ratings. Everything above 30 is rated as a High Likelihood, but there is considerable range within the High category and the size of the drainage and the Burn Severity Index may help to refine the hazard rating. These ratings take no account of the notion of acceptability of risk but are meant to convey probability of an event. Appendix 1 shows a graphical representation of the size of collecting areas by vegetation burn severity and site. This may help to visualize the differences between drainages of the probability of an event.

Map 1- Showing Vegetation Burn Severity, drainages and site locations. A bigger paper or electronic map is available on request.



Interpretation

Alluvial Sites: This information has been used by Doug Nicol to evaluate the incremental partial risk to various structures on the alluvial sites denoted above. The partial risk to structures is determined to a large degree by their proximity to existing channels, the likelihood of channel alteration to contact the structure, and by the probability of an event. People who place themselves in the potential pathways of events in Medium or High Likelihood drainages should be aware that they are at an elevated risk of being affected by flood or mud flow during and for several hours after an intense or prolonged rainfall or snowmelt. Blockages in channels may back up water and prolong the period of elevated risk.

An elevated risk will persist for a few years (even decades), but perhaps the period of highest risk was this fall immediately after the fire. Simple infiltration tests suggested that the infiltrability of the soil increased markedly from the period during the fire to shortly afterward. This was almost certainly due to a light snow that slowly wetted the soil as it melted which in turn increased its suction (as in the way a sponge soaks up water more actively once it is wetted). Also, during the later inspection, we observed that grass (and willows) had sprouted extensively, even in severely burned areas. It was our perception that the site will revegetate quickly with grasses, which could significantly reduce the probability of a hazardous event by as early as next summer. However, the spring freshet will be a time of elevated risk, particularly for higher than expected flood levels.

The following circumstances, (courtesy of Peter Jordan, BCMFR, Nelson) may be indicative that a dangerous event is imminent:

- Long-duration frontal rainstorms 2 days or longer exceeding the 10-year return period event
- Sudden change in discharge (up or down) or change in colour in small streams
- In steep channels - streamflow which suddenly stops (an indicator of an approaching debris flow)
- or domestic water intakes with a fire upstream - a lot of black sludge in the water intake (This happened at Kuskonook, an indicator that overland flow is occurring, as the wettable layer of ash and charcoal above a water repellent layer is eroded away)

If any of these conditions is present, people in the area should be extremely cautious and avoid drainage channels (dry, wet or seasonally wet) that come from the burned area.

Floodplain Sites: The effects of forest removal on water yield and peak flows are extremely well studied (Neary et al). Until a vegetative cover is restored there exists a potential for higher peak flows and higher water yields. Grass appears to be recovering quickly on the Kelly Creek fire and a dense herbaceous layer can transpire water per unit area almost equivalent to a forest. Therefore, the likelihood of flooding should diminish rapidly over a few years.

Flows almost always tend to be more variable post-fire because weather variables are no longer moderated by tree cover. To quote Neary: "Fire has the potential to increase flood peak flows well beyond the normal range of variability observed among watersheds having fully vegetated conditions. For this reason, understanding of peak flow response to fire is one of the most important aspects of understanding the effects of fire on water resources".

We have not done a detailed analysis of the likelihood of higher than expected floods on the flood plains of Kostering and Porcupine Creeks. The likelihood of higher than expected floods is determined to be high based on typically observed consequences of large scale vegetation destruction in watersheds. However, the Porcupine Creek floodplain is quite wide and so high volumes of water are likely to be dispersed over a larger area so that "higher than expected floods" have a good potential to be not so high or damaging. Nevertheless, the likelihood of an event remains high and channel alterations or debris dams in high floods always have the potential to be dangerous. We observed that numerous structures are located within a few metres of the creeks and within a few metres of the high water marks. Also, there are numerous beaver dams on the creeks which store large volumes of water. A peak flow of sufficient volume could breach the beaver dams with a cascading effect of increasing flow downstream. Part 3 of this report examines the risk to floodplain structures from a topographic vulnerability perspective.

Part 2
SPATIAL PROBABILITY

The exposure of elements at risk to post-wildfire effects can be considered as part of the process of determining the degree of partial risk to identified elements at risk (Wise et al 2004). The risk analysis forms a component of Post Wildfire Erosion Hazard Assessment and Risk Management that the Ministry of Forests and Range (MFR) completes on interface wildfires in B.C. The partial risk component of this analysis is included in Part 3.

Site location and field review
The spatial probability review was general in nature and not all sites could be specifically assessed due to restrictions relating to access across and onto private property. The review did not include a historical airphoto review (which was subsequently completed by Tim Giles), an assessment of upslope drainages or an evaluation of the potential for the initiation of landslide or flood events. As such an estimate of the potential entrained volume, geomorphic drainage and channel conditions, and detailed magnitude and run-out estimates was not made. The estimation of element at risk exposure was made based on observations made of the fan and lower channels and should be considered as approximate and for the purposes of hazard communication.

General alluvial fan characteristics
There are specific natural hazards (with or without post-wildfire effects) relating to elements located on alluvial fans. Alluvial fans are created through the deposition of sediment and debris by processes relating to floods, debris floods and debris flows. These natural hazards are present without the effects of wildfire and this review does not attempt to estimate the extent or degree that these hazards may already be present or how they may affect the noted elements at risk. After a fire, the type and extent of a hazard to an element at risk can vary depending on which of the processes are active post-wildfire. Observations of fan and geomorphic drainage indices were used to categorize the likely dominating process; however, it is not always possible to definitively determine which process will dominate post-wildfire. It can be difficult to distinguish between hyperconcentrated and debris flows based on their deposits (Giraud 2005). As well, fan landforms can be formed by a continuum of processes from purely fluvial to mixed debris flow-fluvial to predominately debris-flow. Debris flows are most destructive in their confined channel and in the proximal fan areas where they generally have the highest velocity and greatest flow depth and deposit thickness (Giroud 2005). In distal fan areas the flows are less destructive and may be dominated by stream-flow processes only. Hungr at al 1987 outlined the use of three debris flow hazards zones as follows:

- direct impact zone
- indirect impact zone
- flood zone

An example of the differences between debris flow deposition in the direct impact zone and indirect impact zone is shown by Jakob et al 2000 where a debris flow deposit in the direct impact zone was several metres thick compared with deposit depths of 0.1m to 0.5m in the indirect impact zone.

Typically the fans of debris flow deposits are steeper (7% and steeper) while stream flow generated deposits are generally less steep (less than 7%); however some debris flow fans with high clay content have been measured at 4% (Jakob et al 2005). Hooke (1967) found that fan slopes between 7% and 14% were constructed via alternating debris flow and fluvial processes.

Debris flow fans typically have no stratification, poor sorting, matrix supported clasts, presence of debris flow levees and lobes, and presence of lone boulders on the fan surface. Floods and debris flood channels typically have a large width-to-depth ratio and deposits contain bars, sheets and splays.

A study by Jackson (1987) looked at 42 alluvial fans in the Canadian Rockies and found that Melton's Ruggedness number (Melton 1965) could be used in combination with the fan slope angle to differentiate between debris flow and fluvial fans. Jackson concluded that debris flows are likely to reach fan apices where fan slopes exceed 7% and Melton's ratio is 0.3 or greater. Jackson did not separate debris floods from debris flows or floods.

Another study by Wilford et al 2004 reviewed 65 fans in north western B.C. prone to flooding, debris floods, and debris flows and compared basin characteristics such as Melton's ratio, drainage length, relief ratio, and proportion of watershed with slopes between 30° and 40°. Wilford et al found that typically debris flow basins have a Melton ratio of > 0.6, a length of <2.7km and a relief ratio of >0.35. The division between floods and debris floods seems to occur at a Melton ratio of 0.3, relief ratio of 0.15, and drainage length of 9km.

In a Klohn-Crippen study of alluvial and debris flow fans in the Kootenays, where obvious debris flow features were lacking, Klohn-Crippen rated the fans based on debris flow fan features, fan angles, stream order, ruggedness, and stream gradient. For debris flow prone fans Klohn-Crippen used fan slope of > 14%, first order stream, Melton's ratio of >3, and a stream gradient >17% as indicators of debris flow prone gullies.

These above geomorphic drainage indices along with surficial observations made in the field were used to classify each fan in terms of the dominate alluvial process. Some watershed characteristics are included in Table 1. It is noted that field observations were general and consistent with rapid post-wildfire assessments and no trenches, radiocarbon dates, dendrochronology analysis, tephrochronology analysis, or channel debris volume estimates were made.

Resources at Risk

The primary objective of the spatial probability review is to identify elevated hazards to public safety due to the potential post-wildfire effects of the Kelly Creek fire. There are a number of values which were initially identified by MFR which are potentially at risk. The elements at risk field reviewed may not be inclusive of all primary structures present or at risk. Only house locations visible from the adjacent public roads were assessed.

The Porcupine Creek valley contains several houses and farms and outbuildings most of which are located on the east side of the valley. Many of these houses are located in the flood plain and are exposed to an elevated flooding hazard from Porcupine Creek and its tributaries. In addition some of these houses are located on and adjacent to debris flow fans and are now exposed to an elevated hazard of debris flows originating from the burned slopes on both sides of the valley.

Specific Observations
Goodrich Creek is located at the south end of the burn area (Photo 1) and drains into Kelly Lake. Pavilion-Clinton road is located at the base of the Goodrich Creek debris flow fan which has a deposit slope angle of approximately 18% (Photo 2). The Goodrich drainage has an area of 202 hectares and a local relief of 800m with a Melton ratio of 0.56 to 0.58 and may be prone to both debris flows and debris floods. The burn severity score is 53 (see Hazard Likelihood Section) with a hazard rating of high (see Table 1). The shape of the Goodrich Creek drainage (elongated) is such that a tributary creek located at the south end of the drainage could be debris flow prone (area 30 hectares, length 1.1km, relief 500m, Melton Ratio 0.91). Small levees near the apex of the fan, moderate clast size across the fan with occasional large boulders near the apex and weak channel development all support a mix of debris flow and debris flood processes. This tributary drainage also has a very high percentage of high and moderate vegetation burn severity.

One house (E4 in Table 5) is located above the Pavilion-Clinton road on the fan while another property (E2 - house and mobile home) is located below the road at a location where the fan gradient drops to 9%. A highway rest stop (E1) is located at the fan contact with slopes to the northwest and Kelly Lake to the west. A campground (E3) is located further downslope where the slope gradients drop to 1% (perhaps part of Porcupine Creek flood plain and/or lacustrine deposits). A CN Staging area (E5), with outbuildings, is located half way between Goodrich creek and Porcupine creek below the highway at the east side of the Goodrich creek fan. According to a local resident Goodrich Creek does not normally flow to the highway (subsurface through the fan) and no culverts were observed at the highway location.

