D.R.NICOL GEOTECH ENGINEERING LTD.

Springer Creek Fire Number 50372

Long-term Risk Analysis

Prepared for Ministry of Forests and Range
Southern Interior Forest Region
March 17th, 2008

Table of Contents

Executive Summary	Page 1
Introduction, Report Objective and Scope of Work	Page 4
Information Reviewed	Page 4
Definitions	Page 5
Site Location, Physiography, Surficial Materials and Bedrock Geology	Page 6
Landslide History	Page 6
2007 Springer Fire – Extent and Severity	Page 8
Short-term verses Long-term Hazards	Page 11
Completed Hazard Mitigation	Page 13
Long-term Hydrological Influences	Page 15
Hazard Determination	Page 19
Elements at Risk	Page 22
Salvage Logging and Future Harvesting	Page 27
Risk Reduction measures on Crown Land	Page 29
Existing Residences and Future Residential Development	Page 29
Summary and Recommendations	Page 30
Acknowledgements	Page 33
Closure, Report Use and Limitations	Page 33
Appendix A Vegetation and Soil Burn Severity	Page I

Executive Summary

The Springer Creek Fire burned an area of 23 km^2 northeast of the Village of Slocan during the summer of 2007. Shortly after the fire was contained a Post–Wildfire Risk Analysis was completed by Nicol et al (September 1st) that summarized the slope related short-term (up to 5 years) risks associated with the fire. The following report summarizes the long-term (30+ years) slope related (landslide including debris flow) risks associated with the fire.

Long-term slope hazards that were considered for this review include open slope debris slides, debris flows (originating either within channel or via a debris slide) and debris floods resulting from potential changes in surface drainage flows, overland flows and peak flows, and root strength. These hazards have the potential to either hit the highway, impact infrastructure, or threaten public safety. Expected changes in the local hydrology are due to the loss of forest cover causing elevated snow accumulations, more rapid snowmelt, and decreased evapotranspiration. Event triggers would typically include extreme rain on snow events, high snowmelts rates following extended warm weather, or long duration rainfall events. A snow avalanche risk assessment is being completed by others and is not included in this report.

While the annual risks due to landslides as a result of the fire effects on forest hydrology are expected to decrease after 3 years, for many of the drainage units (see Figure 2 for a drainage unit map) the risk to public safety and infrastructure are still considered high after 3 years. This is partly due to the fact that the total exposure (number of years) to the long-term hazard is greater (order of magnitude higher) than the exposure to the short-term hazard. The qualitative risk to highway infrastructure and public safety (travelling public and residences) is shown in Tables 1 and 2. The risk to other infrastructure (power lines, fibre optic cables etc) was not specifically considered as the risk is site specific and depends, for example, on pole locations and depth of burial and would require more site specific consideration.

Table 1 Estimated long-term risk to travelling public and partial risk to highway infrastructure

Drainage Unit	Travelling Public	Partial Risk to Highway Infrastructure
Bluff 1	L	L
R1	L	L
Memphis	M	M
R2	L	L
South VanTuyl	H	H
Middle Van Tuyl	H	H
North Van Tuyl	H	H
R3	L-M	L-M
South South Cory	H	H
South Cory	M-H	M-H
Cory	M-H	M-H
R4	L	L
Allen	M	M
R5	M	M
R6	M	M
Ent 1	M-H	M-H
R7	L-M	L-M
Enterprise Creek	L	L

Table 2 Partial Risk to public safety – residences

Location	Location	Partial Risk
Lot L1011	Below R6	L
Lot 1023	R5 and Allen Creek	M
Lot 6531	Cory Creeks	H
Lot 11722	Van Tuyl Creeks and R2	L

Recommendations are as follows:

1. The long-term hazards and risks should be communicated to local residents, landowners, stakeholders, local government, Provincial Emergency Program (PEP), and Ministry of Transportation (MOT).

2. Consideration should be given by the following agencies and stakeholders to the implementation of available risk reduction measures as follows:

   Ministry of Forests and Range (MFR)

   On the crown forest, reforestation is a risk reduction measure. While reforestation will occur naturally, the speed of reforestation can be accelerated through tree planting and will have the effect of reducing the time period the long-term hazards remain elevated above background levels by improving hydrological recovery and root strength. As such it is recommended that MFR determine the areas where tree planting is practical and can be accomplished safely in light of the potential risk reduction particularly for drainage units above the highway and residences (drainage units above Highway 6 from R1 to R7 inclusive) and tree planting should be considered in those areas where the tree density (taking into account expected tree mortality) is significantly less than the natural undisturbed forest density. The selection of species and spacing requirements should consider (in addition to biodiversity, insect tolerance, future fire potential, etc.) the desire to restore hydrological recovery as soon as possible. Existing active roads and trails located within the drainage units above Highway 6 from R1 to R7 should be appropriately maintained or deactivated (see Recommendation 5).

   Ministry of Transportation (MOT)

   To date, in response to the short term risk analysis, MOT has widened the ditch below drainage units R6 and R7 to improve rock fall catchments, has replaced a culvert at the Ent 1 creek crossing, has installed 2 new overflow culverts in the Van Tuyl Creek crossings, and has created additional debris flow storage capacity above the Van Tuyl creek crossings by removing over $1000 m^3$ of material.

   MOT should review the long-term risk analysis and determine if additional risk reduction is required and is feasible. Additional MOT related risk reduction strategies could include the construction of check-dams, installation of additional overflow culverts, creation of depositional areas, terminal walls, and debris strains (includes trash racks), and installation of highway notification signage.

Local residents, PEP, RDCK

Given the moderate and high long-term partial risk to some residents, the implementation of risk reduction measures is warranted. Private residence risk reduction could be accomplished with the construction of check-dams, lateral walls, and deflection walls.

Other Infrastructure Stakeholders

Owners of power lines, poles, and fibre optic cables should review the location of this infrastructure in relation to the hazards to determine if additional risk reduction measures are warranted.

3. While there are benefits associated with salvage logging, the presence of 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 drainage units of the Springer Fire. In order to minimize the potential incremental risk, salvage logging should not occur within any of the drainage units listed below unless a detailed drainage unit site assessment determines the burn severity, hazards and/or risks are not as described and salvage logging can be conducted safely. The detailed drainage unit assessment must consider the potential positive effects of leaving the timber on site (including potential effects relating to snow avalanches), the access requirements, the ability to remove dead trees without impacting adjacent live trees or understory vegetation, the need to retain buffers along riparian areas and debris flow draws to allow for shade and long term large woody debris collection, and the long-term positive effects of fallen trees on sediment collection and forest floor regeneration:

   South Memphis, Memphis, South Van Tuyl, Middle Van Tuyl, North Van Tuyl, South South Cory, South Cory, Cory, Allen, R5, R6, Ent 1, R7, Ent 2, R8, Ent 3, R9, Ent 4, R10, N Ent 1, N R1, N Ent 2, N Ent 3, N Ent 4, N R2, N Ent 5, and N R3.

   Selective salvage logging could occur in drainage unit R3 contingent upon the completion of a less detailed site assessment (than above) that considers the potential hazards and risks. The extent of salvage logging, if any, in the other drainage units must consider the potential impacts of the logging on slope stability and elements at risk.

4. Before any proposed residential development is approved adjacent to the highway below drainage units located from R1 to R7 inclusive and extending up Enterprise Creek, it is recommended that a landslide assessment be conducted, by the proponent, consistent with the guidelines produced by APEGBC 2006, and that the professional conducting the assessment be familiar with the landslide history and the possible short-term and long-term effects of the recent fire. The RDCK and/or MOT may consider adopting a defined level of landslide safety or natural hazard safety.

5. In order to minimize the potential changes in the local hydrology due to the loss of forest cover and the potential hydrological effects of roads and trails, future forest harvesting, road construction, or trail construction should not occur within the following drainage units until such time as it can be shown that soil and hydrological recovery is such that harvesting can be accomplished with no significant additional risk: drainage units R1, South Memphis, Memphis, South Van Tuyl, Middle Van Tuyl, North Van Tuyl, R3, South South Cory, South Cory, Cory, Allen, R5, R6, Ent 1, R7, Ent 2, R8, Ent 3, R9, Ent 4, R10, Ent 5, N Ent 1, N R1, N Ent 2, N Ent 3, N Ent 4, N R2, N Ent 5, and N R3.

   Until the appropriate hydrological recovery occurs, all maintained roads and trails located within these drainage units should continue to be actively maintained or deactivated.

Introduction, Report Objective and Scope of work

The Springer Creek Fire burned an area of 23 km^2 during the summer of 2007. The fire was located upslope of several values including Highway 6 (and travelling public), houses, power transmission lines, fibre optic cables, and domestic water supplies. The effects of wildfires on slope and stream stability have been well documented. Because of the potential values at risk, a Post–Wildfire Risk Analysis was completed by Nicol et al (September 1st) that summarized the slope related short-term (up to 5 years) risks associated with the fire. The report contained 12 recommendations intended to reduce the risk to public safety and infrastructure.

This report is intended to satisfy Recommendation Number 11 from the Nicol et al September 2007 Risk Analysis which states "conduct an assessment of the long-term hydrologic and slope stability effects due to the wildfire with recommendations relating to possible long-term mitigative measures. The assessment should include a summary for local governments for consideration with respect to the issuance of rezoning, subdivision, and building permit approvals". The following report summarizes the long-term (30+ years) slope related risks associated with the fire.

Information reviewed

Airphotos
Terrain Stability Mapping
Orthophotos
Biogeoclimatic Zone Mapping
Terrain Stability Maps
Topography Maps – 1:20,000 TRIM Maps
Fire Perimeter Maps
RDCK 1:10000 Cadastral Map
MSRM 1:50000 2004 Flood Hazard Map
Bedrock Geology and Soil Maps
2005 Hydrologic Update Reports for Harvesting
Quick Bird Satellite Imagery
BARC Burn Severity Map (Landsat 5)

Road Treatment and Helimulch Area Maps
Various reports, studies, and papers – as referenced

Definitions

Consequence[1]	The effect on human well-being, property, the environment, or other things of value; or a combination of these. Conceptually, consequence is the change, loss, or damage to the elements caused by the landslide.
Elements at Risk[2]	Things of social, environmental and economic value, including human well-being and property that may be affected by a landslide.
Hazard[1]	A source of potential harm, or a situation with a potential for causing harm, in terms of human injury; damage to property, the environment, and other things of value; or some combination of these.
Landslide[1]	A movement of rock, debris or earth down a slope. Includes debris flows, debris slides, and rockfalls. A debris flood is transitional between a debris flow and a flood.
Risk[1]	The chance of injury or loss as defined as a measure of the probability and the consequence of an adverse effect to health, property, the environment, or other things of value.
Risk Analysis[1]	The systematic use of information to identify hazards and to estimate the chance for, and severity of, injury or loss to individuals or populations, property, the environment, or other things of value.
Risk Assessment[1]	An assessment that combines risk analysis and risk evaluation to determine if a risk is acceptable or tolerable.
Soil Burn Severity[3]	A relative measure describing the effects the wildfire had on soil hydrologic function through observations of the remaining woody debris, forest floor litter, duff, and the surface mineral soil.
Vegetation Burn Severity[3]	Also referred to as Fire Severity. Describes the effects a wildfire has on the overstory and understory. Used to predict the potential effects wildfire could have on local hydrology, snowpack accumulation, soil erosion, and needle casting. Data usually collected by aerial visual means or remote sensing (satellite imagery) of a burned area.
Water repellency[3]	The degree to which soil resists the infiltration of water. A water repellent layer can be formed when the forest floor is almost completely or totally consumed by wildfire.

[1] Adopted from 2004 LMH 56 Landslide Risk Case Studies in Forest Development Planning and Operations 2004 MOFR.
[2] From APEGBC 2006.
[3] Modified from Curran et al 2006.

Site Location, Physiography, Surficial Materials and Bedrock Geology

The Springer Creek Fire was located 8 km northeast of the Village of Slocan (see Figure 1) and was bounded by Highway 6 to its west, the Enterprise Creek drainage to the north, and the Springer Creek drainage to the south. Figure 2 shows elevation contours with an outline of the drainage units that were burned. The total area of these drainage units totals 100 km^2 while the actual burned area totals 23 km^2.