	
Photo 1 Part of H1 watershed (Goodrich Creek)	Photo 2 Goodrich creek fan

Houses and a ranch (E6) are located above the highway and on the west side of Porcupine Creek. The Porcupine Creek drainage area is 6917 hectares and the creek meanders through private property above the Pavilion-Clinton road and then crosses under the road through an 1800mm culvert (Photo 3) with a 600mm overflow culvert. Some sand/gravel was observed in the overflow culvert indicating past flow activity. Upstream of the highway culvert, Porcupine Creek flows through a culvert on private property (Photo 4) which appears to be about half the size of the highway culvert and could be a potential constriction point.

Photo 3 Porcupine Creek at Pavilion-Clinton Road

Photo 4 Porcupine Creek on private property

Five houses (E7) and several cabins are located on the west side of Jesmond road (330m from the Pavilion-Clinton road junction). The houses are located on the Porcupine Creek flood plain and are exposed to a flooding hazard.

At 1+965 of the Jesmond road a house and out buildings (E8) are located below the Jesmond road (between the Jesmond road and Porcupine Creek). The property is located where there are two debris flow gullies on the west side of the valley; watersheds H11a and H11b (Melton ratios greater than 1) and one debris flow gully on the east side of the gully; watershed H11c. At the road location H11c is a dry gully (deposit angle 13%) with no evidence of recent flows and there is no culvert. All three of these drainages have been rated as having low post-fire related event likelihood.

Two Mile Creek crosses the Jesmond Road at 2+900 through a 600mm culvert. The creek was not flowing at the time of the field review. Three houses are located on the Two Mile Creek alluvial fan. Two Mile Creek drains an area of 612 hectares and the fan has a deposit angle of 7%. The Melton ratio for the drainage is approximately 0.4 and could be prone to debris floods. Although levees were observed on the fan, these are likely as a result of debris floods and not debris flows. To the west of these houses there are 3 debris flow prone gullies (H2b-3, H2b-2, H2b-1). H2b-2 has a low event likelihood and may actually be too small to be debris flow prone while H2b-3 and H2b-1 have high event likelihood classifications. Melton ratios for these west side gullies range from 0.91 to 1.16. The creek channel of H2b-1 had no creek flow at the time of the field review; however, debris flow levees were observed at the fan location. The house (E10) located on the north side of the Two Mile Creek fan is located about 80m to the east of where the most recent creek flows from H2b-1 reach the distal portion of the fan. The slope gradients from the fan toe to the house are 1% so the house is not located in the direct impact zone. A house (E9) located 130m to the north of H2b-2 and about 250m to the north of H2b-3 and on the Two-Mile Creek fan is about 30m to the east of Porcupine Creek. Two Mile Creek appears well incised at this location. The fans of H2b-2 and H2b-3 were not field reviewed; however, the slopes were walked to a location 100m to the southwest of this house (E9) and the house did not appear to be situated on either the direct or indirect impact zones of either fan H2b-2 or H2b-3. Another house (E11) is located on the Two Mile Creek fan and above the Jesmond Road. This house is exposed to a small gully to the north and to flooding of Two Mile Creek. The event likelihood for the small gully is low while Two Mile Creek drainage has moderate event likelihood.

A house (E12) is located above Jesmond Road immediately to the north of the Two Mile Creek fan. The house is situated on a fan below a small drainage which is adjacent to the H2c drainage (which is also above E10). This small drainage is only 8 hectares in size with local relief of 250m. As such it may not be debris flow prone. However as this drainage was not field reviewed to determine the actual drainage area, for the purposes of this review, it was assumed that the characteristics of the adjacent H2c drainage would apply. It is noted that both drainages have a low event likelihood.

About 700m upgrade of the Two-Mile creek fan three houses/properties (E13, E14, E15), (Alan Park), are located to the west of the Jesmond Road. Porcupine Creek flows adjacent to the Jesmond road and access to two of the properties is via bridges across Porcupine Creek. The creek at this location is about 2.5m wide with a bank height of 0.5m to 1.0m. The properties are exposed to hazards relating to the H3a-1, H3a-2, H3b-1, and H3b-2 drainages. All these gullies are likely debris flow prone; however, the gullies located on the east side (H3a-1 and H3a-2) have a low vegetation burn severity classification (Photos 5 and 6). The gullies on the west side have high vegetation burn severity classifications with severity scores of 94 for H3b-1 and 83 for H3b-2. The fan apex of H3b-1 is located about 200m west of the Jesmond Road (Photos 7 to 10). There was no flow in the H3b-1 creek at this location at the time of the field review; however, debris flow levees were observed. Creek flows were present 125m up slope of the fan apex and water was flowing over very steep bedrock cliffs above. The south side of the fan was walked to a location where the fan gradients drop to 5%. The northernmost house (E15) was about 200m from this location (the house is located 275m from the fan apex). H3b-2 is a smaller drainage (32 hectares) with a lower channel gradient of 45%, gully height of 12m and sideslopes of 90%+ (Photos 11 and 12). A debris flow/debris slide deposit is located at the toe of the gully. The deposit covers an area of about $300m^2$ with a deposit angle of 27%. The deposit is located 108m from the nearest house in Alan Park.

Photo 5 watershed H3a-1

Photo 6 watershed H3a-2

Photo 7 H3b-1 drainage

Photo 8 H3b-1 drainage

Photo 9 H3b-1 fan apex

Photo 10 H3b-1 debris flow levees

	
Photo 11 H3b-2 drainage looking up	Photo 12 H3b-2 drainage looking down

At 4.5km of the Jesmond Road a cabin (E16) is located 70m below the road and about 100m east of Porcupine Creek. Although the cabin is likely high enough above the banks of Porcupine Creek to avoid flooding it is exposed to potential debris flow gullies (H9a and H9b) located on the both the east and west sides of Porcupine Creek both of which have a high event likelihoods and Melton ratios of 0.78 to 1.0.

At 4.9km of the Jesmond Road a house, farm and outbuildings (E17) are located below and to the west of Jesmond Road. The house appears to be high enough above Porcupine Creek to avoid flooding; however, it is exposed to potential debris flows from a drainage to the west (H4b) and a drainage to the east (H4a). H4a has an area of 59 hectares with a moderate event likelihood. These drainages are treed and no culverts are located at the road locations where the gullies cross. H4b is a 257 hectare drainage with a high event likelihood (burn severity rating of 93). The alluvial fan is sloped at 15% and the creek was dry at the time of the field review. The south side of the fan was reviewed at the location where it intersects Porcupine Creek. Porcupine Creek has down cut through the debris flow fan by 4m. The house is located 220m to the south east of this location and is not located in the direct impact zone. The Melton ratio for H4b is 0.39 which suggests the drainage may be more debris flood prone than debris flow prone.

At 7.44km of Jesmond Road a mobile home (E18) is located at the toe of the slope on the west side of Porcupine Creek (access to the property is over a bridge). The mobile home is located below drainage H5 which has a high vegetation burn severity classification (severity rating of 83). There is no creek at this location; however, some small swales were observed. The overall slope gradient is about 50%.

At 8km of Jesmond Road, Porcupine Creek flows into the valley from the east. A culvert located across the Jesmond road is 1400mm by 900mm with an overflow culvert of 600mm (outlet half plugged). The drainage area of Porcupine creek to this location is 2045 hectares. A cabin (E19) is located at 8.1km between a tributary to Porcupine Creek and Jesmond Road. The cabin is also located just to the south of the H8b fan. H8b is a 41 hectare drainage with a high event likelihood and a Melton ratio of 0.75.

At 16.5km of the Jesmond Road there are several cabins (E20) located adjacent to a creek flowing from a 221 hectare drainage. The creek was flowing at the time of the field review and there was a 500mm culvert across the road with a partially plugged 450mm overflow. Adjacent slopes are 5%. The Melton ratio is 0.52 which suggests the creek at this location may be prone to debris floods. Near the same location, Kostering creek flows to the north (west side of the road) with a drainage area of 1702 hectares.

At 19.2km of the Jesmond Road a house (E21) is located below the road and adjacent to a creek (watershed H12). H12 has a drainage area of 111 hectares and there is a 450mm culvert at the creek location (no flows at the time of the field review). The Melton ratio for the drainage is 0.55 indicating the creek may be prone to debris floods or debris flows; however, the event likelihood is low.

At 22.5km a lodge with several out buildings (E22) is located on the fan of watershed H7. H7 drains an area of 815 hectares. The fan has typical slopes of 7% and with a Melton ratio of .3 may be prone to debris flooding or regular flooding. A 900mm culvert is located in a well incised (2-3m) creek channel (flowing at the time of the field review).

Table 2
Some Characteristics of Local Watersheds

Drainage	Size	Burn Sev. Score	Event Likelihood	Max Ht	Min Ht	Relief	Length	Relief Ratio[1]	Melton Ratio[2]	Prim. Process	Slopes
H7	815	38	H	2220	1360	860	6190	.14	0.30	Flood/ debris flood	7% fan
H12	111	9	L	1920	1340	580	2500	.23	0.55	Debris Flood/ debris flow	slopes above road 20%
H6A	221	6	L	2200	1420	780	2950	.26	0.52	Debris Flood	5% fan
H8A	2045	21	M	2240	1320	920	4270	.22	0.20	Flood/ debris flood	
H8B	41	80	H	1800	1320	480	1280	.38	0.75	Debris Flow	15% fan
H5	20	83	H	1700	1300	400	830	.48	n/a	Debris Slide	
H2A	612	17	M	2160	1180	980	5270	.19	0.38 To 0.40	Debris Flood	7% fan
H4A	59	14	M	2080	1240	840	2200	.38	1.09	Debris Flow	10 % at house location
H9B	86	38	H	1980	1220	720	2275	.32	0.78	Debris Flow	
H3A-1	12	0	L	1600	1200	400	1200	.33	1.15	Debris Flow	15% fan
H3A-2	27	0	L	1780	1200	580	1450	.4	1.11	Debris Flow	Lower channel 35-40% upper 60-70%
H2C	23	0	L	1820	1180	640	1780	.36	1.33	Debris Flow	15% fan
H11C	235	0	L	2120	1140	980	4260	.23	0.64	DebrisFlood/ Debris Flow	13% fan
H4B	257	93	H	1860	1240	620	2700	.23	0.39	Debris Flood/ Debris flow	15 % fan
H9A	22	74	H	1700	1240	460	950	.48	0.98	Debris Flow	
H3B-1	104	94	H	1880	1200	680	2000	.34	0.67	Debris Flow	5 to 20% fan, 60%+ upslope
H3B-2	32	83	H	1660	1200	460	800	.58	0.81	Debris Flow	27 % fan, 45% channel, 90%+ sideslope
H2B-1	49	62	H	1820	1180	640	1500	.43	0.91	Debris Flow	25% fan
H2B-2	13	0	L	1600	1180	420	800	.53	1.16	Debris Flow	
H2B-3	36	31	H	1780	1180	600	1240	.48	1.00	Debris Flow	
H11A	33	0	L	1720	1140	580	1090	.53	1.01	Debris Flow	
H11B	32	0	L	1720	1140	580	1130	51	1.03	Debris Flow	
H1	202	53	H	1880	1080	800	3000	.27	0.56 To 0.58	Debris Flow/ debris flood	18% fan
Porcupine All	6917	34	H	2240	1080	1160			0.14	Flood	
Kostering Upper	1702	41	H	2220	1420	800			0.19	Flood/ debris flood	

1 Relief Ration (Schumm 1956) is the maximum basin relief divided by the horizontal distance of the basin measured parallel to the major stream. It indicates the overall steepness of the basin.
2 Melton Ratio = relief / √ area. It is an index of average watershed slope. A study by Wilford et al (2004) in northwestern B.C. concluded that watersheds subject to debris flows and debris floods typically had Melton ratios of >0.6 and 0.3-0.6 respectively while fluvial processes (floods) dominated in watersheds with Melton rations of <0.3 .

Part 3
PARTIAL RISK ANALYSIS

Partial Risk Methodology
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 (Wise et al 2004). Partial risk methodology can also be applied to events that are not landslides.

Partial risk (perhaps more accurately referred to as a hazardous and affecting event) can be mathematically defined as P(HA) = P(H) x P(S:H) x P(T:S) where P(HA) is the estimate of partial risk, P(H) is the probability of occurrence of a specific hazardous landslide, P(S:H) is the spatial probability or the potential of a landslide to reach or affect the element under consideration and P(T:S) is the temporal probability or the potential for a mobile element to be at the site at the time an event occurs.

The product of the probability of event occurrence and the temporal and spatial probability can be described in several ways. Various methods include quantitative, qualitative, risk matrices, and event tree decomposition.

For the areas potentially affected by the post-wildfire effects of the Kelly Creek Fire, MFR has estimated the incremental event probability P (H) qualitatively through the use of BARC mapping, field reviews, soil testing, and calibration. Given the qualitative nature of the described event probability it was determined that the estimate of partial risk should also remain qualitative.

The event probability estimated by MFR has been divided into three primary categories; low, moderate, and high. These qualitative categories have not been directly related to numeric probabilities due to the preliminary nature of the assessments, the limited available data correlating the hazard assessments to actual post wildfire events in BC, and the uncertainty and variability involved in incorporating the geomorphic characteristics of individual drainages. In addition the event probability is also a function of future precipitation patterns and events. The event probabilities also do not relate to one specific event. Instead it groups several potential hazardous events (flooding, debris flows, debris floods etc.) into one category.

Subjective probability (Vick 2002) can be applied to the estimated event probability and ratings can be established similar to Table A4.3 of Wise et al 2004 that relate the qualitative event probability over a 5 year duration (likely duration of the short term post wildfire effects). For example a high event probability could correlate (as per Table A4.3 of Wise et al) to a 5 year probability of > 0.18 (annual probability of >0.04). Alternatively Arksey and VanDine (2008) provide an example whereby high and very high yearly hazard probability is considered greater than 0.01 , moderate yearly hazard probability is considered between .002 and .01, and low and very low are less than .002. However caution must be used in the application of these numbers due to the degree of uncertainty as discussed above.

The determination of the spatial and temporal probabilities considered the hazard relative to known house locations through field inspections of the fans and creeks where access was possible. As such, the temporal probabilities are assumed to be 1.0. However there are temporal probabilities that relate to individuals walking or driving across or into hazardous areas at times of significant snowmelt or rainfall. These situations have not been considered in this review. It will be important to notify local residents and others accessing the areas reviewed of the post wildfire hazards generally present in all areas located downslope of the burn. In addition, when an event does occur it can be followed by second and third events at the same location during subsequent periods of high rainfall or significant snowmelt. As such, areas where events have occurred must be avoided until the site has stabilized. For sites exposed to debris flows, the spatial probability can depend upon which debris flow hazard zone the element is located (i.e. direct impact, indirect impact, and flood). The distinction is important as the potential magnitude and destruction in a direct impact zone is significantly different than the indirect impact and flood zone. The partial risk estimate included in Table 5 considers only the exposure within the direct impact zone. It must be assumed that all elements at risk located below or near debris flow prone gullies are exposed to indirect impact and flood potential.

The spatial probability was also estimated qualitatively. Arksey and VanDine (2008) provide example definitions for spatial probability whereby high and very high is greater than 0.6, moderate is 0.4 to 0.6, and low to very low is .001 to .4. For simplicity this review generally considers high to be greater than 0.5, moderate 0.1 to .5, and low less than 0.1.

It is noted that a hazard or exposure rating of low does not imply that there is no hazard or exposure. Only that the hazard or exposure is low relative to those sites classified as having moderate or high hazard or exposure.

The event probability and the spatial probability can be combined to arrive at an incremental partial risk. A risk matrix (Table 3) can be used similar to Table 8 of Wise et al. However the combination of spatial probability and event probability in a symmetrical matrix form may not be useful for the Kelly Creek fire. For example where the burn is very limited and of low hazard it is reasonable for communication purposes to classify the partial risk as also low. For comparison, a modified matrix (Table 4) is included that utilizes the methodology of an event tree decomposition whereby each additional probability product has the effect of lowering the resulting affecting hazard.

Table 3
Qualitative partial risk matrix from Wise et al

P(HA)		P(S:H) x P(T:S)		
		High	Moderate	Low
P(H)	Very High	Very High	Very high	High
	High	Very High	High	Moderate
	Moderate	High	Moderate	Low
	Low	Moderate	Low	V. Low
	Very Low	Low	V Low	V. Low

Table 4
Modified qualitative partial risk matrix

P(HA)		P(S:H) x P(T:S)		
		High	Moderate	Low
P(H)	High	High	Moderate	Low
	Moderate	Moderate	Low	V. Low
	Low	Low	V Low	V. Low

Table 5 summarizes the elements at risk that were reviewed, their location and description, the hazard source and type and resulting estimated incremental partial risk. The incremental partial risk estimate was made with consideration to both matrix types (Table 3 and Table 4) with the application of judgement and experience.

Pat Martin concluded that the structures below the Barney and Butcher Creek drainages were at minimal risk. However, these drainages both had very high burn severity indices. Even though the structures involved are at low risk, the water intakes on both creeks are at very high risk to damage. Both creek channels are narrow and steep sided near the bottom and pose an extreme hazard to human safety at times of elevated runoff until revegetation is well under way. Servicing the water intakes when sedimentation is a problem could be extremely hazardous for the next few years and even longer if an event does occur, because if one event occurs, there is an increased probability that another will occur.

Discussion

For the noted elements at risk, MFR has grouped the estimated incremental hazards into categories of low, moderate, and high; however, the hazard level for all areas below the burned areas is generally greatly increased from pre-fire conditions. In addition, even though the partial risk has been estimated as low for some of the elements noted, since the consequence is high (public safety) all of the elements noted will likely have at least a moderate risk with most being high risk (although the risk results shown in Table 5 did not extend beyond a partial risk estimate). The MFR may modify or update the partial risk estimates given additional information collected through their field reviews or given new information such as slope and channel performance post rainfall and snowmelt events. The partial risk estimates should not be used exclusively without consideration of the individual components of the hazard and spatial exposure.

Element exposure to an event is estimated based on field reviews, contours maps, and satellite imagery. In many locations adjacent to creeks the actual flood exposure of the elements at risk is not only dependent upon the flow capacity of the creek channel but also the height of the element at risk above the present creek banks. In addition, upstream debris flow or debris flood events can cause damming and or erosion that can change the stream hydrology and geomorphology. In most locations the stream was not assessed directly adjacent to the elements at risk due to limited access and private property and it was generally assumed that if a house was located near or adjacent to a creek, or was in the flood plain, that P(S:H) is high. In some locations exposure is also a function of the magnitude and run-out of potential events which have some inherent uncertainty. For this assessment the run-out was estimated based on the size and slopes of existing fans and, as such should be considered approximate. It is noted that a study by Fannin et al in 1996 compiled run-out data for 247 landslides on the Queen Charlotte Islands and found that the median length of terminal deposition ranged between 36m and 93m depending on channel gradients. Another study in the intermountain western United States (Canon et al 2009) found that post wildfire debris flow volume varied with the area of the basin having slopes greater than 30%, the area of the basin burned at high and moderate severity, and the total storm rainfall. Van Dine (1985) noted several methods for estimating debris flow volume which included comparisons with past events, empirical analyses, and unit volume analysis. A more detailed numeric analysis could be completed if warranted or desired which could take into account potential entrained debris and other geomorphological site conditions.

Many of the identified hazards are related to creeks and gullies with debris flow potential. Many of these gullies may be relics from glaciation or they may be active post-wildfire. Some of these gullies; however, are clearly debris flow prone (example H3B-1) and may have natural return periods in the order of hundreds of years (with elevated post-wildfire return periods).
Consideration should be given, during risk evaluation phase, to the possible influences of upslope roads and trails. Upslope roads were observed accessing the powerlines to the east of Jesmond road and some logging roads were observed particularly north of the Jesmond Road/High Bar Road Junction. Upslope roads and trails have the potential to redirect or concentrate surface and overland flows. In addition culverts are not often sized for post wildfire events. It is noted that upslope roads and trails were not reviewed as part of this assessment
As noted the immediate effects of the loss of soil cover, potential water repellency, loss of soil storage capacity and potential for significant increases in overland flows may last up to 5 years. However there could be, to a lesser degree, long-term (a few decades) hydrological effects due to the loss of forest canopy.

The partial risk estimation shown in Table 5 is one component of risk management. Risk evaluation, risk control, and risk communication with stakeholders form some of the other components. Risk evaluation includes comparing the risk to acceptable or tolerable levels to determine if risk control is required or desirable. Often stakeholders will determine the tolerability of the risk and if risk control measures are desirable and/or feasible.

Although partial risk was estimated only for the elements noted in Table 5, other elements of value exist along and above the Pavilion-Clinton Road and Jesmond Road and are also at risk. These include road infrastructure, public road use safety, powerlines, telecommunication lines, water intakes, outbuildings, machinery, fencing etc.

Part 4
RISK MITIGATION

This assessment does not determine whether the noted risks are acceptable, or if they should be mitigated. For risks that are considered either intolerable or unacceptable several risk mitigation treatments have been described by Napper 2006 some of which are listed in Table 6. In addition to these treatments the most effective strategy, where possible, is avoidance of hazardous sites during or shortly after high snowmelt or rainfall events.

Treatments can be divided into land treatments, channel treatments and road/trail treatments. Land treatments attempt to stabilize burned areas by providing soil cover and reducing erosion. Channel treatments attempt to maintain channel characteristics, reduce peak flows, temporarily store sediment or divert debris flow events. Road and trail treatments attempt to minimize the effects of the road/trail on downslope elements at risk while protecting road infrastructure.
Land treatments (heli-straw mulch) and road/trail treatments (by MFR and MOT) were implemented on the 2007 Springer Creek Fire (see Nicol, 2008) while Channel treatments were implemented on the 2003 Kuskonook Fire (post debris flows).

Land treatments, channel treatments and road treatments all have potential applicability to the Kelly Creek Fire; however, their feasibility will depend on the level of acceptable and/or tolerable risk and cost benefit analysis. General recommendations relating to this assessment will be included under separate memo.