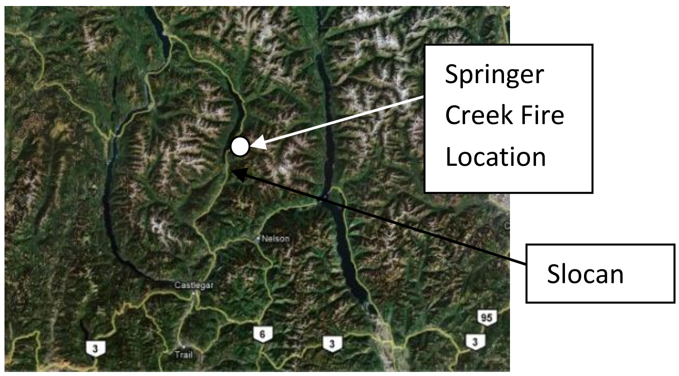

Figure 1 Site location

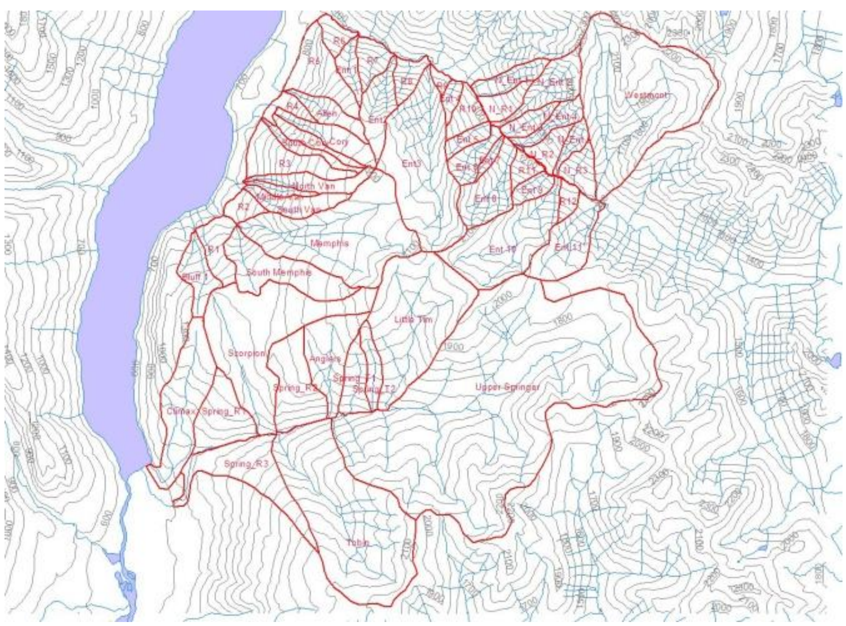
Figure 2 Fire location and associated drainages (supplied by MFR)

The site physiography, surficial materials and bedrock geology of the area are discussed in Nicol et al 2007.

Landslide History

Several landslides have been documented within the burned area some of which have been discussed in Nicol et al (2007). Curran et al (1990) and VanDine (1990) listed the occurrence of 12 debris flows between 1958 and 1990. Many of these were linked to changes in surface hydrology as a result of harvesting operations. Terrain mapping by Marc Deschenes (1997/1998) identified 30 historical landslide locations between Memphis Creek and Enterprise Creek with 16 of these above Highway 6 between Memphis Creek and Allen Creek.

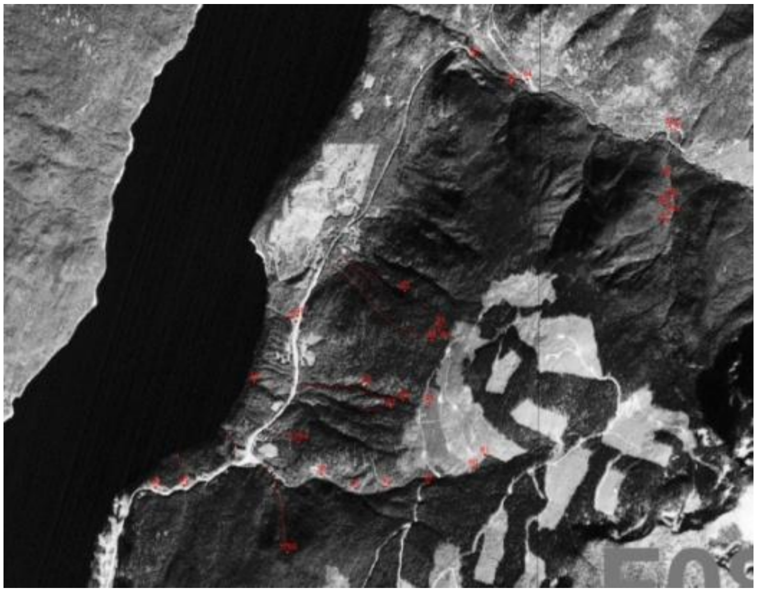
Photo 1 Landslides identified by terrain mapping (Deschenes 1997/1998) and landslide inventory (Jordan 2002).

In 1999 a landslide occurred in drainage unit R2 (see Photo 2). The landslide was investigated by the Arrow Forest District and was found to have been caused by surface drainage that was redirected by an old mining road. The road was subsequently deactivated.

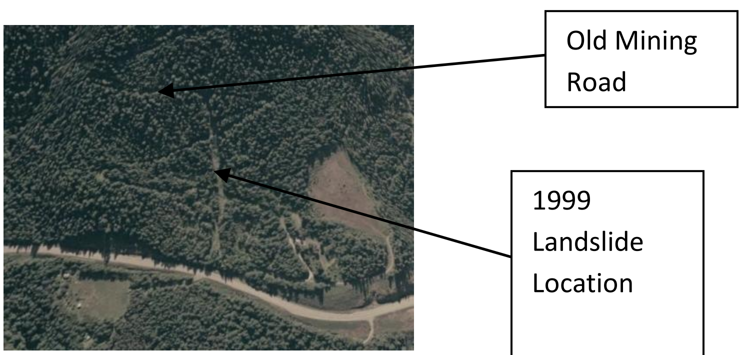

Photo 2 1999 landslide location

On August 31, 2007 (reported September 3 but thought to have occurred the night of August 31), a debris flow occurred within drainage unit N Ent 2 – a tributary (at 5km) to Enterprise Creek (see Photos 3 to 7). The drainage area of drainage unit N Ent 2 is 123 hectares of which 88% was burned to a moderate or high severity. Only 2.2mm of precipitation was recorded at the Slocan weather station on the evening of August 31. Data of the rainstorm was collected from 3 of the weather stations that were installed by MFR in the burn area during August 2007. The first station was located at an elevation of 1726m in the Allen drainage unit, the second station was located at an elevation of 1593m in the Cory drainage unit and the third was located at the 1754m elevation in the upper R3 drainage unit. Station 1, located 3.9km to the southwest of the centre of N Ent 2 drainage unit recorded 2.8mm with a 10 minute intensity of 12.1mm/hour, Station 2, located 4.7km to the southwest of the centre of N Ent 2 recorded 1.6mm with a 10 minute intensity of 4.7mm, and Station 3, located 4.9km to the southwest of the centre of N Ent 2 recorded 4.2mm with a 10 minute intensity of 22.3mm/hour. The stations themselves are located within 1.5km of each other.

Although the total rainfall magnitudes were low, these were the highest 10 minute intensities recorded for Stations 1 and 3 for the recording period of August 21 to December 7. While triggered by this high intensity, short duration rainfall the landslide is believed to have been caused by the effects of the Springer Fire on the soil.

Photo 3 N Ent 2 pre-fire

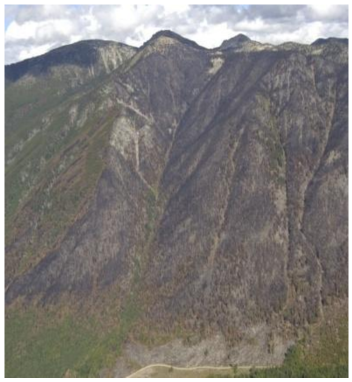

Photo 4 N Ent 2 post fire (MFR)

Photo 5 Upper N Ent 2 post fire (MFR)

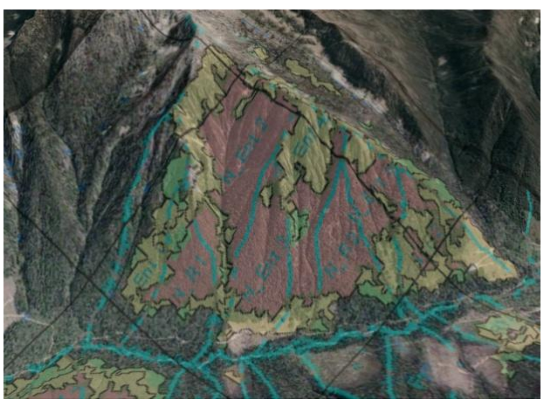

Photo 6 N Ent 2 with BARC fire severity overlay

Photo 7 N Ent 2 part of debris flow deposit

2007 Springer Fire – Extent and Severity

As noted, the 2007 Springer Creek fire burned an area of 23km^2. The area was divided into 55 drainage units (see Figure 2) for the purposes of estimating the burn severity using post fire satellite imagery within each drainage unit. Some discussion regarding the determination of vegetation and soil burn severity is included in Appendix A.

Field checking indicated that soil and vegetation burn severity were highly correlated in this fire. About 80% of plots in “High” vegetation burn severity polygons (preliminary maps by P.Jordan from hand-held aerial photography) had strong water repellency, and all had high soil burn severity. In “Moderate” and “Low” polygons, about 45% of plots had strong water repellency.

Burned Area Reflectance Classification (BARC) mapping was used to estimate the vegetation burn severity with the use of GIS techniques and satellite imagery (Landsat 5) through the comparison and calibration of pre-fire and post-fire satellite images. In areas that had open crown forests or were logged before the fire, BARC mapping may be more directly correlated to soil burn severity. A BARC map was prepared for the Springer Fire by the USDA Forest Service and calibrated by MFR using field check data and is shown in Figure 3. Red represents high burn severity, yellow moderate, green low and no colour represents no burn. The fire severity map was overlain onto a 3-dimensional image and is shown in Photo 8. Of the areas burned, 35%, 39% and 26% of the burned area burned to a high, moderate, and low burn severity respectively. The preliminary maps correlated well with the BARC maps and the areas were generally within 10% of the calculated high and moderate vegetation burn severity from the BARC map. Generally the preliminary maps tended to underestimate the total burn severity.

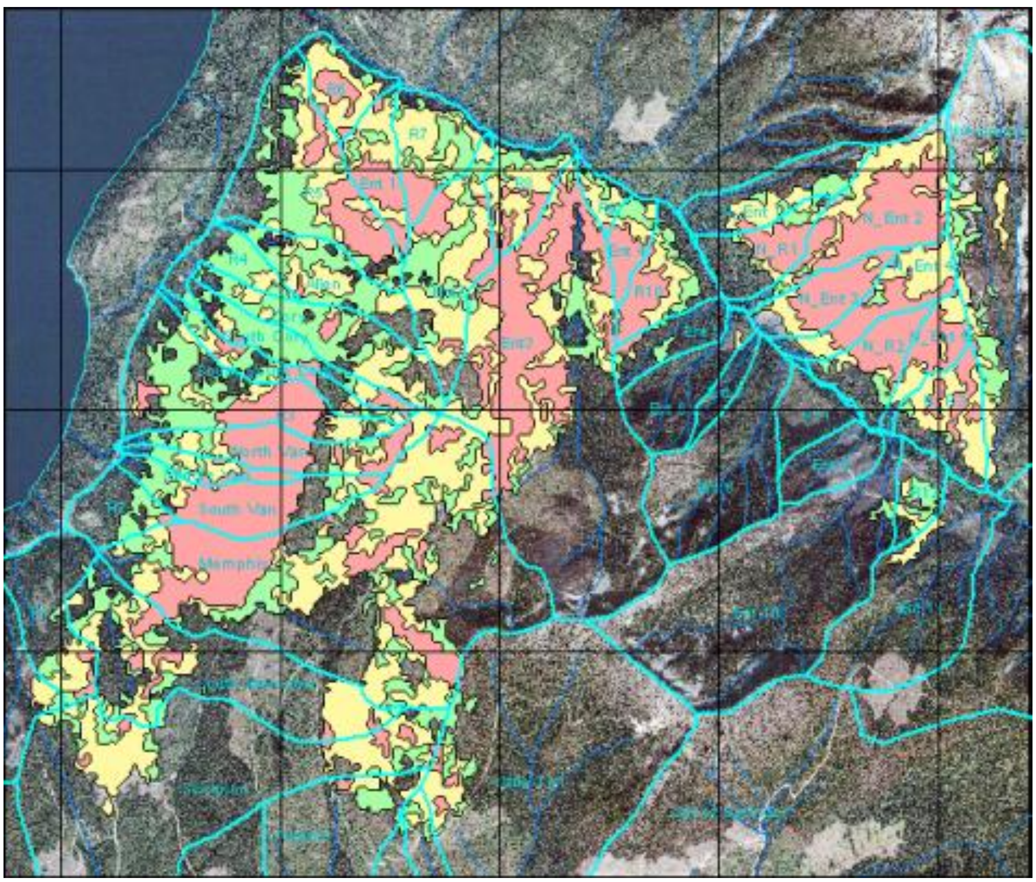

Figure 3 BARC Fire Severity Map (MFR)

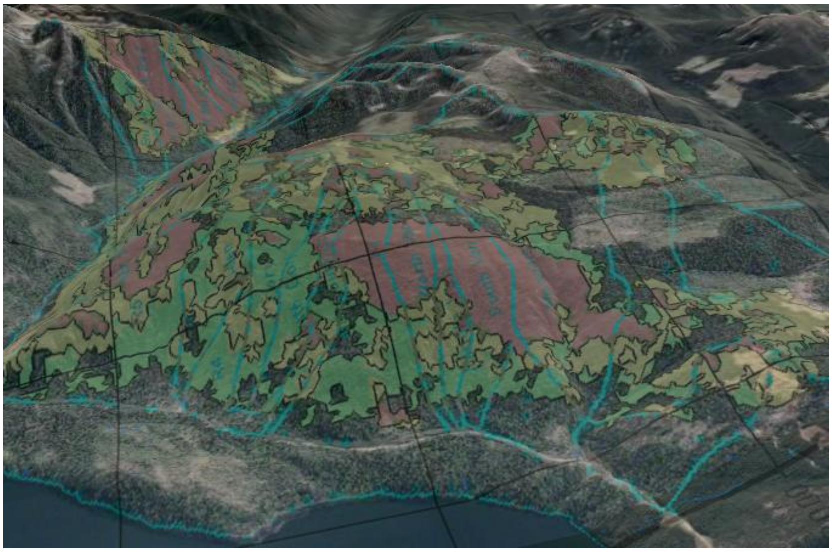

Photo 8 BARC Fire Severity overlay onto 3-d terrain model

A summary of the watershed areas and the burn severity percentages from the BARC mapping is shown in Table 3.