<u>Salvage Logging and Future Harvesting:</u> As noted in Nicol 2008, salvage logging can be part of an active management strategy after a fire by slowing the build-up of insect populations and by removing fuel from the path of subsequent fires (though fuels are normally considered as being <7.5cm in diameter and logging tends to create more fuel than it reduces). The removal of dead trees after a fire could in theory reduce fuels and thus the intensity of fires that may occur in the future (Duncan 2002) though in practise this has rarely been the case. Salvage logging may also break up water repellent layers and promote water infiltration. However, post fire salvage logging can have immediate environmental effects which can depend on the severity of the burn, slope, soil texture and composition, the presence or building of roads, type of log retrieval systems, and post fire weather conditions (Duncan 2002). Construction of logging roads and trails, soil scalping and other disturbances associated with logging have the potential to divert water and increase the risk of post-fire events. Therefore salvage logging should be restricted from steep slopes, severely burned areas, erosive sites, fragile soils, riparian areas and in any area where accelerated erosion is possible (Beschta et al 1995). Salvage logging sometimes removes stands that are only partially dead and thereby has negative influence on hydrological regime. In addition, dead stands can provide some shade that can influence the snowpack melt rates and they have the potential to influence the initiation and/or run-out of snow avalanches.

In the Kelly Creek burn the presence of Provincial parks, steep slopes, unstable and potentially unstable terrain, elements at risk and areas of high and moderate burn severity preclude salvage logging in many of the watersheds.

<u>Existing Residences and Future Residential Development</u>: Residential development includes subdivision of property, construction of new buildings or structures, and structural alteration of, or addition to, existing buildings or structures (APEGBC 2006 revised 2008). Residential developments, in order to proceed, must be accepted by the Approving Authority which is a Subdivision Approving Officer, a Building Inspector, Planner, or local government Council.

The local approving officer may determine that some of the areas below the burn may benefit from a landslide assessment before additional residential development is considered. A qualified professional conducting the landslide assessment would then compare the results of their analysis with a level of landslide safety (APEGBC 2006). Whether the potential landslides would result in risks that are unacceptable would depend on the location of the proposed development, potential landslide magnitude and run-out, hydrological recovery at the time of proposed development, and the installation of possible stabilization or protective works. Ultimately the risks could be compared with published background risks and generally accepted levels of acceptable and tolerable risks such as those discussed in Leroi et al 2005 and Fell et al 2005.

Table 5

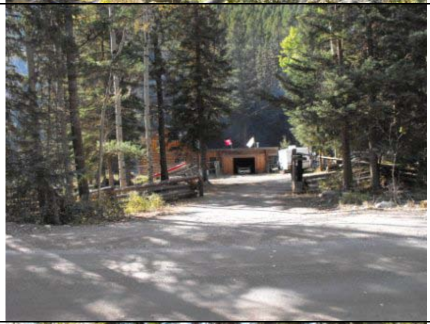
Incremental Post Wildfire Partial Risk Summary

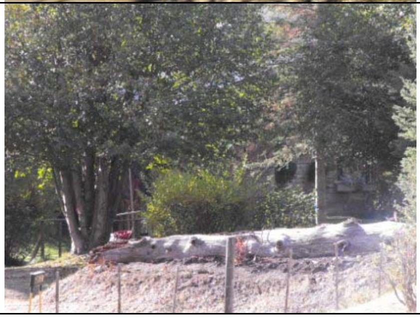
Element Number	UTM	Description	Drainage /Hazard Source and Type	P(H)	P(S:H)	Partial Risk P(HA)	Photo
1	585748/5651777	Highway side rest area located on and adjacent to Goodrich Creek fan.	H1Goodrich Creek. debris flow/flood	High	Mod.	High	
2	585852/5651746	Downing Property -Log House, mobile home and outbuildings located below highway and on Goodrich Creek fan	H1 Goodrich Creek. debris flow/flood	High	Mod	High	 

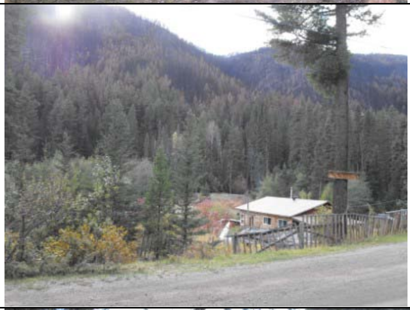
Element Number	UTM	Description	Drainage /Hazard Source and Type	P(H)	P(S:H)	Partial Risk P(HA)	Photo
3	585946/ 5651678	Provincial campground	a)H1 Goodrich Creek - flood b) Porcupine Ck flooding	a)High b)High	a)Low b) Mod	a)Low b)Mod	
4	585945/ 5651822	A-Frame house and outbuildings located above highway and on Goodrich Creek fan	H1 Goodrich Creek flooding and debris flow	High	High	High	
5	586027/ 5651925	Road to CN staging and old outbuilding located below (south of) highway.	H1, a) Goodrich Creek flooding b) Porcupine Creek flooding	a) High b) High	a)Low b) Low	a)Low b) Mod	

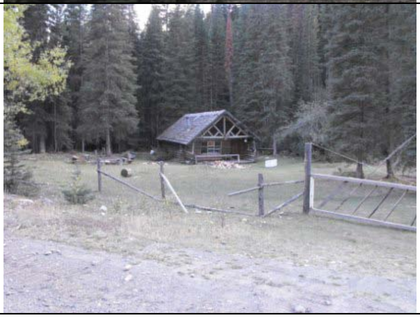
Element Number	UTM	Description	Drainage /Hazard Source and Type	P(H)	P(S:H)	Partial Risk P(HA)	Photo
							
6	586130/ 5651952	Kelly lake Ranch Multiple houses/ outbuildings located adjacent to Porcupine Creek	Porcupine Creek - flooding	High	High	High	 

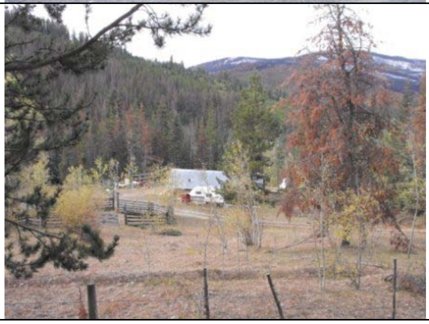
Element Number	UTM	Description	Drainage /Hazard Source and Type	P(H)	P(S:H)	Partial Risk P(HA)	Photo
7	586185/ 5652303	6421 Chevalier Court 5 houses and 2-3 outbuildings or cabins located adjacent to Porcupine Creek	Porcupine Creek - flooding	High	High	High	  

Element Number	UTM	Description	Drainage /Hazard Source and Type	P(H)	P(S:H)	Partial Risk P(HA)	Photo
8	585782/ 5653810	6656 House and out buildings located below and to the west of Jesmond Road	a)H11c debris flow gulley located above Jesmond Road. b)H11a,b Debris flows/slides from west side c)Porcupine ck flooding	a)Low b)Low c) High	a)High b)Low for affecting house c)Low for house	a)Low b) Low c) Low	
9	585027/ 5654594	6797 House located below Jesmond Road and on the 2 Mile Creek fan	a)Porcupine Creek flooding b)H2a-2 Mile Creek flooding/debris flood c)H2b2-debris slide/H2b3debris flow west slopes	a) High b) Mod c) Mod	a)High b)Mod c)Mod	a) High b) Mod c) Mod	
10	585071/ 5654821	6815 House ,barn, outbuildings located below Jesmond Creek road and on 2 Mile Creek fan	a)Porcupine Creek flooding b)H2a-2 mile creek flooding/debris flood (house located at edge of fan) c)H2c - debris flow from adjacent drainage to H2c east slope d)H2b1 debris slide/flow west slope	a) High b) Mod c) Low d) High	a)High b)Mod c)High d)Low	a) High b)Mod c)Mod d)Mod	

Element Number	UTM	Description	Drainage /Hazard Source and Type	P(H)	P(S:H)	Partial Risk P(HA)	Photo
11	585122/ 5654678	6808 House and outbuildings located above Jesmond road and on the 2 mile Creek fan.	a)H2a 2 Mile Creek flooding/debris flood b)debris flow from small gulley to the north	a)Moderate b)Low	a)Mod b)Low	a)Mod b)Low	
12	585071/ 5654821	6820 House located above Jesmond Road and to the north of the 2 mile creek fan	H2c Debris Flow from adjacent drainage to H2c	Low	High	Mod	
13	584718/ 5655029	6853 "Alan Park" House located on west side of Jesmond Road and Porcupine Creek	a)Porcupine Creek flooding b)H3a2 Debris flow gulley on east slope c)H2b1 Debris flow/slide west slope	a) High b) Low c) High	a)High b)High c)Low	a)High b)Mod c)Mod	

Element Number	UTM	Description	Drainage /Hazard Source and Type	P(H)	P(S:H)	Partial Risk P(HA)	Photo
14	584570/ 5655126	2nd prop Alan Park House and mobile home	a)Porcupine Creek flooding b)Debris slide east slope c)H3b2 Debris flow/slide west slope	a) High b) Low c) High	a)High b)Low c)Low	a) High b) Low c) Mod	
15	584507/ 5655172	6889 House located to west of Jesmond road but east of Porcupine creek	a)Porcupine Creek flooding b)H3a1 Debris flow gulley on east side c)H3b1 Debris Flow west slope	a) High b) Low c) High	a)High b)High c)Low	a) High b) Mod c) Mod	
16	583907/ 5655510	Cabin located below Jesmond Road	a)H9a Debris flow/slide from west side of Porcupine Creek b)Porcupine Creek flooding c)H9b debris flow east side	a) High b) High c) High	a)Mod b)Mod c)High	a)High b) Mod c)High	

Element Number	UTM	Description	Drainage /Hazard Source and Type	P(H)	P(S:H)	Partial Risk P(HA)	Photo
17	583638/ 5655869	6977 The Masons House and out buildings to west of Jesmond road	a)Porcupine Creek flooding b)H4b Debris flow from gulley to north west c)Debris slide to west d)H4a Two debris flow gullies from east side of Jesmond road	a) High b) High c) Mod d) Mod	a) Low for house (outbuildings?) b)Low for house c)Low for house d)Low to moderate for house	a)Mod b)Mod c).Mod d)Mod	
18	582257/ 5657784	Jim and Grace Barnum Mobile Home on west side of Porcupine Creek	a)H8a Porcupine Creek Flooding b)H5 Debris slides from west side of valley	a) Mod b) High (mod for debris slide?)	a)Mod b)High	a)Mod b)High	
19	581996/ 5658219	Cabin located to west of Jesmond road and north of Porcupine Creek junction with no-name creek	a)H8a Porcupine creek and no-name creek flooding b)H8b Debris flow from west side of valley	a) Mod b) High	a)Mod b)Mod	a)Mod b)Mod	

Element Number	UTM	Description	Drainage /Hazard Source and Type	P(H)	P(S:H)	Partial Risk P(HA)	Photo
20	577697/ 5664122	Several cabins adjacent to a tributary creek of Kostering Creek, flowing from the east	a)H6a Creek flooding b) Kostering Ck Flooding	a) Low b) High	a) High b) Low to mod	a) Mod b) Mod	 
21	575865/ 5666132	House adjacent to a tributary creek of Kostering Creek, flowing from the east	H12 Creek flooding or debris flow	Low	High (did not determine channel height adjacent to house)	Moderate	

Element Number	UTM	Description	Drainage /Hazard Source and Type	P(H)	P(S:H)	Partial Risk P(HA)	Photo
22	574382/ 5668163	Circle H Mountain Lodge House, cabins, outbuildings adjacent to a tributary creek of Kostering Creek, flowing from the east	H7 Creek flooding	High	High (did not determine channel height adjacent to house	High	

Table 6
Potential Risk Mitigation Treatments

Land Treatments	Channel Treatments	Road and Trail Treatments
Hydromulch	Checkdams (straw bale, log, rock)	Culvert Modifications
Straw Mulch	Tree Felling	Debris racks and deflectors
Slash Spreading	Grade Stabilizers	Cross ditches, waterbars, rolling dips
Erosion Control Mats	Channel Armouring	Deactivation
Log Erosion Barriers	Channel Deflectors	Outsloping
Fiber Rolls or Wattles	Debris Basins	
Silt Fences		
Soil Scarification		
Seeding		
Reforestation (long-term)		

Report Closure and Limitations

This review has been carried out in general conformance with generally accepted practices in B.C. It is limited to the identification of hazards and elements at risk as a result of the changed conditions caused by the Kelly Creek Fire. This review does not address latent risks not reasonably apparent during the work undertaken and no liability is accepted for such latent risks. The work is conducted in a rapid manner and focused on identifying visible potential risks to public safety only. The rapid manner is required because such potential risks exist once the slopes have been burned and experience suggests that in some instances, the storm that triggers these risks can also be the one to have extinguished the fire. No assessment is undertaken on levels of acceptable or tolerable risk. The results are presented to affected stakeholders for their determination as to the implementation of any mitigative strategies. No liability is accepted for decisions made in regard to the implementation or lack thereof of any mitigative strategies. Some aspects of the review are preliminary and may require more detailed work at a later date. With respect to such preliminary matters, no liability is accepted. This review does not address any geotechnical or hydrologic concerns on, or adjacent to the burned slopes that would have been present prior to the fire.

This review was prepared by the Ministry of Forests and Range and D.R.Nicol Geotech Engineering (authors) and the information provided in it is intended for the use of the direct recipients only. Any use which a third party makes of this review, or any reliance on or decisions to be made based on this report are the responsibility of such third parties. The authors accept no responsibility for damages, if any are suffered by the third party, based on the information contained in this review.

In recognition of the relative risks and benefits of the review to both the direct recipients of this review and the authors, the risks have been allocated such that the direct recipients agree, to the fullest extent permitted by law, to limit the liability of the authors for any and all claims, losses, costs, damages of any nature whatsoever or claims expenses from any cause or causes, including legal fees and costs and disbursements., so that the total aggregate liability of the authors shall not exceed the total fee for services rendered for this matter. It is intended that this limitation will apply to any and all liability or cause of action however alleged or arising, unless otherwise prohibited by law. Notwithstanding the foregoing, it is expressly agreed that there shall be no claim whatsoever against the authors for loss of income, profit or consequential damages howsoever arising.

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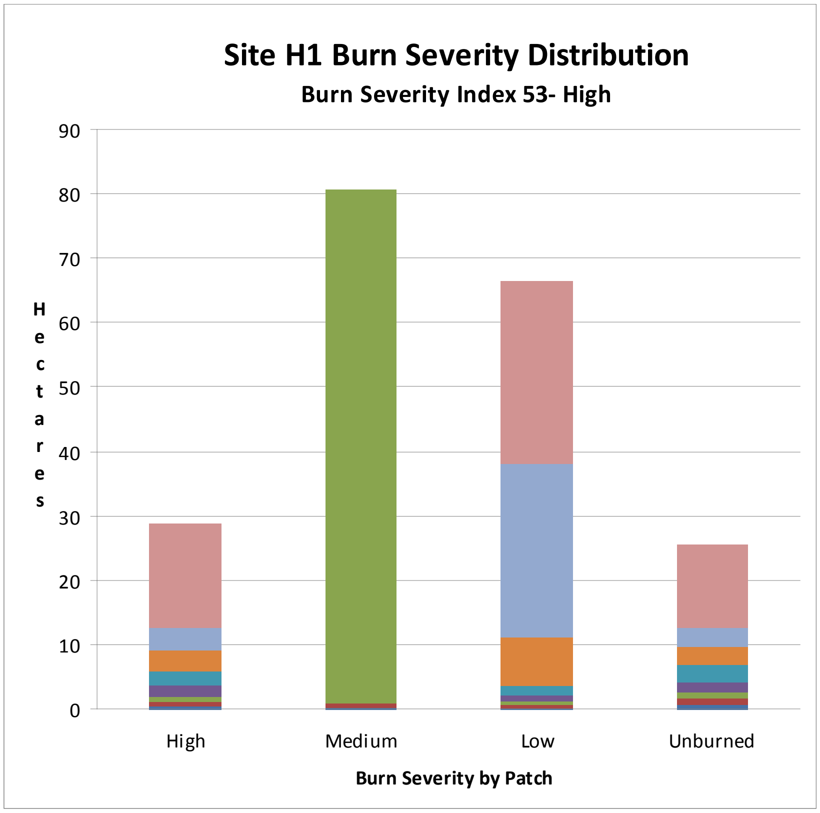
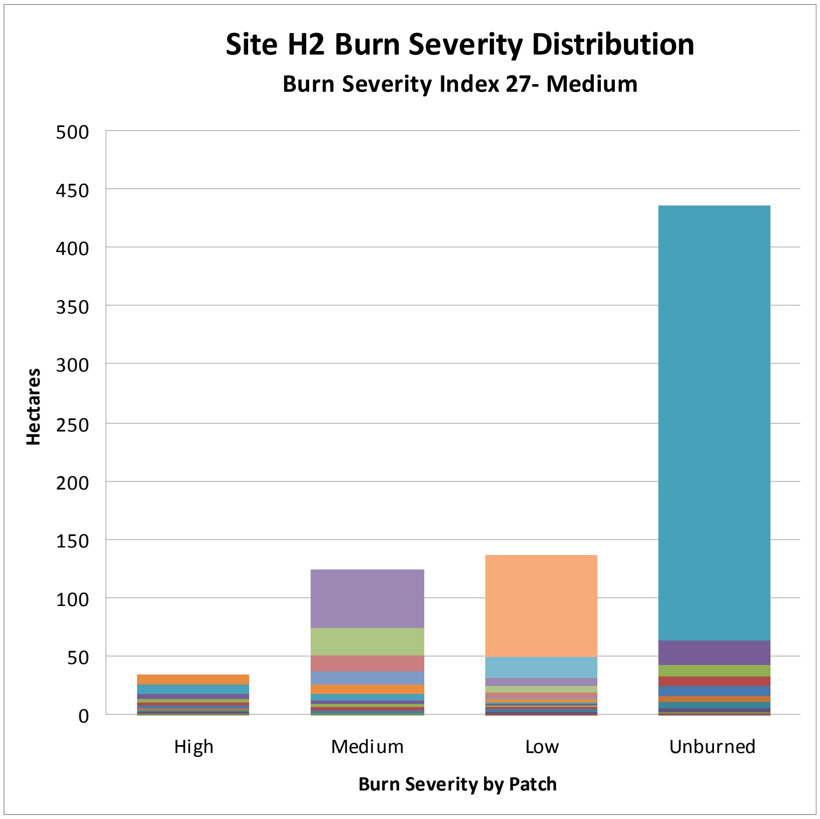
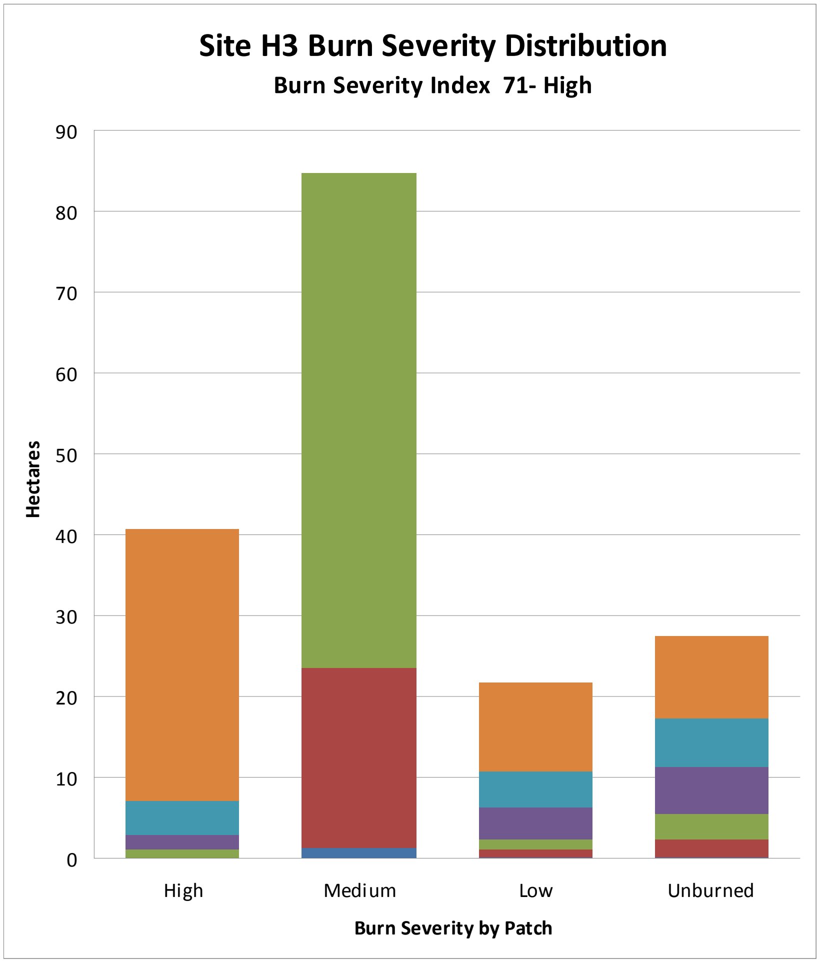
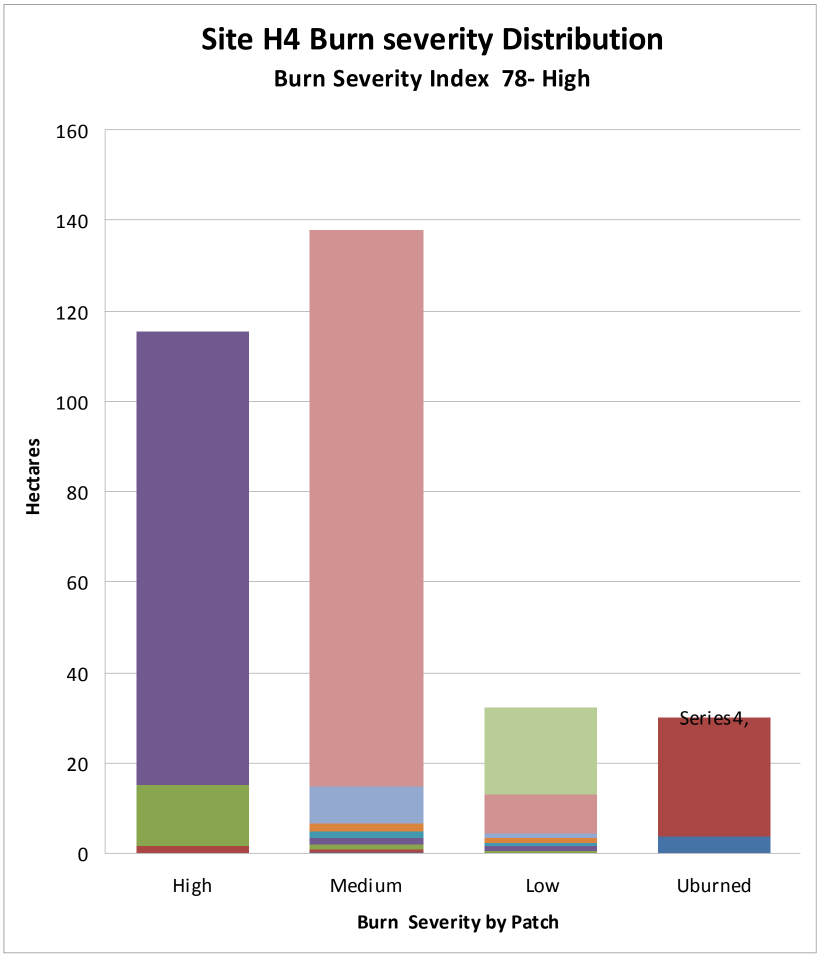
APPENDIX 1
Event Likelihood by Site