Table 3 Drainage unit areas and burn severity percentages from the BARC mapping

Watershed	Total Area Hectares	% High	% Mod	% Low	% Unburned
Ent 1	48.8	45%	43%	11%	1%
Ent 4	26.8	58%	21%	18%	3%
N_Ent 4	61.1	44%	46%	3%	7%
N_Ent 5	38.5	58%	34%	1%	8%
N_Ent 2	122.5	60%	28%	3%	9%
Ent2	109.2	17%	47%	27%	9%
Middle Van	26.0	36%	31%	23%	10%
North Van	80.3	51%	25%	13%	11%
R7	62.1	17%	43%	29%	11%
R8	51.7	24%	48%	16%	12%
N_Ent 3	50.5	67%	18%	2%	13%
South Cory	48.1	16%	16%	52%	16%
South Van	86.0	56%	11%	16%	18%
R6	42.8	27%	51%	4%	18%
R9	16.1	8%	50%	23%	19%
Cory	90.8	4%	28%	46%	22%
Allen	70.3	1%	32%	42%	24%
South South Cory	44.5	22%	25%	27%	26%
R5	158.1	21%	22%	29%	28%
N_R3	66.4	24%	44%	4%	28%
R10	61.5	33%	23%	16%	28%
R3	139.6	24%	15%	30%	31%
N_R2	54.0	50%	8%	7%	35%
Memphis	538.7	19%	28%	14%	38%
R4	38.5	0%	11%	48%	40%
N_R1	56.1	33%	10%	10%	46%
Ent3	474.2	28%	17%	5%	51%
South Memphis	210.5	8%	24%	12%	57%
R12	31.6	0%	13%	27%	60%
N_Ent 1	68.2	3%	22%	12%	63%

Watershed	Total Area Hectares	% High	% Mod	% Low	% Unburned
R2	43.1	3%	4%	21%	71%
R1	85.4	5%	15%	8%	72%
Ent 5	39.8	5%	3%	10%	81%
Scorpion	528.3	2%	11%	5%	83%
Spring_T2	57.8	0%	8%	6%	86%
Anglers	182.4	1%	4%	5%	91%
Bluff 1	89.7	0%	5%	2%	93%
Westmont	757.4	0%	3%	3%	93%
Little Tim	508.1	1%	3%	2%	94%
Ent 11	171.2	0%	4%	0%	96%
Ent 6	68.0	0%	2%	0%	98%
Ent 10	323.1	0%	0%	1%	99%
Spring_T1	83.9	0%	0%	1%	99%
Ent 7	18.8	0%	1%	0%	99%
Climax	270.1	0%	0%	0%	100%
Ent 8	146.9	0%	0%	0%	100%
Ent 9	43.3	0%	0%	0%	100%
R11	38.5	0%	0%	0%	100%
Spring_R1	157.7	0%	0%	0%	100%
Spring_R2	190.4	0%	0%	0%	100%
Spring_R3	235.1	0%	0%	0%	100%
Tobin	754.8	0%	0%	0%	100%
Upper Springer	2258.4	0%	0%	0%	100%
Total Area	**10025.7**	**8%**	**9%**	**6%**	**77%**

It is apparent from the above maps and tables that some of the drainages have high percentages of moderate and high burn severities. 17 of the drainage units have a combined moderate and high burn severity of greater than 50%. Wildfires that extensively cover a watershed and consume both upland and riparian sites create conditions conducive to severe hydrologic response (Ice 2003).

Short-term verses long-term Hazards

The short-term effects of wildfire includes increased overland flows as a result of the removal of protective forest floor cover and/or creation of a water-repellent layer formed as the waxes, lipids and other compounds vaporize and diffuse into the soil profiles where the compounds condense coating the mineral soil particles (Curran et al 2006). Overland flows can also be increased as a result of forest floor removal and exposure of mineral soil and ash creating conditions where rain-drop bombardment and splash can seal soil pores at the surface and the creation of a water-repellent layer that restricts infiltration and percolation, adding to surface runoff (Ice 2003). Normally, uncompacted/undisturbed forest soils have infiltration rates that exceed the rainfall intensities of even the most intense precipitation events (Ice 2003). Rothacher et al. (1967) tested several unburned forest soils in the Cascades and found most had infiltration rates exceeding 12.5 cm per hour which is much higher than expected extreme in rainfall events. However post wildfire conditions can be created whereby infiltration rates are much lower than high intensity rainfall events resulting in extreme overland flows.

In addition, the removal of organic obstructions to flow by wildfire can enhance the erosive power of overland flow, resulting in accelerated stripping of material from hill slopes. Increased overland runoff can erode significant volumes of material from slopes (sediment bulking) and channels and the net result is the transport and deposition of large volumes of sediment (Canon et al 2004). The short-term effects have been discussed and considered in Nicol et al 2007. The increase in overland flows can trigger debris flows which can be the most hazardous slope related outcome of burned hill slopes. They can occur with little warning, can exert great impulsive loads on objects in their paths, and even small debris flows can damage structures, and endanger human life (Cannon et al 2004). Two types of short-term post wildfire landslide triggers have been observed on fires within the Kootenays. They are short duration, high-intensity summer rainstorms and long duration frontal rainstorms which typically occur in fall or early winter. As noted above, one debris flow has already occurred within the Springer Creek burn area because of a short duration intense rainstorm. Other notable similar events were observed at Kuskonook 2004 and Lamb Creek 2004. Examples of landslides caused by the effects of a fire and triggered by a frontal rainstorm are Mt. Ingersoll near Burton in 2005 (2 years after the fire).

Another short-term hazard is rockfall initiation during and after the fire. Rock falls and rolling rocks were observed above Enterprise creek and are caused by the local loss of supporting root systems and forest floor. Falling trees can also cause local small scale rockfalls.

The long-term slope hazards relate to changes in the local hydrology as a result of an increase in snowmelt generated peak flows due to the loss of forest cover due to the fire. The increase in peak flows is caused by resulting elevated snow accumulations, more rapid snowmelt, and decreased evapotranspiration. The long-term effects exclude the influences of fire caused water repellency which are believed to diminish within 5 years. The long-term effects of wildfire can include reduced evapotranspiration losses, deeper snowpacks that melt earlier, increased water availability for replenishing soil and groundwater levels, increasing stream flows, and earlier and larger peak flows (Scott and Pike 2003). It can be assumed that the combined high and moderate severity burn areas are equivalent to a clear-cut condition with respect to the degree of reduced evapotranspiration and deeper snowpacks. However, the effects of wildfire on a watershed can be more prominent than timber harvesting because wildfire can affect large portions of a watershed in a short time, alter riparian areas, and expose large areas of mineral soil (Scott and Pike 2003). The soil may not fully recover its water storage capacity and erosion resistance within the first 5 years even though the effects of water repellency are no longer evident. The increase in runoff can persist for decades until full green-up of the forest canopy, which could take more than 30 years (Dobson Engineering Ltd 2006). Vegetative recovery will depend upon the characteristic of the plant species, ability to resist heat of the fire, recovery mechanisms, post –fire weather, animal use and plant competition; while seedling establishment will depend on the seedbed within the exposed mineral soil, the seed bank (buried, canopy, carried from offsite), and fire influence on seeds (Parminter 2005).

The long-term soil strength may be affected by a loss of root strength. Various studies have attempted to quantify the influences of root strength on slope stability and have estimated effective root strengths of from 1.6 kPa to 50 kPa (Buchanon and Savigny 1990, Wu et al 1979, and Roering et al 2003). It has been noted that disturbances such as forest fires alter the complex mosaic of vegetation (Roering et al 2003) and the strength effects it has on the slope. Understory vegetation (post wildfire) is expected to have lower root strength than a mixed forest (Buchanon and Savigny 1990). Ekanayake and Phillips 2002 noted that the effects of root strength force the critical shear plane deeper resulting in more soil resistance. The decrease in root strength following a fire is complex and will vary depending upon the tree species, tree density, size and extent of root systems, type and strength of soils, location of bedrock, and the time it takes for the reduction of root strength before re-vegetation occurs. The effect of the loss of root strength appears to be more significant in coastal climates than the interior based on the frequency of landslide occurrences following harvesting, however, the steep gully systems in the Springer burn area could also be sensitive to the effects of root strength loss. The loss of root strength may influence the slope stability within those drainage units that have moderate to high burn severities (trees are dead or are expected to die) and which are located on the steep slopes generally below the 1500m elevation such as Memphis, the Van Tuyl Creeks, R3, R5, and the Enterprise drainage units.

The long-term effects are considered hazards where they can negatively affect a value at risk. Potential hazards as a result of long-term fire effects include: flooding and erosion which includes landslides (debris flows, debris slides, and debris floods) and surface/channel erosion. Values that can be negatively affected are infrastructure (highway, homes, land, and utilities), public safety, water supply (quality and quantity), and the environment.

Another slope related hazard that can result from the effects of a fire are snow avalanches. Mature timber can add stability to a snowpack and can add protection downslope of avalanche initiation. In addition, the potential increase in snowpack and changes in melt rates can increase snow avalanche potential. Recommendation 8 from Nicol et al 2007 was "complete an avalanche risk assessment with regards to avalanche magnitude, frequency and potential impacts to Highway 6 and private land". It is understood that MOT has retained a consultant (Chris Stethem & Associates) who will complete this review by the end of March 2008. Snow avalanches will not be further discussed here other than to note that snow avalanches can effectively turn into mixed flows containing snow, timber, and debris as occurred at Ranch Ridge in 1988 (see Weir 2002) 30km northwest of the Springer Fire. At that location avalanches initiated within a clear-cut at about the 1300m elevation and deposited snow and debris onto Highway 6 at the 600m elevation. A debris flow subsequently travelled down the avalanche track during the spring freshet.

Completed Hazard Mitigation

Subsequent to the Springer Creek Post-Wildfire Risk Analysis (Nicol et al 2007), several hazard mitigation strategies to reduce short-term risks were implemented by MFR and MOT. MFR completed helimulch treatments of some of the moderate and high severely burned areas located on moderately steep slopes above identified elements at risk as per a hill slope soil mitigation treatments proposal by Curran et al 2007. The helimulch was applied by dropping bales of straw from helicopters. A map of the helimulch treatment areas is shown in Photo 9 and photos of the process of applying the mulch is shown in Photos 10 and 11.

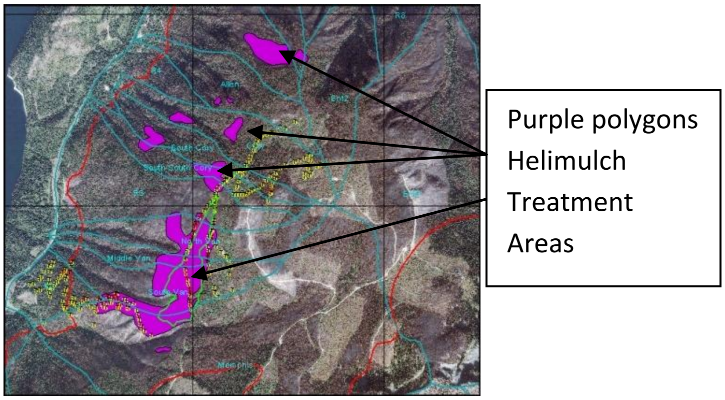

Photo 9 Helimulch Treatment Ares (from MFR)

Photo 10 Helimulch drop

Photo 11 Helimulch break up before grd impact

A study of the causes of the debris flows that occurred in 1990 (Curran et al 1990) made recommendations at that time regarding the deactivation of all the logging roads in the vicinity of the landslides. Several of these logging roads and trails were further reviewed on the ground during 2007 (post fire) to determine if additional drainage control was required in order to adequately disperse the additional overland flows anticipated. In addition some old mining roads and trails were also assessed. New machine cross-ditches were installed on some of the old roads while hand cross-ditches were installed in areas of poor access. Photo 12 shows the locations of newly installed road cross-ditches and hand placed trail cross-ditches.

The mitigation treatments were intended to address some of the increased hazards relating to the short-term wildfire effects. While the additional cross-ditching on the roads and trails will reduce the potential for long-term water diversions, the influence of the helimulching on the long-term hazard is not anticipated to be significant.

To date MOT has widened the ditch below drainage units R6 and R7 to improve rock fall catchments, has replaced a culvert at the Ent 1 creek crossing, has installed 2 new overflow culverts in the Van Tuyl Creek crossings, and has created additional debris flow storage capacity above the Van Tuyl creek crossings by removing over 1000m^3 of material.