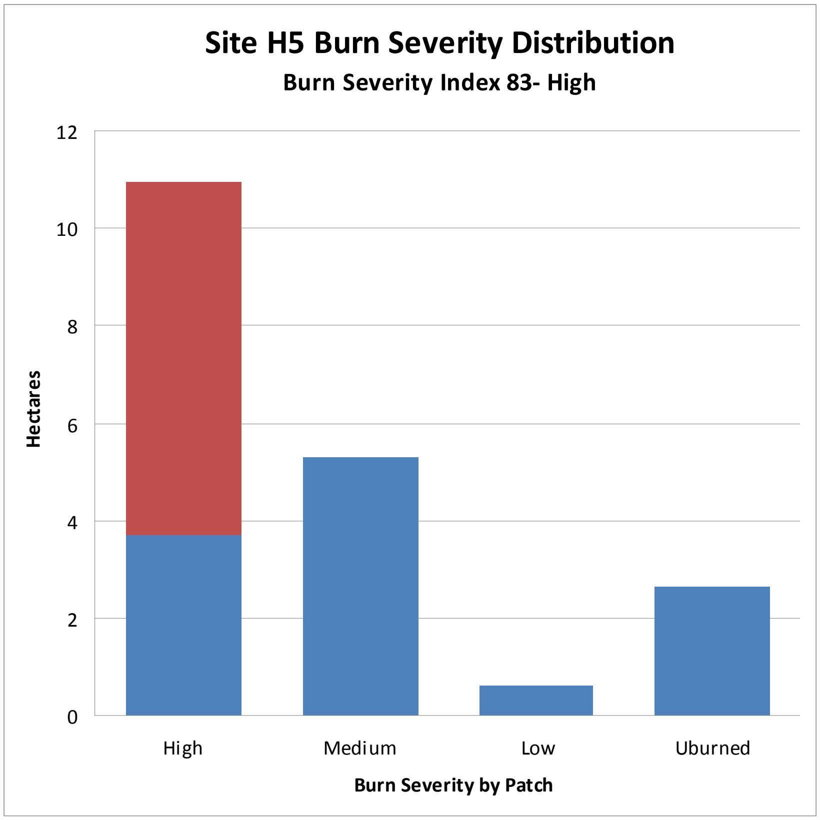
Interpretation- Each different band in each bar represents a different polygon identified on the BARC map. The polygons are arranged smallest to largest. For high and medium areas, taller columns and bigger polygon sizes would indicate greater likelihood, while taller columns in the low and unburned columns would indicate a lower likelihood of an event.



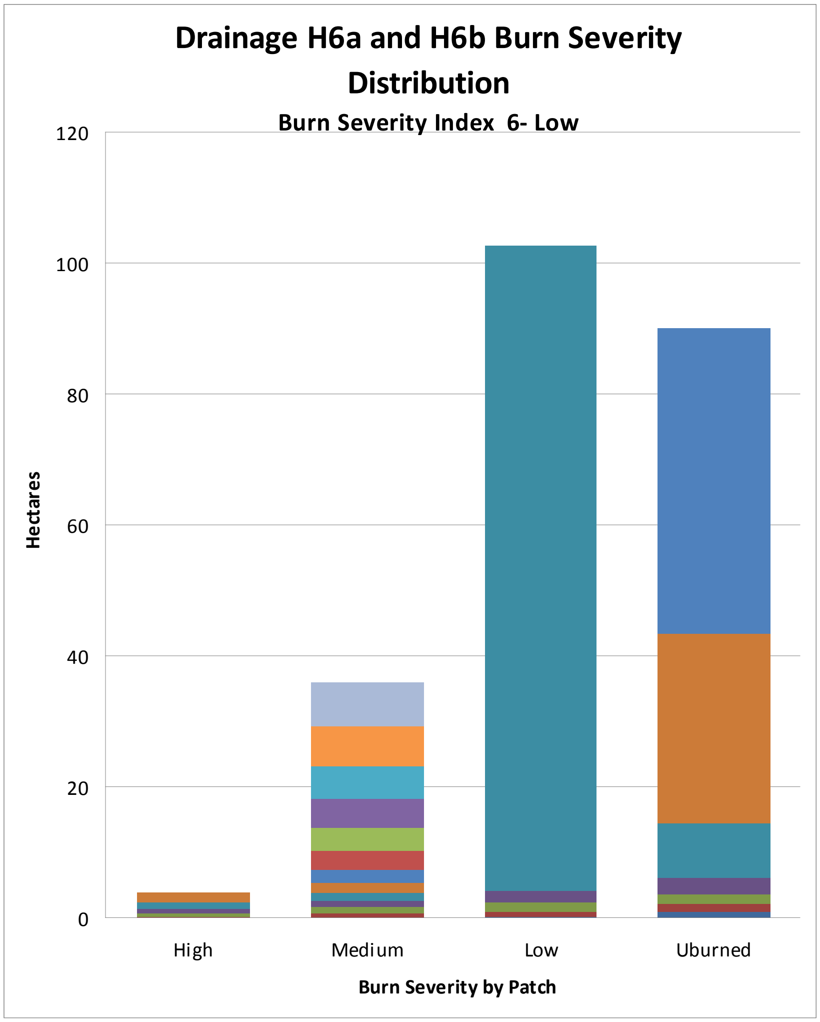

Site H2 Burn Severity Distribution
Burn Severity Index 27- Medium
Hectares
500
450
400
350
300
250
200
150
100
50
0
High
Medium
Low
Unburned
Burn Severity by Patch


Site H3 Burn Severity Distribution
Burn Severity Index 71- High
Hectares
90
80
70
60
50
40
30
20
10
0
High
Medium
Low
Unburned
Burn Severity by Patch

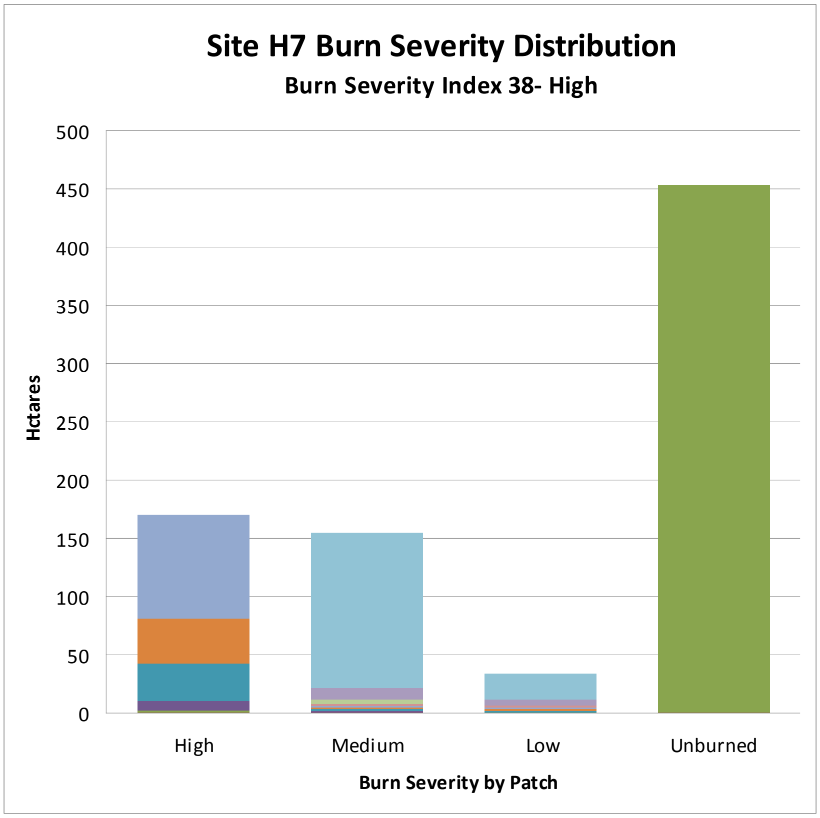

Site H4 Burn severity Distribution
Burn Severity Index 78- High
160
140
120
100
80
60
40
20
0
Hectares
Series4,
High
Medium
Low
Uburned
Burn Severity by Patch

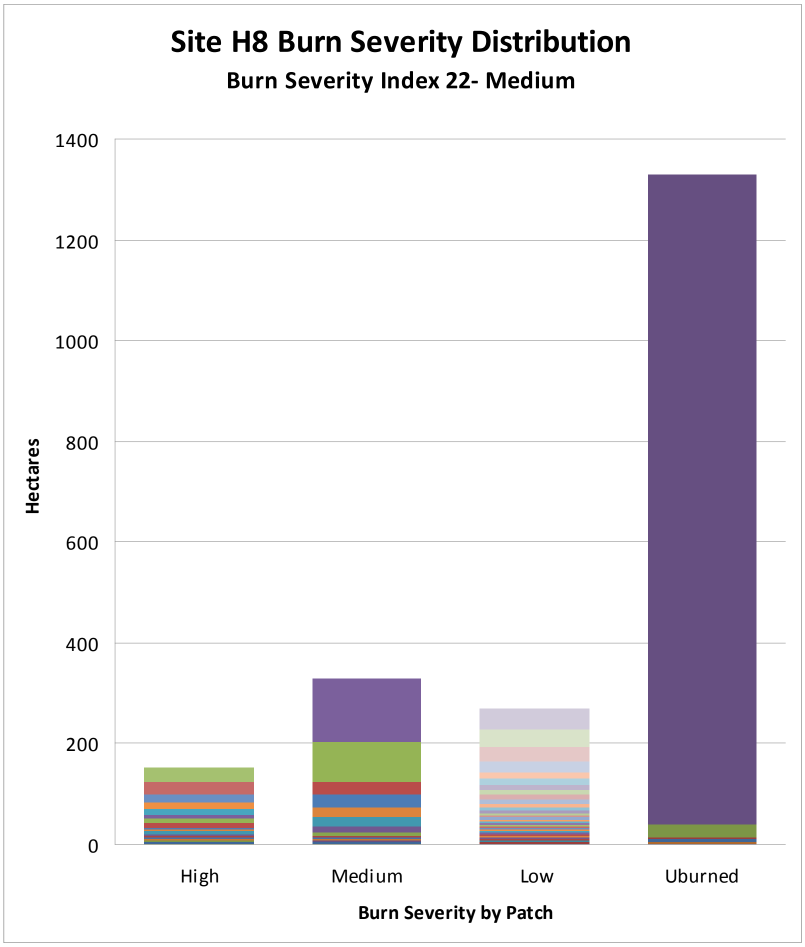


Site H5 Burn Severity Distribution
Burn Severity Index 83- High
Hectares
0
2
4
6
8
10
12
High
Medium
Low
Uburned
Burn Severity by Patch

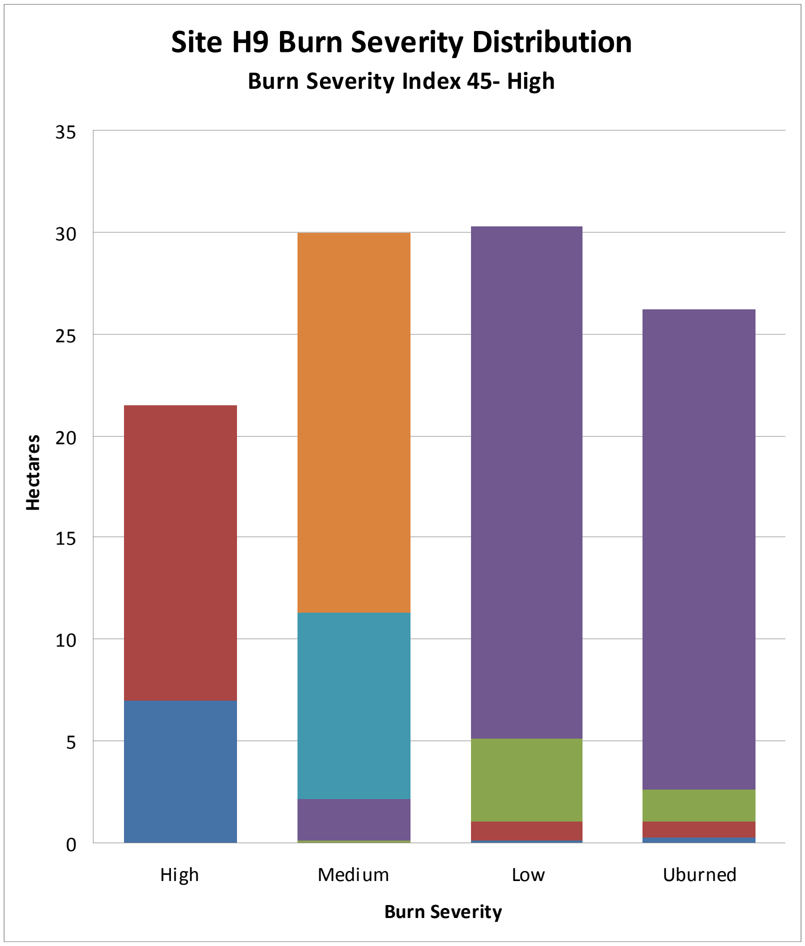


Drainage H6a and H6b Burn Severity Distribution
Burn Severity Index 6- Low
Hectares
120
100
80
60
40
20
0
High
Medium
Low
Uburned
Burn Severity by Patch

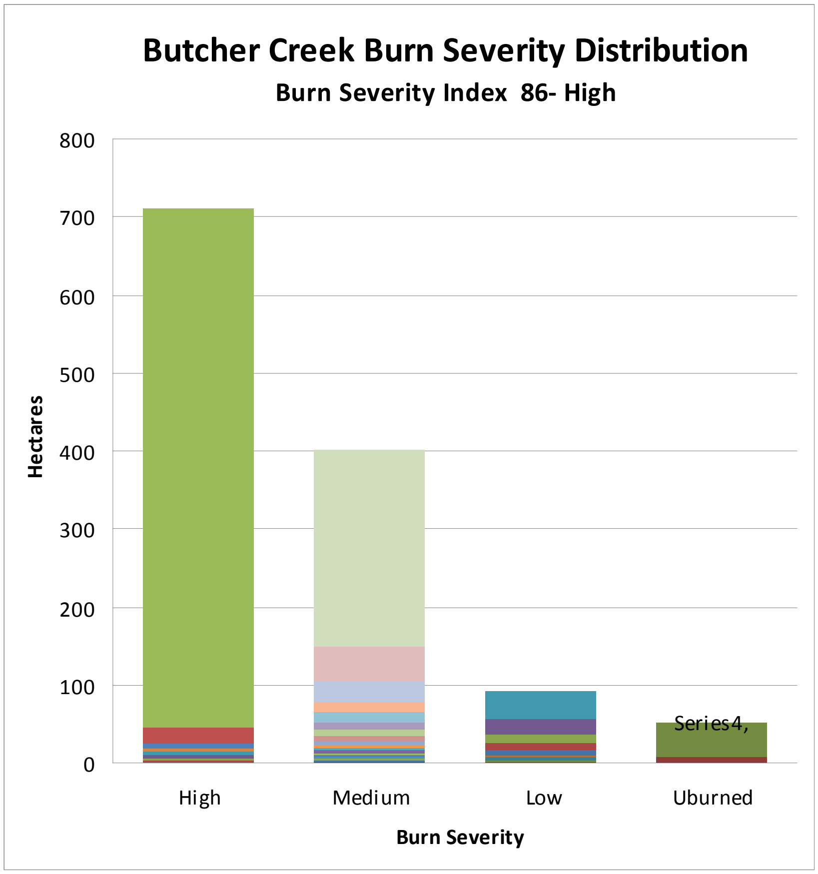

Site H7 Burn Severity Distribution
Burn Severity Index 38- High
500
450
400
350
300
250
200
150
100
50
0
Hctares
High
Medium
Low
Unburned
Burn Severity by Patch

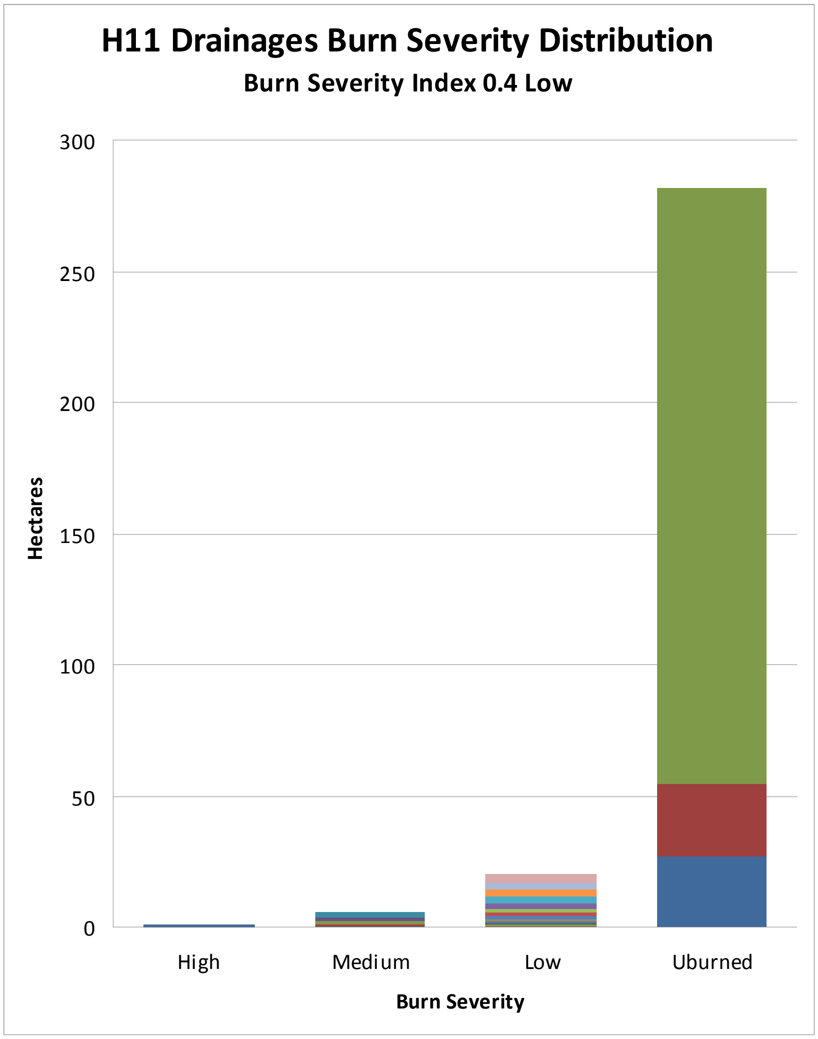


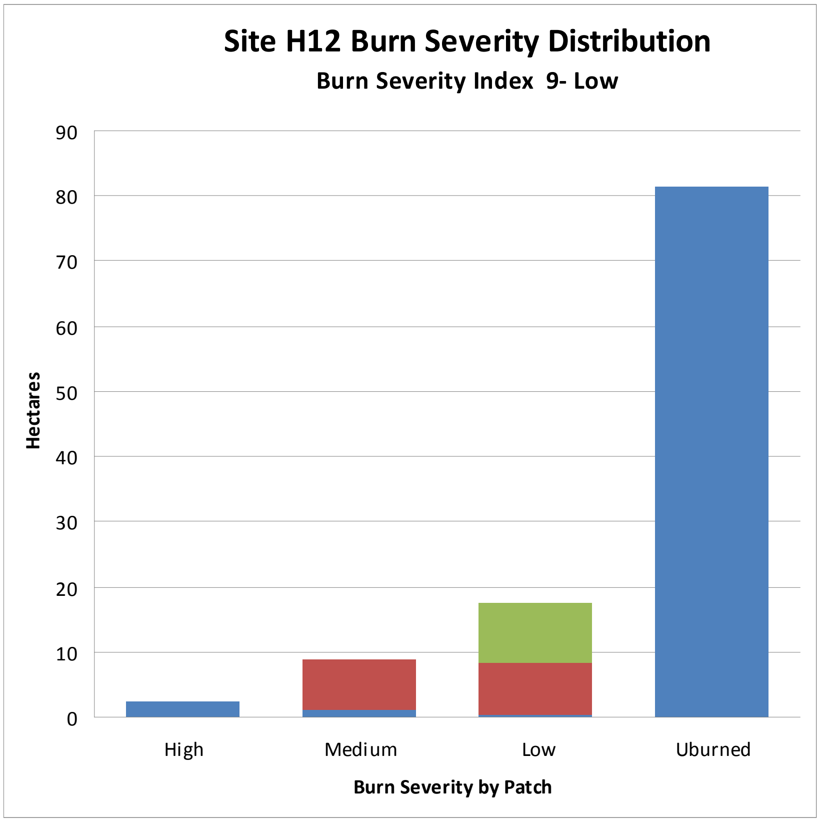
Site H8 Burn Severity Distribution
Burn Severity Index 22- Medium
Hectares
1400
1200
1000
800
600
400
200
0
High
Medium
Low
Uburned
Burn Severity by Patch