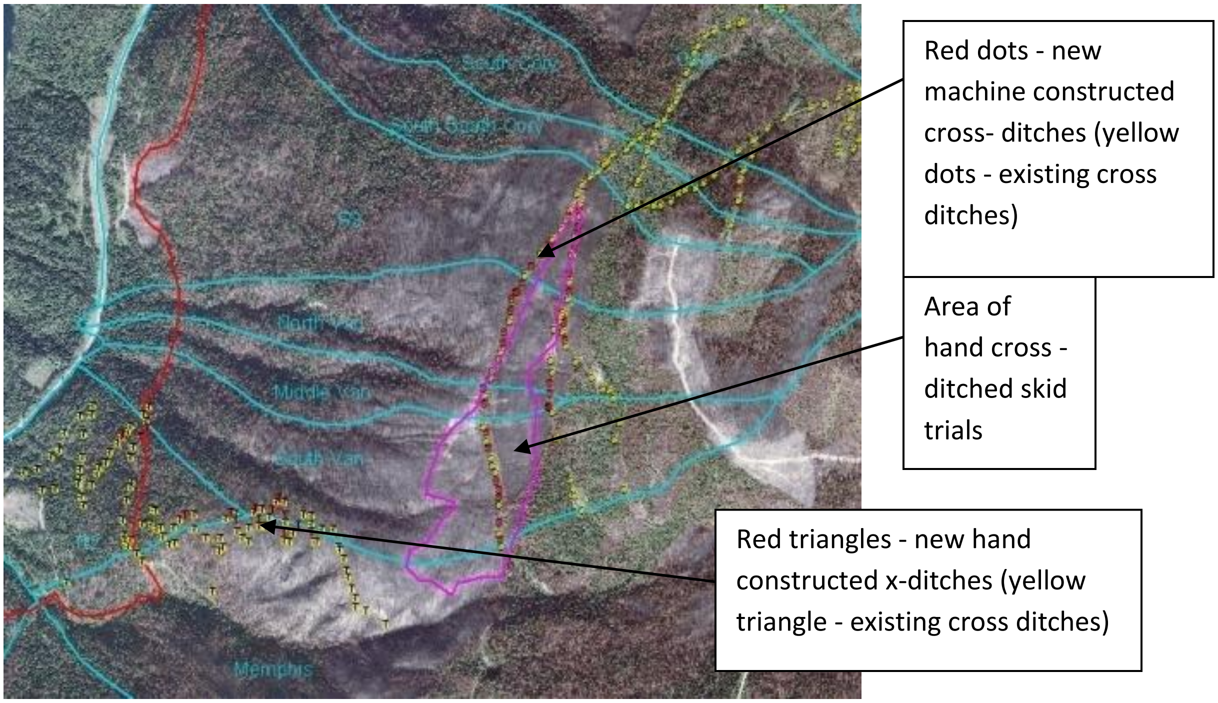

Photo 12 Location of road and trail works (from MFR)

Long-Term Hydrological Influences

It can be assumed that the combined high and moderate severity burn areas are equivalent to a clear-cut condition with respect to evapotranspiration and snow accumulation, and that snowpacks in areas affected by wildfire will behave similarly to snowpacks in clear-cut areas and melt earlier in the year (Scott and Pike 2003). Removal of forest vegetation through harvesting or wildfire may increase peak flows by generating greater snow accumulations, reducing sublimation, and accelerating snow melt. Snow accumulation in clear-cuts has been shown to be greater than snow accumulation in mature and juvenile forest (Winkler et al 2005). In the West Kootenays snow accumulation has been shown to increase by 30% over mature forest with a change in snow depletion dates of up to 14 days (Toews and Gluns 1986). Snowmelt rates in a forest at high elevation sites have been shown to be 2/3rds of the snow melt rate (up to 40mm/day) in a clear-cut (Spittlehouse and Winkler 2004). An increase in peak flow above natural levels can cause channel de-stabilization, flooding, increased erosion, and decreased water quality. The effects of harvesting on peak flow can depend on the runoff synchronization from snowmelt between various elevation bands. A numerical simulation by Schnorbus and Alila (2004), using Distributed Hydrology-Soil-Vegetation Model (DHSVM) and data from Redfish Creek (30km southeast of Springer Fire) found that the degree of increased synchronization was greatest following harvesting above the H_{60} (the elevation of which 60% of the watershed is above). The modelled change in peak flows was sensitive to the amount of area harvested and elevation of harvesting and was not sensitive to peak flow return periods. Harvesting below the H_{60} elevation did not have a significant impact on the peak discharge magnitude regardless of the harvest area whereas harvesting above the H_{60} had a significant effect.

The DHSVM model was used by Schnorbus et al 2004 to model 241 Creek northeast of Penticton (located 140km to west of Springer Fire) which is a 480 hectare watershed with an elevation range of 1600m to 2025m. The model correlated the percentage of a watershed area cut to the percentage increase in daily peak flow. The DHSVM was compared with field measurements of creek hydrographs, snow accumulation and melt rates, rainfall interception, tree transpiration, and differences in soil moisture. The results of the study indicated that the changes in daily peak flows (as a result of harvesting) vary depending on the return period and percentage of watershed cut. Some sensitivity was observed to the elevation of the harvesting with increasing changes in the higher elevations (see Figure 4). When 50% of the watershed is harvested, changes in daily peak flows ranged from 7 to 23% depending on the return periods. For 100% harvesting changes in peak flows ranged from 36 to 47%.

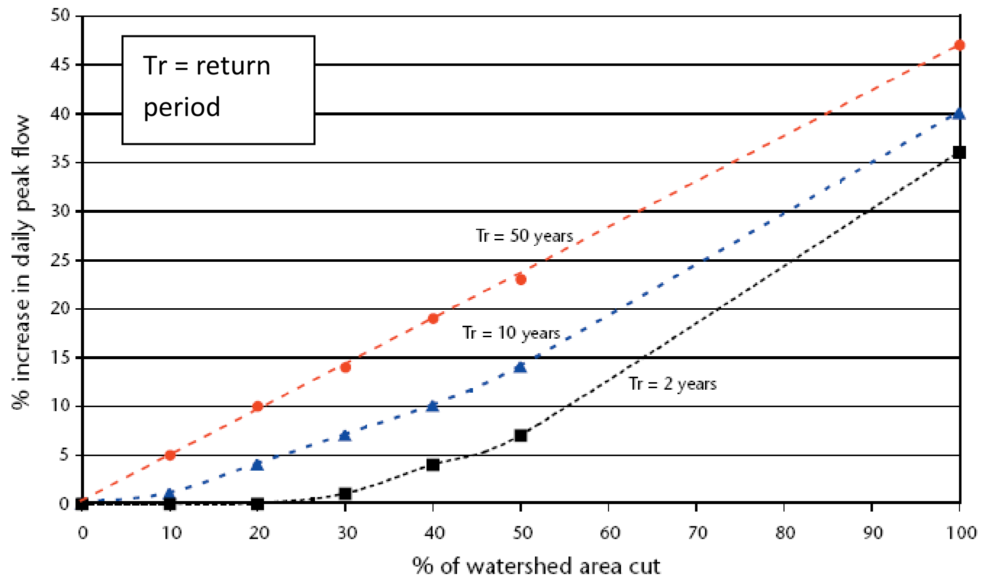

Figure 4 From Schnorbus et al 2004

The results of the study suggest that even with 100% clear cutting of the drainage the change in peak flows are limited to below 50%.

Jordan and Gluns (2007) estimated the effects on peak flows of a 2007 fire on the Sitkum Creek drainage (located 22 km to the southeast of Springer Fire). The Sitkum Creek Fire perimeter covered 39% of the drainage (26 km^2 drainage) and the area covered by moderate and high burn severities represents 21% of the drainage area. Jordan and Gluns (2007) estimated that the peak flows in the main stem could increase from 10 to 20% as a result of this burn.

The Springer burn area combines some of the attributes from both of the Redfish Creek and 241 Creek study areas. The drainage sizes are better represented by the 241 Creek study area, while the location, hypsometric curve, and elevation range are better represented by Redfish Creek. In the Springer Creek Fire the burn severity varied from one watershed unit to another; however, much of the burn area was located at or near the top of the watersheds i.e. above the H_{60}. It is likely that the increase in peak flows within the drainage units will be sensitive to both the location of the burn (above the H_{60}) and the return period. Some of the watershed units experienced very high proportions of moderate and high burn severities (above 90%) which may result in peak flow changes of up to 50%.

For the 55 drainage units within the Springer Fire burn area, the sum of the area of high and moderate BARC burn severity was determined along with the area of previous harvesting. A total Equivalent Clear-cut Area (ECA) was estimated and was factored using relationships developed by Schnorbus et al (2004) to estimate the increase in peak flows for 10 year and 50 year return period events (results are shown in Table 4).

Table 4 Estimated changes in peak flows

Watershed Unit	Watershed Area (Hectares)	M+H [1]burn severity (Hectares)	M+H burn severity (%)	Additional ECA [2]from harvesting (outside of M&H) (Hectares)	Total Post fire ECA %	H60	Estimated Average elevation of M&H burn severity	10 year Tr % increase peak flow	50 year Tr
Ent 1	48.8	42.9	88%		88%	1160	1200	34%	44%
Ent 4	26.8	21.2	79%		79%	1164	1270	30%	40%
N_Ent 4	61.1	54.8	90%		90%	1568	1650	35%	45%
N_Ent 5	38.5	35.3	92%		92%	1593	1630	36%	46%
N_Ent 2	122.5	107.6	88%		88%	1802	1850	34%	44%
Ent2	109.2	69.7	64%	6	69%	1486	1420	25%	35%
Middle Van	26.0	17.4	67%		67%	1118	1320	24%	34%
North Van	80.3	60.9	76%	6	83%	1337	1640	32%	42%
R7	62.1	37.2	60%		60%	938	1000	20%	30%
R8	51.7	37.2	72%		72%	984	1146	26%	36%
N_Ent 3	50.5	43.0	85%		85%	1230	1350	33%	43%
South Cory	48.1	15.1	31%	3	38%	1261	1775	10%	19%
South Van	86.0	57.5	67%	9	77%	1374	1500	29%	39%
R6	42.8	33.3	78%		78%	814	940	29%	39%
R9	16.1	9.4	58%		58%	966	1050	19%	29%
Cory	90.8	28.7	32%	13	46%	1596	1750	12%	23%
Allen	70.3	23.8	34%	8	45%	1363	1460	11%	23%
South South Cory	44.5	20.6	46%	6	60%	1278	1620	20%	30%
R5	158.1	68.2	43%		43%	902	1200	11%	22%
N_R3	66.4	45.5	69%		69%	1269	1400	24%	34%
R10	61.5	34.1	55%		55%	1126	1330	18%	28%
R3	139.6	54.5	39%	5	43%	978	1600	11%	21%
N_R2	54.0	31.2	58%		58%	1238	1400	19%	29%
Memphis	538.7	254.9	47%	86	63%	1692	1600	22%	32%
R4	38.5	4.5	12%		12%	761	1180	3%	6%
N_R1	56.1	24.5	44%		44%	1118	1350	11%	22%
Ent3	474.2	210.4	44%	54	56%	1685	1500	18%	28%
South Memphis	210.5	66.0	31%	58	59%	1334	1500	19%	29%
R12	31.6	4.2	13%		13%	1242	1370	3%	7%
N_Ent 1	68.2	17.0	25%		25%	1317	1400	6%	12%
R2	43.1	3.3	8%		8%	798	1080	2%	4%
R1	85.4	17.1	20%		20%	905	1230	5%	10%
Ent 5	39.8	3.5	9%		9%	1296	1550	2%	4%
Scorpion	528.3	68.0	13%	56	23%	1308	1550	6%	12%
Spring_T2	57.8	4.6	8%		8%	1522	1900	2%	4%
Anglers	182.4	8.2	4%		4%	1571	1800	1%	2%
Bluff 1	89.7	4.8	5%		5%	1056	1220	1%	3%
Westmont	757.4	25.6	3%		3%	1992	1800	1%	2%

Watershed Unit	Watershed Area (Hectares)	M+H [1]burn severity (Hectares)	M+H burn severity (%)	Additional ECA [2]from harvesting (outside of M&H) (Hectares)	Total Post fire ECA %	H60	Estimated Average elevation of M&H burn severity	10 year Tr % increase peak flow	50 year Tr
Little Tim	508.1	17.9	4%		4%	1844	1960	1%	2%
Ent 11	171.2	6.1	4%		4%	1660	1550	1%	2%
Ent 6	68.0	1.3	2%		2%	1481	1124	0%	1%
Ent 10	323.1	0.4	0%		0%	1835		0%	0%
Spring_T1	83.9	0.0	0%		0%	1368		0%	0%
Ent 7	18.8	0.1	1%		1%	1337		0%	0%
Climax	270.1	0.0	0%		0%	890		0%	0%
Ent 8	146.9	0.0	0%		0%	1671		0%	0%
Ent 9	43.3	0.0	0%		0%	1366		0%	0%
R11	38.5	0.0	0%		0%	1192		0%	0%
Spring_R1	157.7	0.0	0%		0%	1004		0%	0%
Spring_R2	190.4	0.0	0%		0%	1357		0%	0%
Spring_R3	235.1	0.0	0%		0%	986		0%	0%
Tobin	754.8	0.0	0%		0%	1616		0%	0%
Upper Springer	2258.4	0.0	0%		0%	1735		0%	0%
Enterprise	10500	870	8.3%					2%	4%
Springer	5250	98.7	1.9%					0.5%	1%

[1]From BARC map

[2] Previous harvested areas estimated and it was assumed that blocks had, as yet, had no hydrological recovery

Influences on Slope Stability

Between Memphis and Allen Creeks much of the slope below the 1500m elevation has been mapped as Terrain Stability Class IV and V (Deschenes 1997-98 and Banting 1996 – see Figures 5 and 6). Thirty landslides have been mapped between Memphis Creek and Enterprise Creek. Many of these events can be attributed to harvesting and road influences related to the concentration and diversion of surface water.

The influence of increased groundwater pressures in contributing to landslide initiation has been well documented. Increases in surface flows can influence the location of the local phreatic surface (location of the top of the unconfined ground water table) resulting in landslide initiation and the increased flows can result in local channel scour which can initiate in-channel debris flows. The required rise in the phreatic surface in order to initiate a landslide, or the degree of scour required in order to initiate a debris flow are both highly variable and depend on many factors including: slope geometry, soil strength, soil permeability, depth to bedrock or layers of low permeability, root strength, preferential drainage paths, and existing channel deposits. Because of the complex relationship (and number of variables) between increases in surface flows and landslide initiation, it is not possible to accurately predict the increases required in surface flows to initiate a landslide. Instead, an attempt is generally made to restrict ECA's in areas of high hazards and consequences. Some guidelines have been established that propose to limit the ECA above slopes mapped as Class IV or Class V. An example is the 1996 Forest Practices Code Community Watershed Guidebook that recommended restricting the ECA to 20% above Class V slopes within community watersheds.

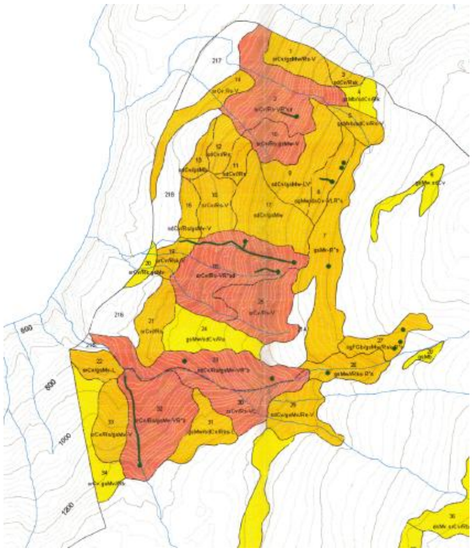

Figure 5 Terrain stability mapping Deschenes 1997

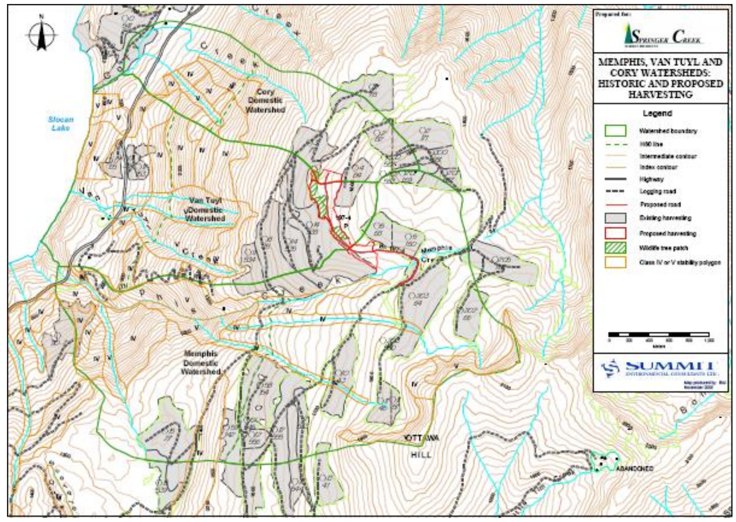

Figure 6 Terrain stability mapping polygons from SEC 2005 and Banting 1996

The terrain mapping reflects the general shape of the slopes within the Springer Fire boundary in the vicinity of Memphis, Van Tuyl and Cory Creeks. The slopes are generally steep (60% to 80%) from 700m to 1500m (coinciding with the mapped Class IV and V terrain). Above the 1600m elevation the slopes flatten to 30%. The area above the slope break is generally above the H_{60} and the historical harvested areas have also been located within these more gently sloped areas. In addition, the centroid of the combination of the moderate and high burn severities is generally above the H_{60} elevation and is often within 100m of the slope break. Thus all of the old harvesting is above the H_{60}, much of the severely burned area is above the H_{60} and most of the Class IV and Class V slopes are located at and below the H_{60} resulting in their exposure to the potential increased surface flows and increased groundwater pressure. As noted earlier, the estimated increase in peak flows for each drainage unit are shown in Table 4 and are based on the increase in ECA's for the entire drainage unit to account for possible synchronization effects. These increases in peak flows resulting from increases in surface and subsurface flows may, for most years, fall within the range of natural climatic variation. However during more extreme climatic events (events that may only occur once every 20 years) the additional surface and subsurface flows may exceed those required to initiate slope instabilities. In particular, with higher anticipated snowpacks and faster snowmelt rates due to the loss of forest cover, the likelihood of having locally saturated soil conditions adjacent to the receding snowpack is higher at the time that an extreme climatic event occurs.

Hazard Determination

Long-term slope hazards that require consideration include open slope debris slides, debris flows (originating either within channel or via a debris slide) and debris floods that have the potential to either run out onto the highway, impact utilities or infrastructure, or threaten public safety. The potential changes in surface flows, overland flows and peak flows are considered in relation to the potential for these to affect slope stability. While peak flows have been linked to snowmelt above the H_{60} elevation, local changes in surface flows are more likely controlled by the adjacent receding snowpack. In-channel debris flow initiation is most sensitive to changes in peak flows while debris slides are more influenced by local changes in surface and subsurface flows. However debris flow initiation can also occur as a result of a debris slide into a confined channel. Thus the potential for debris flow initiation can increase as a result of both an increase in peak flows and in increase in local runoff. Event triggers would typically include extreme rain on snow events, high snowmelts rates following extended warm weather, and long duration rainfall events.

While it is not possible to accurately quantify the increase in potential slope instability, it is possible to qualitatively provide an indication of the increased hazard. Jordan (2002) summarized West Kootenay landslide frequency based on terrain attributes and found landslide densities averaged 0.15/km^2 (the study areas included all visible slides which would include slides which occurred up to 30 years ago). Jordan also found that landslide frequencies were 6 times higher in areas that had forestry development (.32/km^2 verses .05/km^2). The existing landslide frequency between Memphis and Allen Creeks is an order of magnitude higher than the average summarized by Jordan, likely due to the combination of steep slopes and historical upland development (forestry and mining). As discussed in the completed hazard mitigation section, the old roads and trails that may have contributed to some of these events were assessed post-fire and additional drainage control structures were constructed by MFR in the fall of 2007 to accommodate the additional anticipated overland flows.

The anticipated changes in hydrology due to the fire are expected to last several decades which coincides with the time period for which slide occurrence was included in the Jordan study. This may have the effect of extending the previous decade's elevated landslide frequency rate (1 to 2 per km^2) for the next several decades. If the fire had not occurred, it would be expected that over the next several decades, the landslide frequency would drop to levels more in line with the other areas reviewed in the study. The effects of the fire are incremental to this background hazard. The estimated hazards and risks are considered over the expected life of the hydrological influences and have not been normalized to a yearly basis.

For each drainage unit, a hazard matrix was used to estimate the qualitative incremental hazard as a result of the effects of the fire. An example of the matrix is shown in Table 5 and it is noted that Table 5 is not a risk matrix, but rather an incremental hazard matrix that was used to qualitatively superimpose hydrological influences onto terrain hazard. Terrain stability mapping is generally intended to describe terrain hazards in response to conventional harvesting practises (road, trail and logging practices). Where terrain stability mapping was available, Class IV was considered moderate, Class V high, and everything else low. Where mapping was not available the terrain stability was estimated with the use of air photos and satellite imagery. The hydrological influences were defined as very low - where the 50 year peak flow is estimated to increase less than 5%, low - between 5 and 15%, moderate - between 15 and 30%, and high for peak flow increases greater than 30%. The existing harvested areas were included as they can have an incremental influence on the peak flows.

Table 5 Hydrological and terrain stability hazard matrix

Total Incremental Hazard[1]		Hydrological Influences			
Terrain Stability		VL	L	M	H
	L	VL	VL	L	M
	M	VL	L	M	M-H
	H	VL	M	M-H	H

[1] VL = very low, L = low, M = moderate, M-H is a transitional zone between moderate and high, and H = high

It should be noted from Table 5 that where the hydrological influence is low the incremental hazard is independent of terrain stability and remains very low. A hazard rating of very high was not utilized in the hazard matrix as the hazard levels still have to be multiplied by the consequences to arrive at a risk level and the use of very high hazard levels tend to skew the risk results. The compilation and use of the hazard matrix is subjective. The primary purpose of the matrix is to describe the hydrologic hazard in the context of the background terrain hazard. The results of the hazard analysis are shown in Table 6. In some cases a modifier was used to adjust the hazard because of additional unique attributes of the drainage unit.

Table 6 Estimated hazard levels

Watershed Unit	Hydrological Influence	Terrain Stability Influence	Hazard
Ent 1	H	M	M-H
Ent 4	H	M	M-H
N_Ent 4	H	H	H
N_Ent 5	H	H	H
N_Ent 2	H	H	H
Ent2	H	H	H
Middle Van Tuyl	H	H	H
North Van Tuyl	H	H	H
R7	H	M	M-H
R8	H	M	M-H
N_Ent 3	H	M	M-H
South Cory	M	H	M-H
South Van Tuyl	H	H	H
R6	H	M	M-H (modified to M)
R9	M	M	M
Cory	M	H	M-H
Allen	M	H	M-H (modified to M)
South South Cory	H	H	H
R5	M	H	M-H (modified to M)
N_R3	H	M	M-H
R10	M	M	M
R3	M	M	M (modified to L-M)
N_R2	M	M	M
Memphis	H	H	H
R4	L	M	L
N_R1	M	M	M
Ent3	M	H	M-H
South Memphis	M	H	M-H
R12	L	M	L
N_Ent 1	L	M	L
R2	VL	*	VL
R1	L	M	L
Ent 5	VL	*	VL
Scorpion	L	H	M (modified to L)
Spring_T2	VL	*	VL
Anglers	VL	*	VL
Bluff 1	VL	*	VL
Westmont	VL	*	VL
Little Tim	VL	*	VL
Ent 11	VL	*	VL
Ent 6	VL	*	VL
Ent 10	VL	*	VL
Spring_T1	VL	*	VL
Ent 7	VL	*	VL
Climax	VL	*	VL
Ent 8	VL	*	VL
Ent 9	VL	*	VL
R11	VL	*	VL

Watershed Unit	Hydrological Influence	Terrain Stability Influence	Hazard
Spring_R1	VL	*	VL
Spring_R2	VL	*	VL
Spring_R3	VL	*	VL
Tobin	VL	*	VL
Upper Springer	VL	*	VL
Enterprise	VL	*	VL
Springer	VL	*	VL

* Where the hydrological influence is very low the terrain stability does not influence the incremental hazard

Elements at risk

The expressions of specific value of risk and partial risk (from Wise et al 2004) are as follows:

Specific Value of Risk = R(SV) = P(H) x P(S:H) x P(T:S) x V(L:T) x E[1]. Partial Risk = P(HA) = P(H) x P(S:H) x P(T:S). Partial Risk is the probability of occurrence of a specific hazardous landslide and the probability of it reaching or otherwise affecting the site occupied by a specific element. It does not take into account the vulnerability or worth of the element (as does Specific Value of Risk).

In order to determine the specific value of risk a determination of the vulnerability and element worth must be made. Elements at risk that are considered as part of this review are human safety (local residents, users of the highway), linear infrastructure (highway), and local private property (residences). The public safety of local residents and the travelling public along Highway 6 is considered of significant value and therefore has been assigned a high consequence value. The risk to other infrastructure (power lines, fibre optic cables etc) was not specifically considered as the risk is site specific to pole locations, depth of burials and other factors and would require more site specific consideration.

Travelling public and Highway Infrastructure

When assessing the risk to the travelling public consideration must be given to the likelihood of a vehicle being caught in the landslide or colliding with the landslide debris given that the landslide reaches the highway. This has been discussed in Bunce et al 1997 and Hungr et al 1999 and depends on the landslide width corridor, the highway speed, site visibility, traffic volume and vehicle length. For the Springer corridor adjacent to the burn, the likelihood of a vehicle being impacted by a large landslide, given a landslide reaches the highway, is estimated in the order of 0.02 and events that occur at night and in wet weather (which is often the case) can expect to have high impact rates i.e. vehicles driving into the debris on the highway. Thus the combined impact probability is conservatively estimated in the order of 0.1. The vulnerability $V(L:T)_{\text{human life}}$ of a person in a vehicle could be estimated at 0.5 for a vehicle hit by a landslide (adopted from Wong et al 1997) with a lower vulnerability for vehicles colliding with debris on

[1] P(H) is the probability of occurrence of a specific hazardous landslide
P(HA) is the probability of occurrence of a specific hazardous landslide and the probability of it reaching or otherwise affecting the site occupied by a specific element.
P(S:H) is the probability that there will be a spatial effect, given that a specific hazardous landslide occurs.
P(T:S) is the probability that there will be a temporal effect, given that there is a spatial effect.
V (L:T) is a measure of the robustness of the element and its exposure to the landslide
E is the worth of the element.

the highway. The temporal and vulnerability probabilities with regards to the highway users is believed to be high enough that R(SV) is not significantly smaller than P(H:A) and therefore P(H:A) can then be used to describe the risk to highway users.

Given the initiation of a landslide the determination of partial risk to highway infrastructure depends on the spatial exposure of the highway to the hazard. The overall convex nature of the slopes results in debris flows, once initiated, travelling all the way to the highway with some smaller debris slides stopping on the flatter slopes above the highway. An evaluation of the likely potential highway damage and associated repair costs would be required in order to determine the specific risk to highway infrastructure. Instead the partial risk was estimated and is summarized in Table 7.

Table 7 Estimated long-term risk to travelling public and partial risk to highway infrastructure

	Risk to Travelling Public	Partial Risk to Highway Infrastructure
Bluff 1	L	L
R1	L	L
Memphis	M	M
R2	L	L
South VanTuyl	H	H
Middle Van Tuyl	H	H
North Van Tuyl	H	H
R3	L-M	L-M
South South Cory	H	H
South Cory	M-H	M-H
Cory	M-H	M-H
R4	L	L
Allen	M	M
R5	M	M
R6	M	M
Ent 1	M-H	M-H
R7	L-M	L-M
Enterprise	L	L

The high risks shown in Table 7 are associated with the debris flow prone gullies located adjacent to the highway. As noted above, in order to mitigate the short term risk MOT has widened the ditch below drainage units R6 and R7 to improve rock fall catchments, has replaced a culvert at the Ent 1 creek crossing, has installed 2 new overflow culverts in the Van Tuyl Creek crossings, and has created additional debris flow storage capacity above the Van Tuyl creek crossings by removing over 1000m^3 of material (see Photos 13 and 14).