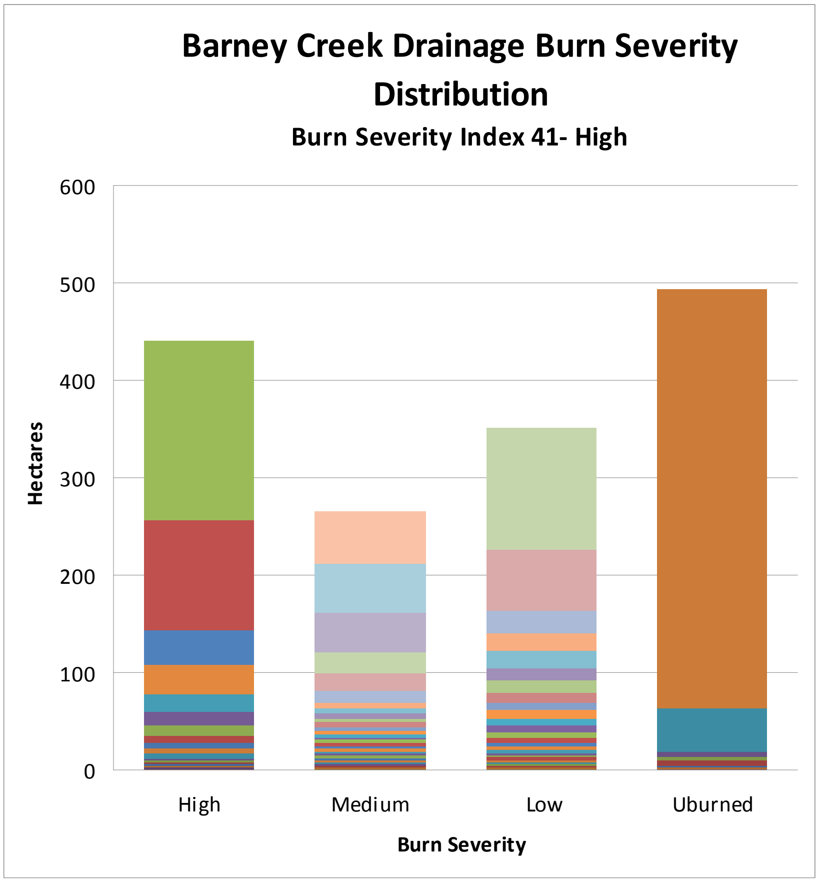


Site H9 Burn Severity Distribution
Burn Severity Index 45- High
Hectares
0
5
10
15
20
25
30
35
High
Medium
Low
Uburned
Burn Severity

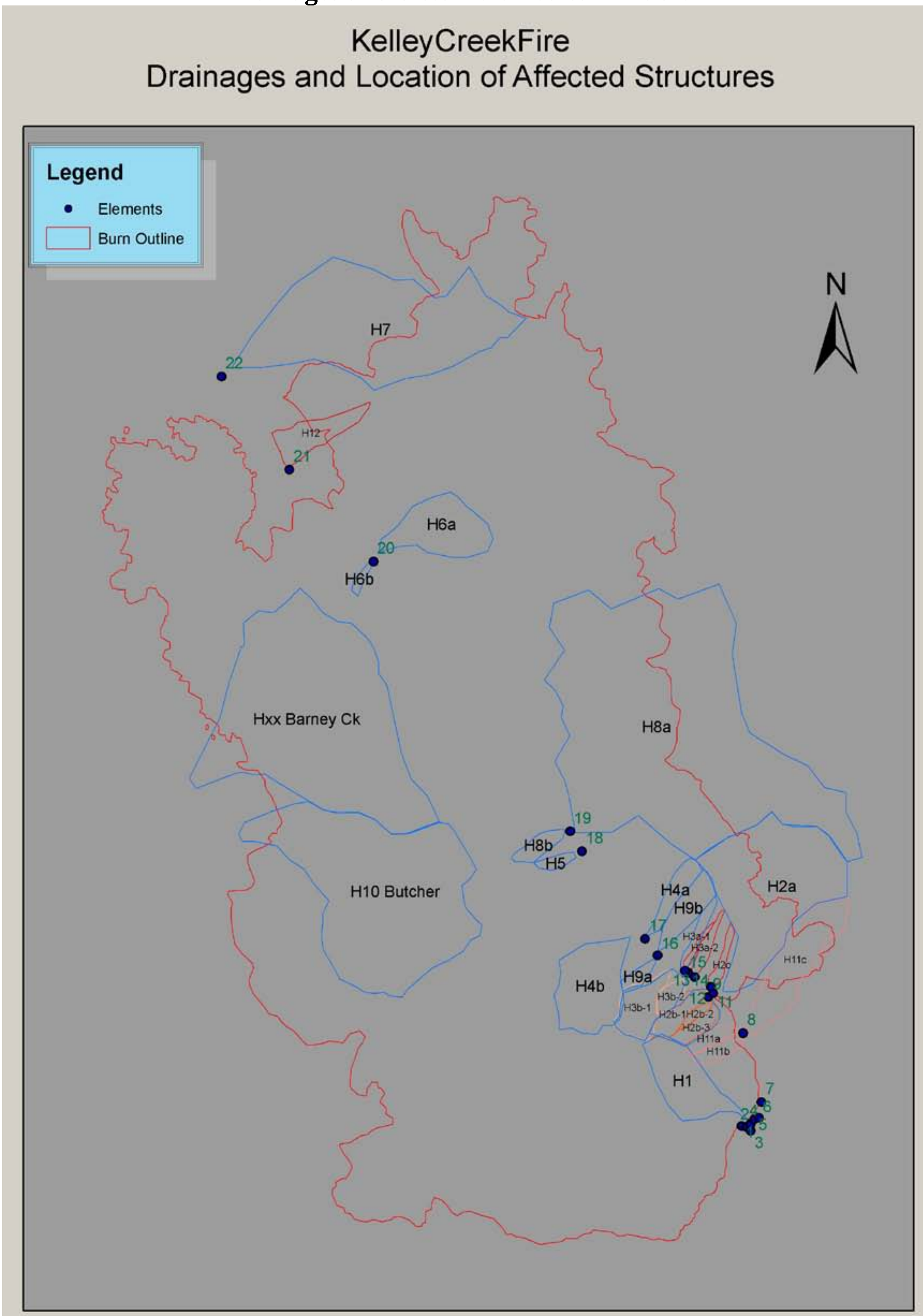

Butcher Creek Burn Severity Distribution
Burn Severity Index 86- High
800
700
600
500
400
300
200
100
0
Hectares
Series4,
High
Medium
Low
Uburned
Burn Severity


H11 Drainages Burn Severity Distribution
Burn Severity Index 0.4 Low
Hectares
300
250
200
150
100
50
0
High
Medium
Low
Uburned
Burn Severity


Site H12 Burn Severity Distribution
Burn Severity Index 9- Low
90
80
70
60
50
40
30
20
10
0
Hectares
High
Medium
Low
Uburned
Burn Severity by Patch


Barney Creek Drainage Burn Severity Distribution
Burn Severity Index 41- High
600
500
400
300
200
100
0
Hectares
High
Medium
Low
Uburned
Burn Severity

Appendix 2
Map 2
Drainages and Sites Referred to in Table 1



Appendix 3
Pat Martin Report

BRITISH COLUMBIA
The Best Place on Earth

Ministry of Forests and Range

Southern Interior Forest Region

MEMORANDUM

To: Ken Soneff
Forest Science Manager
Southern Interior Forest Region

From: Patrick Martin

Re: <u>Preliminary Aerial Risk Assessment, Kelly Creek fire</u>

This report completes the risk assessment of part of the SW sector of the Kelly Creek fire (C40429), located approximately 12 km NW of Kelly Lake. This assessment was completed because of concern for structures (element at risk) downslope from a severely burned area. This area was identified as one where post wildfire erosion, including debris flow, landslides or flooding, could potentially occur and might pose a risk to public safety, buildings and infrastructure.

The objective was to assess whether the identified structures were at risk from post-wildfire erosion, including debris flows, landslides or flooding.

On Monday September 14 2009 I made an aerial reconnaissance flight over the structures of concern and upstream at the S/W sector of Kelly Creek fire. I was accompanied on the flight by Leon O'Dette and Rory Colwell.

Coordinates of the structures are:

1- 51^{0} 03' 26.5"N, 121^{0} 55' 55"W Southern single building
2- 51^{0} 04' 15.3"N, 121^{0} 56' 06.9"W House on main drainage, upslope
3- 51^{0} 04' 12.7"N, 121^{0} 56' 02.6"W Barn close to creek channel
4- 51^{0} 04' 08.9"N, 121^{0} 56' 33.9"W House on main drainage, downslope

These observations are preliminary, as they're based on a helicopter overview. It is my professional opinion, however, that there is a low probability of an event impacting the structures present on site on September 14, 2009 in the two drainages observed. The reasons for this opinion are:

1. The two houses (2 and 4)on the main drainage are elevated from the creek bed. So even if we had an event, there is a low probability that the structures would be impacted.

2. The barn (3) on the main channel is situated on the inside of the curve of the creek. If there was an event, there is a low probability that the structures would be impacted.

3. The unburned forest floor is mainly sandy and rocky and looks like there is a minimal amount of duff. The burned forest floor has a different colour, but still has the same sandy and rocky appearance. These observations indicate that the burned slopes above the house (1) should not be more prone to instabilities than before. This house stands on a little mount where the natural drainage path is on the north side and has a secondary

drainage path on the south side of the house. If there was an event, there is a low probability that the structures would be impacted.

It is recommended that a ground assessment of the slopes above the structures be completed to determine the severity of the burned soils. During this assessment it will be important to determine if the soils exhibit water repellency and if so, the strength, depth and extend of the water repellency. It is also advisable that during any heavy rainfall event this fall and next spring, or during periods of intense snowmelt during spring freshet, resident avoid entering the creek draw in case of debris flow, landslide or flood does occur.

Patrick Martin, P. Eng.
Regional Geotechnical Engineer
Southern Interior Forest Region