MOT should review the long-term risk analysis and determine if additional risk reduction is required and is feasible. Additional MOT related risk reduction strategies could include the construction of check-dams, installation of additional overflow culverts, creation of depositional areas, terminal walls, and debris strains (includes trash racks), and installation of highway notification signage.


Photos 13 and 14 Additional debris flow storage volume and new overflow culvert installation above highway near middle Van Tuyl Creek

The acceptability or tolerability of the highway risk level depends on many factors including the existence of similar or greater risk segments elsewhere. In addition, the risk to a highway user is cumulative over the length of a highway corridor and consideration must be given to the total risk exposure (Hungr and Wong 2007).

The risk analysis at Memphis Creek assumes that the volume storage above the highway is sufficient to provide adequate storage of a debris flow event. The culvert could still plug and result in a backup of water behind the fill resulting in overtopping of the fill and potential associated erosion. MOT has recently cleaned out the trash rack above the old highway culvert and the risk analysis assumes that the trash rack will continue to be periodically cleaned of debris. The risk at Memphis creek could be refined by more accurately comparing the storage volume with anticipated debris flow volumes and by assessing the erodability of the highway fill. It appears that much of the fill is coarse rock and as such this highway segment may not be prone to erosion.

Some of the subunits draining into Enterprise Creek have significant hazards (example Ent 1, Ent 2, Ent 3, Ent 4, N. Ent 2, N. Ent 3, N. Ent 4, N. Ent 5). The longer possible debris flow paths are located within Ent 3 (2.8km) and N. Ent 2. (2.2km). These channels could supply debris flow volumes in the range of 10,000m^3 to 40,000m^3 (based on methods in Vandine 1985 and Fannin and Rollerson 1993). At high creek flows, debris flows of these magnitudes could be attenuated downstream or could propagate as a debris flood. At lower creek flows a debris flow entering Enterprise Creek has a greater likelihood of temporarily damming Enterprise Creek. For large drainages (peak flows > 100m^3/s) debris flow peak flows can be 5 to 10 times the Q_{200} (200 hundred year return period peak flood flow) while the ratio can be even higher (40 times) for smaller (where peak flows are < 10m^3/s) drainages (VanDine 1985). Peak flows for debris flows within Ent 2, Ent 3, and N.Ent 2 could be in the order of 40 to 200m^3/s with the higher peak flows having more potential to propagate as a debris flood or result in damming of Enterprise Creek. Debris slides also have the potential to temporarily dam Enterprise Creek.

The peak daily flow at Enterprise Creek over the last 30 years was likely in the range of 45m^3/s based on data from Lemon Creek as a comparison (see Figure 8). Lemon Creek drainage is 180km^2 verses Enterprise Creek drainage of 110km^2. The design Q_{200} (200 year return period flood) for the new multi plate arched culvert was 64.7m^3/s (pers. communication Kent LaRose of McElhanney Consulting Services Ltd.). Given the design peak stream velocity of 3.1m/s and the cross sectional area of the arched culvert of 125 m^2, the culvert has several times the capacity of the Q_{200}.

Jakob and Jordan 2001 summarized measured or back-calculated peak discharge of debris flows and outburst floods in small streams of southern British Columbia relative to their Q_{200}. Their summary suggests that for streams that have a Q_{200} within 25% +/- of the Enterprise Creek Q_{200} that debris flow and outburst flood Q_{max} ranges from 2 to 4 times the Q_{200} (with an average of 2.8 times). Given the capacity of the new multiplate culvert is several times the Q_{200} it is likely of sufficient capacity to pass a potential debris flood or outburst flood. Floating organic debris (for example trees) and log jams could still get caught on the culvert inlet; however the 18m culvert span has the potential to pass much of the debris. A debris flood has the potential to erode the rip rap placed adjacent to the concrete pile cap; however the structure is founded on 600mm steel piles socketed into bedrock so significant removal of the structural fill on the outside of the culvert would have to be eroded before structural deformations in the road subgrade would occur.

While the likelihood of debris flows entering Enterprise Creek is considered high, the likelihood that they will be large enough to block Enterprise Creek, and/or initiate a debris flood and cause a blockage or breach at the highway is considered low.

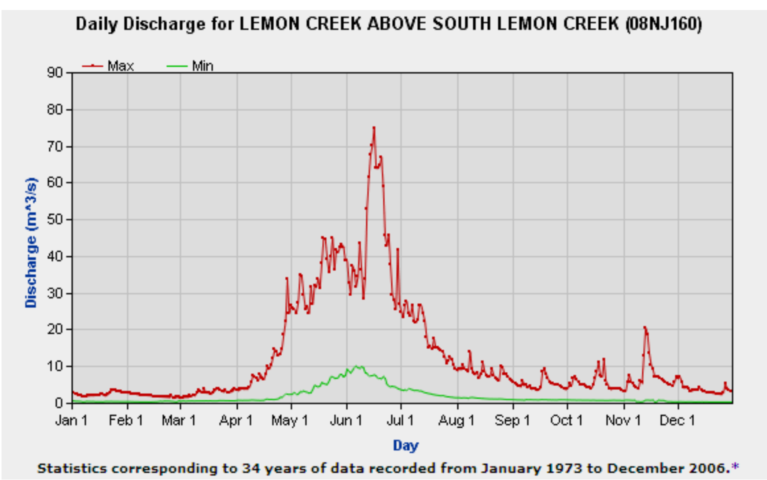

Figure 8 Lemon Creek daily discharge From Water Survey Canada

The drainage units draining to the south (into Springer Creek) i.e. Climax, Spring R1, Spring R2, Anglers, Spring T1, Spring T2, Little Tim and Upper Springer are all considered to have very low long-term hazards resulting from slope instabilities as a result of the fire with the exception of Scorpion which has a low hazard. Thus the resulting hazard to Springer Creek is very low.

Public Safety and Residences

The Regional District Central Kootenay (RDCK) Cadastral map (surveyed lot boundaries) with the BARC fire severity polygons is shown in Figure 7. Photo 15 shows the RDCK cadastral boundaries including mineral claims (dotted lines) overlain onto 3d imagery.

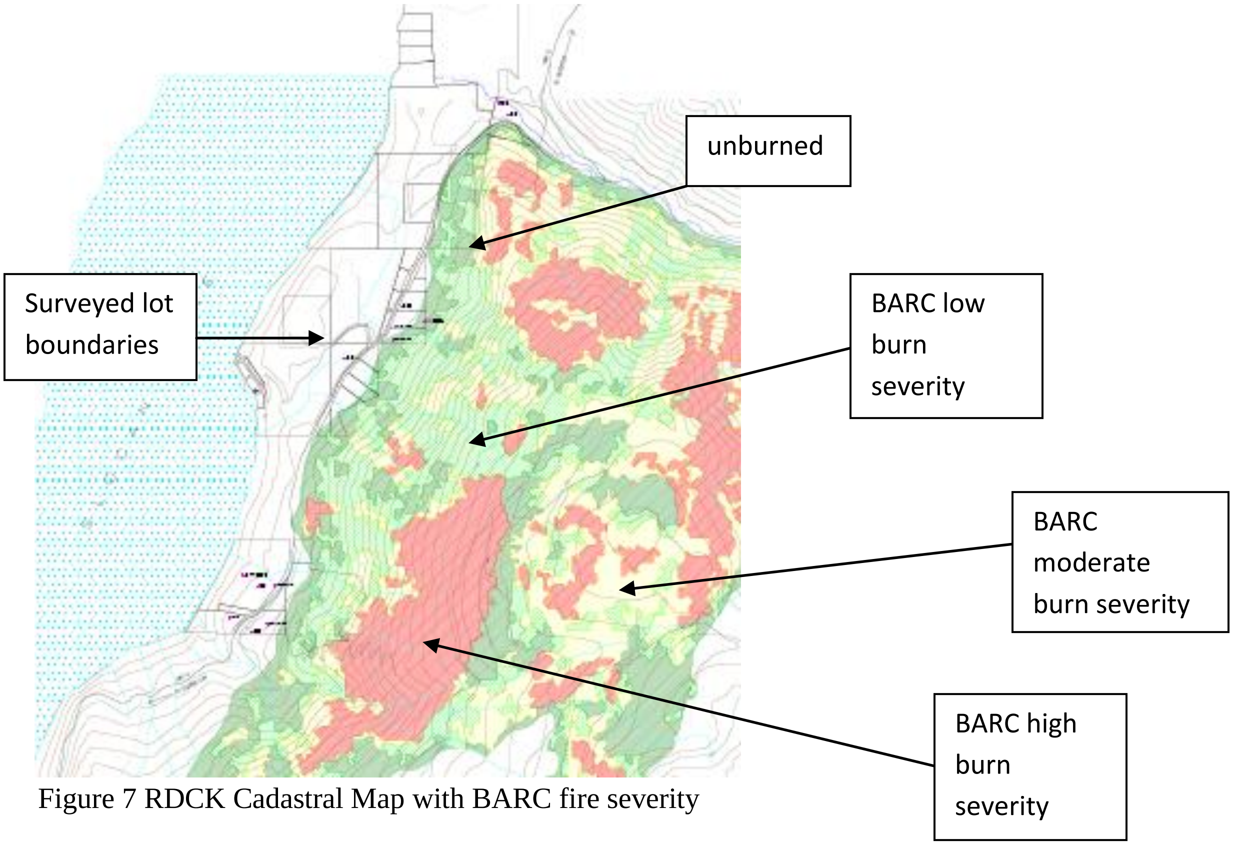

Figure 7 RDCK Cadastral Map with BARC fire severity

From Memphis Creek to Enterprise Creek (6.4km along the highway) most of the land adjacent to Highway 6 is private with the exception of a 200m segment at Memphis Creek, a 900m segment between Van Tuyl and Cory Creeks, and a 600m segment near Enterprise Creek. Known residences/houses adjacent to the highway include a couple of residences below the highway near drainage unit R6 (Lot L1011), 3 residences above the highway below R5 and Allen Creek (Lot 1023), one adjacent to the highway (below) at Cory Creek - Lot 6531 (although a camper and a potential building site were observed above the highway), a house below the highway south of South Van Tuyl Creek , 2 houses below the highway below unit R2, and one house above the highway within R2 (Lot 11722).

Photo 15 Cadastral overlay onto terrain Memphis to Enterprise Creeks

The partial risk to residents and private infrastructure considers the likelihood of hazard initiation and the spatial impact probability P(S: H) i.e. the location of the residences in relation to the potential hazard and run-outs. The vulnerability was not considered. The highest risks are associated with the debris flow prone gullies of Cory Creeks. Possible risk reduction strategies include the construction of check-dams, lateral walls, and deflection walls. A summary of the results are shown in Table 8. It is understood that Rick Rodman P.Eng. of Klohn Crippen Berger Ltd. is reviewing the downslope hazards and will be addressing development restrictions.

Table 8 Estimated long-term partial risk to public safety and infrastructure via residences

Location	Location	Partial Risk
Lot L1011	Below R6	L
Lot 1023	R5 and Allen Creek	M
Lot 6531	Cory Creeks	H
Lot 11722	Van Tuyl Creeks and R2	L

The 2007 Post –Wildfire Risk Analysis (Nicol et al) summarized the short-term (up to 5 years) risks associated with the effects of soil burn severity at and below the Springer Creek Fire and for many of the drainage units the risk to public safety and infrastructure was considered high. The partial risks shown in Tables 5 and 6 address the long-term risk (5 to 30+ years). While the annual probability of a landslide event is expected to drop after 3 years, the total exposure to the long-term hazard is greater (order of magnitude higher) due to the increased probability of an event occurring over the long-term. As a result, the long-term risks are also high for some of the drainage units reviewed and for the risks discussed.

Water quality issues

Although water quality was not considered as part of the risk review, wildfires can have effects on water quality directly initially through the introduction of ash and charcoal, and subsequently through changes in nutrient values, turbity and colour, and indirectly through the effects of erosion and landslides. Disturbance adjacent to riparian areas could affect water quality as riparian areas regulate stream temperatures, maintain stream bank integrity, supply large woody debris, and contribute nutrients, all of which are impacted by a fire. Water quality monitoring following a major wildfire in a community watershed in the East Kootenays indicated that these effects are minimal and within Canadian drinking water standards (Gluns and Toews 1989). In addition, wildfires and harvesting have the potential to influence both the peak flows and low flows. Low flows typically increase after harvesting (and by extension, wildfires), are highly variable, and rarely decrease in quantity. The longevity of the effects of harvesting (and wildfires) on low flows have not been well studied but are expected to coincide with re-vegetation which could take several decades (Pike and Scherer 2003). Similar effects are expected for burned areas.

Salvage Logging and Future Harvesting

Salvage logging can be part of an active management strategy after a fire. Some objectives of salvage logging may include slowing the build-up of insect populations, and removing fuel from the path of subsequent fires, both in addition to the obtained economic values. The removal of dead trees after a fire could reduce fuels and thus the intensity of fires that may occur in the future (Duncan 2002). 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). 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 Springer Fire the presence of 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 drainage units. For the reasons mentioned above, salvage logging should not occur within any drainage units assessed as having moderate to high hazards which includes the drainage units draining directly towards Highway 6 from Memphis Creek to R7 (with the exception of drainage units R2 and R4) and drainage units Ent 2, R8, Ent 3, R9, Ent 4, R10, N Ent 1, N R1, N Ent 2, N Ent 3, N Ent 4, N R2, N Ent 5, and N R3 unless a detailed drainage unit site assessment determines the burn severity, hazards, and risks are not as described and salvage logging can be conducted safely. The detailed drainage unit assessment must consider the access requirements, the ability to remove dead trees without impacting adjacent live trees or understory vegetation, the need to retain buffers along riparian areas and debris flow draws to allow for shade and long term large woody debris collection, and the long-term positive effects of fallen trees on sediment collection and forest floor regeneration. Drainage unit R3 is located above Highway 6 and was assessed as a low to moderate hazard. Although it does not require a detailed drainage unit site assessment for salvage logging, it is recommended that selective salvage logging in this drainage should occur only after the completion of a less detailed site assessment (than that described above) that considers the potential hazards and risks. The extent of salvage logging, if any, in the other drainage units must consider the potential impacts of the logging on slope stability and elements at risk.

Future forest development including harvesting, road construction or trail construction must consider the effects of the forest development in a cumulative respect with regard to the effects of the previous forest development and the more recent effects of the fire and potential salvage logging. It is recommended that forest development not occur in any of the following drainage units; R1 to R10 (inclusive) with the exception of R2 and R4, and N Ent 1 to N R3 (inclusive) until the hydrological recovery is such that it can be demonstrated that harvesting can be accomplished with little additional risk. This includes drainage units R1, South Memphis, Memphis, South Van Tuyl, Middle Van Tuyl, North Van Tuyl, R3, South South Cory, South Cory, Cory, Allen, R5, R6, Ent 1, R7, Ent 2, R8, Ent 3, R9, Ent 4, R10, Ent 5, N Ent 1, N R1, N Ent 2, N Ent 3, N Ent 4, N R2, N Ent 5, and N R3.

Until the appropriate hydrological recovery occurs, all maintained roads and trails located within these drainage units should continue to be actively maintained or deactivated.

Risk Reduction measures on Crown Forest

The long-term risks originating from the burned areas of the crown forest can be reduced through reforestation. While reforestation will occur naturally, the speed of reforestation can be accelerated through tree planting and will have the effect of reducing the long-term risks by improving hydrological recovery and root strength. The optimal species to replant will depend on many issues such as biodiversity, original stand, remaining live stand, insect vulnerability, future potential fires etc. These factors must be considered in addition to the hydrological and slope stability effects of having a quick growing and deeply rooted species. It is recommended that MFR pursue whether tree planting is practical and can be done safely in light of the potential risk reduction particularly for drainage units above the highway and residences (drainage units above Highway 6 from R1 to R7 inclusive) and should be considered in those areas where the tree density (taking into account expected tree mortality) is significantly less than the natural undisturbed forest density. The selection of species and spacing requirements should consider the speed of hydrological recovery and root structure and depth and their effects on slope stability (in addition to biodiversity, insect tolerance, future fire potential, etc.).

Existing Residences and Future Residential Development

The partial risk to public safety and infrastructure associated with existing residences was summarized in Table 8. Some of the sites have been described as having moderate and high partial risks. While Rick Rodman P.Eng. of Klohn Crippen Berger Ltd. is reviewing the downslope hazards and will be addressing potential development restrictions, the implementation of risk reduction measures for existing exposed residents is warranted. Private residence risk reduction could be accomplished with the construction of check-dams, lateral walls, and deflection walls.

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). Residential developments, in order to proceed, must be accepted by the Approving Authority which is either a Subdivision Approving Officer, a Building Inspector, Planner, or local government Council. The Subdivision Approving Officer for the areas adjacent to or within the burn area is the Ministry of Transportation while building permits and inspections are approved and conducted by the regional district.

Given the history of landslides and the recent fire, the area adjacent to the highway from drainages R1 to R7 would likely require a landslide assessment in order for residential development to be approved. A qualified professional conducting the landslide assessment must compare the results of the analysis with a level of landslide safety (APEGBC 2006). Presently the Regional District of Central Kootenay and MOT do not have a defined level of landslide safety. Often without defined levels of landslide safety, professionals conducting the landslide assessments compare their analysis with previous MOT references to 10% in 50 years (or 1 in 475). It is anticipated that at least for the next few decades, the likelihood of landslides exceeds this level of safety for many of the creeks, draws and slopes between drainage units R1 and R7 inclusive. Whether the potential landslides would result in partial risks that are unacceptable will 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. Alternatively the RDCK and/or MOT could consider adopting a defined level of landslide safety.

Before any proposed residential development is approved adjacent to the highway from drainages R1 to R7 and/or extending up Enterprise Creek, it is recommended that a landslide assessment be conducted consistent with the guidelines produced by APEGBC 2006, and that the professional conducting the assessment be familiar with the landslide history and the possible short-term and long-term effects of the recent fire (and possible future fires).

Summary and Recommendations

Expected changes in the local hydrology as a result of the fire due to the loss of forest cover has increased the long-term landslide hazards which have the potential to either run out onto the highway, impact infrastructure, or threaten public safety. Event triggers include extreme rain on snow events and high snowmelts rates following extended warm weather.

While the annual risks due to landslides as a result of the fire effects on forest hydrology are expected to decrease after 3 years, for many of the drainage units the risk to public safety and infrastructure are still considered high after 3 years, because the total exposure (number of years) to the long-term hazard is greater (order of magnitude higher). The qualitative risk to highway infrastructure and public safety (travelling public and residences) has been summarized. The risk to other infrastructure (power lines, fibre optic cables etc) was not specifically considered as the risk is site specific to the infrastructure (example individual pole locations).

South South Cory, South Cory, Cory, Ent 1, South Van Tuyl, Middle Van Tuyl, and North Van Tuyl drainage units have an estimated high or moderate to high partial risk to the travelling public and highway infrastructure while the South South Cory, South Cory, Cory Creek drainage units have an estimated high partial risk to local residents.

Recommendations to reduce and manage these risks are as follows:

1. The long-term hazards and risks should be communicated to local residents, landowners, stakeholders, local government, PEP, and MOT.

2. Consideration should be given by the following agencies and stakeholders to the implementation of available risk reduction measures as follows:

MFR

On the crown forest, reforestation is a risk reduction measure. While reforestation will occur naturally, the speed of reforestation can be accelerated through tree planting and will have the effect of reducing the time period the long-term hazards remain elevated above background levels by improving hydrological recovery and root strength. As such it is recommended that MFR determine where planting is practical and where it can be accomplished safely in light of the potential risk reduction particularly for drainage units above the highway and residences (drainage units above Highway 6 from R1 to R7 inclusive) and tree planting should be considered in those areas where the tree density (taking into account expected tree mortality) is significantly less than the natural undisturbed forest density. The selection of species and spacing requirements should consider (in addition to biodiversity, insect tolerance, future fire potential, etc.) the desire to restore hydrological recovery as soon as possible. Existing active roads and trails located within the drainage units above Highway 6 from R1 to R7 should be appropriately maintained or deactivated (see Recommendation 5).

MOT

To date, in response to the short term risk analysis, MOT has widened the ditch below drainage units R6 and R7 to improve rock fall catchments, has replaced a culvert at the Ent 1 creek crossing, has installed 2 new overflow culverts in the Van Tuyl Creek crossings, and has created additional debris flow storage capacity above the Van Tuyl creek crossings by removing over $1000m^3$ of material.

MOT should review the long-term risk analysis and determine if additional risk reduction is required and is feasible. Additional MOT related risk reduction strategies could include the construction of check-dams, installation of additional overflow culverts, creation of depositional areas, terminal walls, and debris strains (includes trash racks), and installation of highway notification signage.

Local residents, PEP, RDCK

Given the moderate and high long-term partial risk to some residents, the implementation of risk reduction measures is warranted. Private residence risk reduction could be accomplished with the construction of check-dams, lateral walls, and deflection walls.

Other Infrastructure Stakeholders

Owners of power lines, poles, and fibre optic cables should review the location of this infrastructure in relation to the hazards to determine if additional risk reduction measures are warranted.

3. While there are benefits associated with salvage logging, the presence of 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 drainage units of the Springer Fire. In order to minimize the potential incremental risk, salvage logging should not occur within any of the drainage units listed below unless a detailed drainage unit site assessment determines the burn severity, hazards and/or risks are not as described and salvage logging can be conducted safely. The detailed drainage unit assessment must consider the potential positive effects of leaving the timber on site, (including potential effects relating to snow avalanches), the access requirements, the ability to remove dead trees without impacting adjacent live trees or understory vegetation, the need to retain buffers along riparian areas and debris flow draws to allow for shade and long term large woody debris collection, and the long-term positive effects of fallen trees on sediment collection and forest floor regeneration:

> South Memphis, Memphis, South Van Tuyl, Middle Van Tuyl, North Van Tuyl, South South Cory, South Cory, Cory, Allen, R5, R6, Ent 1, R7, Ent 2, R8, Ent 3, R9, Ent 4, R10, N Ent 1, N R1, N Ent 2, N Ent 3, N Ent 4, N R2, N Ent 5, and N R3.

Selective salvage logging could occur in drainage unit R3 contingent upon the completion of a less detailed site assessment (than above) that considers the potential hazards and risks. The extent of salvage logging, if any, in the other drainage units must consider the potential impacts of the logging on slope stability and elements at risk.

4. Before any proposed residential development is approved adjacent to the highway below drainage units located from R1 to R7 inclusive and extending up Enterprise Creek, it is recommended that a landslide assessment be conducted, by the proponent, consistent with the guidelines produced by APEGBC 2006, and that the professional conducting the assessment be familiar with the landslide history and the possible short-term and long-term effects of the recent fire. The RDCK and/or MOT may consider adopting a defined level of landslide safety or natural hazard safety.

5. In order to minimize the potential changes in the local hydrology due to the loss of forest cover and the potential hydrological effects of roads and trails, future forest harvesting, road construction, or trail construction should not occur within the following drainage units until such time as it can be shown that soil and hydrological recovery is such that harvesting can be accomplished with no significant additional risk: drainage units R1, South Memphis, Memphis, South Van Tuyl, Middle Van Tuyl, North Van Tuyl, R3, South South Cory, South Cory, Cory, Allen, R5, R6, Ent 1, R7, Ent 2, R8, Ent 3, R9, Ent 4, R10, Ent 5, N Ent 1, N R1, N Ent 2, N Ent 3, N Ent 4, N R2, N Ent 5, and N R3.

   Until the appropriate hydrological recovery occurs, all maintained roads and trails located within these drainage units should continue to be actively maintained or deactivated.

Acknowledgements

The author would like to thank Ashley Covert of MFR who provided many of the GIS maps and data. In addition the author would like to thank Rick Rodman of Klohn Crippen Berger, Jim Guido MFR Operations Manager of the Arrow Boundary District, Dave Gluns MFR Regional Hydrologist, Daryn Yonin of MOT, and Ed Hadikin of Springer Creek Forest Products for their input, reviews, and comments.

Closure, Report Use and Limitations

This report was prepared for the BC Ministry of Forests and Range, Southern Interior Forest Region. The material in it reflects D.R. Nicol Geotech Engineering Ltd's (NGE's) best judgment and professional opinion in light of the information available to it at the time of preparation. Any use which a third party makes of this report or any reliance on or decision made based on it are the responsibility of such third parties. NGE accepts no responsibility for damages, if any, suffered by any third party as a result of decision made or action based on this report.

The report and analysis has been carried out in accordance with generally accepted practice in B.C. with respect to natural hazard investigations (and specifically the analysis of wildfires and their influence on slope stability). The discussion and recommendations presented above are based on limited field investigation and inferences from surficial features. Shallow test pits and road cuts were examined - no further subsurface investigation was carried out as part of this assessment or development of conclusions or recommendations. Variability in surface and subsurface conditions may create unforeseen situations.

Report prepared by:

Doug Nicol, P.Eng.
Principal, D.R.Nicol Geotechnical Engineering Ltd.

Report reviewed by:

Mike Curran, PhD., P.Ag.
Ministry of Forests and Range
Southern Interior Forest Region

Peter Jordan, PhD., P.Geo.
Ministry of Forests and Range
Southern Interior Forest Region

References:

Anonymous. 1999. Watershed Assessment Procedure Guidebook. 2nd ed., Version 2.1. Forest Practices Branch, Ministry of Forests, Victoria, BC. Forest Practices Code of British Columbia Guidebook.

Anon., 2007. Standard Operating procedure Management of Increased Risk from Natural Hazard Events following Wildfires. Draft discussion paper, BC Ministry of Forests and Range, Southern Interior Forest Region, February 2007.

Anon., 2007. Policy Framework Post-Wildfire Erosion Hazard Assessment and Risk Management. Draft discussion paper, BC Ministry of Forests and Range, Southern Interior Forest Region, February 2007.

Association of Professional Engineers and Geoscientists of British Columbia 2006. Guidelines for Legislated Landslide Assessments for Proposed Residential Development in British Columbia.

Banting Engineering Ltd. 1996. Detailed Terrain Stability Map - TSIL "C" - Van Tuyl Area. Report prepared for Slocan Group, Slocan Division. November 1996.

Beschta, R.L., C.A. Frissel, R. Gresswell, R. Hauer, J.R. Karr, G.W. Minshall, D.A. Perry, and J.J. Rhodes. 1995. Wildfire and salvage logging: recommendations for ecologically sound post-fire salvage logging and other post-fire treatments on federal lands in the west. Oregon State University. Corvallis.

Buchanon, P., Savigny K, 1990. Factors controlling debris avalanche initiation. Can. Geotech J. 27, 659-675

Bunce, C.M., D.M. Cruden, and N.R. Morgenstern.1997. Assessment of the hazard from rock fallen a highway. Canadian Geotechnical Journal 34: 344–356

Cannon, S.H., Gartner, J.E., Rupert, M.G., and Michael, J.A. 2004 Emergency Assessment of Debris-Flow Hazards from Basins Burned by the Cedar and Paradise Fires of 2003, Southern California U.S. Geological Survey

Curran, M., Chow, B., Toews, D., Boyer, D., 1990. Landslide Study – Cape Horn Bluffs Area Detailed Report for the Ministries of Forests and Environment.

Curran, M.P., Chapman B., Hope G.D., and Scott D., 2006. Large-scale Erosion and Flooding after Wildfires: Understanding the Soil Conditions BC Ministry of Forests and Range, Technical Report 030.

Curran M, Springer Fire N50372: Erosion Risk Mitigation Options and Hillslope Soil Mitigation Treatments Proposal September 2007

Deschenes, M., TSIL B Terrain Mapping 1:20,000 1997-98

Duncan, S. 2002. Postfire logging: Is it beneficial to a forest? USFS PNW Res Stn Science Findings 47**.**

Dobson Engineering Ltd., 2006. Risk Assessment of Post –Wildfire Natural Hazards Draft report prepared for BC Ministry of Forests and Range, Southern Interior Forest Region, February 2006.

Dobson Engineering Ltd., 2006. Rationale for Post-Wildfire Risk Assessments for BC Draft report prepared for BC Ministry of Forests and Range, Southern Interior Forest Region, February 2006.

Ekanayake J.C., Phillips, C.J. 2002. Slope Stability thresholds for vegetated hillslopes. Can. Geotech. J. 39: 849-862

Fannin, R.J & Rollerson, T.P. 1993 Debris flows: physical characteristics and behavior. Can Geotech J.30:71-81

Fell, R., Ho, K.K.S., Lacasse, S., and Leroi, E. 2005. A Framework for Landslide Risk Assessment and Management. Proceedings of the International Conference on Landslide Risk Management, Vancouver, Canada. May 31 to June 3, 2005. Hungr, Fell, Couture and Eberhardt (eds).

Gluns, D.R. and Toews, D.A.A. 1989. Effect of a major wildfire on water quality in southeastern British Columbia., P487-499. In Woessner, W.W. and D.F. Potts (eds.) Symp. Proc. on Headwaters Hydrology , Amer. Water Resour. Tech. Publ. Series, TPS-89-2. 708p.

O. Hungr, O., Evans, S.G., and Hazzard, J. 1999 Magnitude and frequency of rock falls and rockslides along the main transportation corridors of southwestern British Columbia. Can. Geotech. J. **36**: 224–238

Hungr, O., Wong, H.N., Landslide Risk Acceptability Criteria: Are F-N Plots Objective. Geotechnical News V: 25 No. 4 PP 47-50 2007

Ice, G. 2003. Effects of Wildfire on Soils and Watershed Processes Paper presented at the Conference on Post-Fire Restoration & Salvage Harvesting: Applying Our Knowledge and Experience.

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

Jordan, Peter, 2002. Landslide Frequencies and Terrain Attributes in Arrow and Kootenay Lakes Forest Districts. In Jordan, P. and J. Orban (editors). 2002. Terrain stability and forest management in the Interior of British Columbia: workshop proceedings, May 12-15, 2001 Nelson, B.C.

Jordan P., Curran, M., and Nicol, D. 2004. Debris flows caused by water repellent soil in recent burns in the Kootenays. Aspect, 9(3): 4-9. Division of Engineers and Geoscientists in the Forest Sector, Association of Professional Engineers and Geoscientists of B.C.

Jordan P., Turner K., Nicol D., and Boyer D., 2006. Developing a Risk Analysis Procedure for Post-Wildfire Mass Movement and Flooding in British Columbia. Canadian Society for Civil Engineering, 1st Specialty Conference on Disaster Mitigation, Calgary, May 23-26, 2006.

Jordan P, Glunns D, Sitkum Creek Fire, 2007, N70347 Post-Wildfire Risk Analysis September 2007.

Klohn Crippen Berger, Draft report - Post Wildland Fire Hazard Assessment - Springer and Sitkum Creek Fires for Provincial Emergency Program February 2008

Leroi, E., Bonnard, Ch., Fell, R., and McInnes, R. 2005. Risk assessment and management. Proceedings of the International Conference on Landslide Risk Management, Vancouver, Canada. May 31 to June 3, 2005. Hungr, Fell, Couture and Eberhardt (eds).

McRae, D.J., L.C. Duchesne, B. Freedman, T.J. Lynham, and S. Woodley 2001 Comparisons between wildfire and forest harvesting and their implications in forest management. Environ Rev. 9(4): 223-260

Miller, C., P.B. Landres, P.B. Alaback. 1999. Evaluating Risks and Benefits of Wildland Fire at Landscape Scales. In proceedings of Joint Fire Science Conference and Workshop: Crossing the Millennium: Integrating Spatial Technologies and Ecological Principles for a New Age in Fire Management.

Ministry of Forests – Forest Road Engineering Guidebook, 2002

Ministry of Forests –Hillslope Restoration in BC – November 2001

Ministry of Forests - Community Watershed Guidebook October 1996

Nicol D, Jordan P, Deschenes M, Springer Creek Fire Post-Wildfire Risk Analysis September 2007

Parminter, J**.,** Wildfire Effects on Ecosystems and Vegetation. Workshop: Post-wildfire Watershed Rehabilitation in BC Okanagan University College, Kelowna, BC - June 8, 2005

Pike, Robin G., and Rob Scherer, 2003. Overview of the potential effects of forest management on low flows in snowmelt dominated hydrologic regimes. BC Journal of Ecosystems and Management. Vol. 3, No. 1. http://www.forrex.org/jem/2003/vol3/no1/art8.pdf

Rothacher, Jack, C. T. Dymess, and Richard L.Fredriksen, 1967. Hydrologic and related characteristics of three small watersheds in the Oregon Cascades, 54 pp., U.S. Dep. Agr., Forest Serv.,Pac. Northwest Forest Range Exp. Sta.

Regional District of Central Kootenay 1:10000 Cadastral Map. Map sheet

Roering J.J., Schmidt K.M., Stock J.D., Dietrich, W.E., Montgomery, D.R. 2003. Shallow landslides, root reinforcement, and the spatial distribution of trees in the Oregon Coast Range. Can. Geotech. J. 40: 237-253

Satellite Imagery via Landsat 5 images, Quickbird Images, Google™ Earth, BC IMAPS, 2008 Europa Technologies, and 2008 Province of B.C. Imagery

Scott, D. and Pike, R. 2003. Wildfires and watershed effects in the southern B.C. interior. Streamline Watershed Management Bulletin, 7(3): 1-4.

Scott, D., Effects of Wildfire on Soil and Water – An Overview. . Workshop: Post-wildfire Watershed Rehabilitation in BC Okanagan University College, Kelowna, BC - June 8, 2005

Schnorbus, M., Winkler, R.D. & Y. Alila 2004. Modelling Forest Harvest Effects on Maximum Daily Peak Flow at Upper Penticton Creek. Extension Note 67. B.C. Ministry of Forests Science Program.

Schnorbus, M. and Y. Alila. 2004. Forest harvesting impacts on the peak flow regime in the Columbia Mountains of southeastern British Columbia: An investigation using long-term numerical modeling. Water Resour.Res. 40, W05205, doi:10.1029/2003WR002918.

Spittlehouse, D.L., Winkler, R.D., 2002. Modelling Daily Snowmelt in a Forest and Clearcut. Proceedings 25th conference on Agriculture and Forest Meterorology, Norfolk, Virginia

Spittlehouse, D.L., Winkler, R.D., 2004. Snowmelt in a Forest and Clearcut. 72nd Western Snow Conference.

Summit Environmental Consultants Ltd. 2005 CP197-4 (Cory, Van Tuyl, Memphis) Hydrologic Update Internal Report for Springer Creek Forest Products Ltd.

Summit Environmental Consultants Ltd. 2005 Springer Creek ECA Update. Internal Report for Springer Creek Forest Products Ltd.

Toews, D.A.A. and Gluns D.R. 1986. Snow accumulation and ablation on adjacent forested and clearcut sites in southeastern British Columbia. Proceedings of the 54th Western Snow Conference, Phoenix, Arizona. Pp. 101-111.

VanDine, D.F., 1996. Debris Flow Control Structures for Forest Engineering MOF Research Program

VanDine Geological Engineering Services, 1990. Geological Engineering Assessment of the Ottawa Hill Debris Torrents of May 1990. Unpublished report prepared for BC Ministry of Forests.

VanDine, D.F., 1985 Debris flows and debris torrents in the Southern Canadian cordillera. Can. Geotech. J. 22, 44-68 (1985)

Wu, T.H., McKinnell W.P., Swanston, D.N., 1978. Strength of tree roots and landslides on Prince of Wells Island, Alaska. Can. Geotech J. 16, 19-33

Weir, P. 2002. Snow Avalanche Management in Forested Terrain, BC Ministry of Forests, Land Management Handbook 55.

Wise, M.P., Moore, G.D., and VanDine, D.F. (eds.) 2004. Landslide Risk Case Studies in Forest Development Planning and Operations. BC Ministry of Forests, Land Management Handbook 56.

Winkler, R.D., Spittlehouse, D.L., Golding, D.L., 2003 Measured differences in snow accumulation and melt among clearcut, juvenile, and mature forests in southern B.C. Hydrological Processes

Wong, H.N., Ho, K.K.S., Chan, Y.C. 1997 Assessment of consequences of landslides. Landslide Risk Assessment, Cruden & Fell (eds).

Appendix A
Vegetation and Soil Burn Severity

Vegetation burn severity, or fire severity, refers to the effects of the fire on the forest canopy and understory. For this analysis, a preliminary severity map was prepared by taking oblique aerial photographs from a high altitude, identifying areas (or polygons) of high, moderate, and low severity on the photos, and transferring the polygons to a base map. The following classification is used (after Curran et al, 2006):

High – trees blackened and dead, needles consumed, understory consumed;

Moderate – Trees burned and dead, needles remain, understory mostly burned;

Low – Canopy and trunks partially burned, understory lightly or patchily burned.

A more detailed and accurate map of vegetation burn severity was also prepared from Landsat satellite imagery and BARC mapping.

Soil burn severity refers to the effects of the fire on soil hydrologic function and includes the removal of protective forest floor cover and/or the creation of a water-repellent layer. A water repellent layer can be formed when the forest floor is partially or totally consumed by wildfire. During combustion, the waxes, lipids, and other compounds vaporize and diffuse both into the atmosphere above the ground and into the soil profile where the compounds can condense when they reach a lower temperature, coating mineral soil particles (after Curran et al, 2006).

The following classification is used (after Curran et al, 2006):

High – forest floor consumed, mineral soil has altered porosity and structure;
Moderate – litter consumed; duff consumed or charred, mineral soil unaltered;
Low – litter scorched or consumed, duff and mineral soil unaltered.

Soil burn severity may, but not necessarily, be correlated with vegetation burn severity. In areas of high and moderate soil burn severity, the soil may be water repellent, increasing the likelihood of overland flow during heavy rain. Soil burn severity can only be determined by observations on the ground. For this analysis, two teams of 2-3 people spent two days doing ground traverses in the areas considered to be of greatest concern. Soil Burn Severity was assessed on a field form, using subjective ratings of six indicators: litter, duff, fine fuel, large fuel, mineral soil exposure, and presence/absence of live roots. Water repellency was assessed using the water drop penetration test: the mineral soil is exposed along a shallow trench, and water drops are applied at various depths. Strong repellency is present if the drops stay on the surface longer than 40 seconds.

A more detailed description of moderate and high soil burn severities is provided by Ice (2003) as follows:
Moderate soil burn severity. Moderate soil heating with moderate ground char; soil structure is usually not altered; decreased infiltration due to fire-induced water repellency4 may be observed; litter and duff are deeply charred or consumed; shallow light coloured ash layer and burned roots and rhizomes are usually present. Indicators include understory foliage, twigs (¼ to ¾ inch) are consumed; rotten wood and larger diameter woody debris are deeply charred or partially consumed; on shrubland sites, gray or white

ash is present and char can be visible in the upper 1 cm of mineral soil, but the soil is not altered; in forested ecosystems, brown needles or leaves may remain (but not always) on overstory trees—these are important as mulch, and should play a role when identifying treatment candidate sites; increase in runoff response may be moderate to high, depending on degree of fire-caused changes to the pre-fire vegetation community, density of pre-fire vegetation, and presence or absence of mulch potential, sprouting vegetation, etc.

(d) **High soil burn severity**. High soil heating, or deep ground char occurs; duff is completely consumed; soil structure is often destroyed due to consumption of organic matter; decreased infiltration due to fire-induced water repellency is often observed over a significant portion of the area; top layer of mineral soil may be changed in color (but not always) and consistence and the layer below may be blackened from charring of organic matter in the soil; deep, fine ash layer is present, often gray or white; all or most organic matter is removed; essentially all plant parts in the duff layer are consumed; increase in runoff response is usually high. Other indicators include large fuels > ¾ inch including major stems and trunks are consumed or heavily charred. On a shrub site, shrub stems and root crowns are often consumed. In forested ecosystems, generally no leaves or needles remain on standing trees; high soil burn severity areas are primary treatment candidate sites if there are downstream values at risk.