Sitkum Creek Fire, 2007, N70347
Post-Wildfire Risk Analysis

Prepared for BC Ministry of Forests and Range:
Southeast Fire Centre, Southern Interior Forest Region,
and Kootenay Lake Forest District

Assessment team:
Peter Jordan, P.Geo. (lead); David Gluns, R.P.F.;
Ashley Covert; Mike Curran, P.Ag.
Forest Sciences Section, Southern Interior Forest Region,
BC Ministry of Forests and Range, Nelson, BC

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Summary

The Sitkum Creek fire burned an extensive area in the upper portion of the Sitkum Creek drainage. The fire perimeter totals 39% of the watershed; areas of high and moderate vegetation burn severity cover 10 and 11% of the watershed respectively. High soil burn severity and water repellency are widespread in some areas, although not as abundant as in some other fires. Some small tributary drainages have high vegetation burn severity in up to 50% of their drainage area.

The most likely hazards to occur in the first 3 to 5 years following the fire are: increased streamflow from the burned area, especially during high-intensity summer rainstorms and long-duration fall rainstorms; soil erosion from the burned area; and debris flows in tributary streams. Possible debris flows in tributaries T1 and T2 have the potential to cause a debris flood in the main channel of Sitkum Creek, if they were to occur during a time of peak discharge, or temporarily block the flow of the main creek.

Sitkum Creek is a community watershed, and its fan is heavily developed. There are high risks to houses and the highway from flooding, debris floods, and possible avulsion of the creek channel. The risk of water quality impacts due to sedimentation of the creek is also high.

The following recommendations are made:

1. Information on the post-wildfire hazards and risks should be communicated to stakeholders, including local residents, landowners, and owners of the mine.

2. The 1990 study on alluvial fan hazards should be updated, to reflect changed hydrologic conditions in the watershed, as recommended by the authors. This should include further study and recommendations (if appropriate) on the return periods of floods on the Sitkum Creek fan, the capacity of the present channel and highway bridge to pass these floods and the associated debris, investigation of possible protective works or other improvement on the fan, and flood preparedness.

3. Mitigation treatments, such as aerial mulching, should be considered in the tributary watersheds of T1 and T2, to reduce the debris flow hazard in these drainages.

4. Deactivation of the Sitkum-Alpine road, from the bridge to the mine, should take place, to reduce the hazard of stream sedimentation due to debris flow or erosion events. (It is our understanding that deactivation prescriptions have been completed, and that work will begin soon.)

5. Reforestation should be considered as a treatment to promote hydrologic recovery in the burned areas.

6. A comprehensive watershed risk mitigation and restoration plan should be developed, including a communications plan, to ensure coordination of activities.

7. Consideration should be given to applying hydrologic models to assess the post-wildfire hydrologic changes to Sitkum Creek, and to produce better estimates of probable streamflow.

8. Streamflow and water quality on Sitkum Creek should be monitored for several years, or until substantial recovery of hydrologic processes in the watershed have occurred. Real-time monitoring of discharge should be considered, to assist in forecasting the occurrence of damaging floods.

9. The mill site and mine waste should be inspected for possible sources of contamination that might be affected by the fire or by post-wildfire flooding.

10. Burn severity mapping based on pre- and post-wildfire Landsat imagery should be completed. (This is now underway.)

11. Acquisition of high-resolution satellite imagery, or aerial photography, should be considered, to facilitate planning of reforestation or other rehabilitation activities in the watershed, and to facilitate monitoring of post-wildfire erosion events and recovery.

12. Rainfall, erosion events, revegetation, and the effectiveness of any mitigation treatments in the burned area should be monitored for several years, to assist with assessment or risks on the fan, and to improve our understanding of post-wildfire hydrologic processes.

Introduction and Objectives

The Sitkum Creek fire (number N70347) burned an area of about 1075 ha from July 27 to about mid-August. It occupies a large portion (about 39%) of the Sitkum Creek drainage, which is a community watershed. The alluvial fan of Sitkum Creek has considerable development, including many houses and Highway 3A.

Beginning in mid-August, a risk analysis of post-wildfire natural hazards in the Sitkum Creek fire was conducted by Southern Interior Forest Region staff. The objectives of the risk analysis were to:

- identify the consequences at risk;
- review relevant information on the affected area;
- identify and map watersheds affected by the fire;
- prepare a preliminary burn severity map;
- assess soil burn severity, and identify areas of water repellent soils ;
- assess the potential for increased overland flow and soil erosion in the burned area;
- evaluate the potential for increased runoff, and increased peak flows and sediment transport in Sitkum Creek;
- evaluate the potential for landslides, debris flows, and other natural hazards in and below the burned area;
- inspect roads and other development in and below the burned area, which might contribute to flood, erosion, and landslide hazards;
- conduct a risk analysis, and identify specific hazards that could affect the elements at risk;
- make recommendations.

Following a wildfire, the likelihood of landslides, erosion, and floods can increase. This can be caused by water repellent soils in areas of severe burn, by loss of forest canopy and forest floor interception capacity, and related factors. Several incidents of destructive events occurred following the 2003 wildfires in British Columbia, including the Kuskonook, Lamb Creek, Cedar Hills, Mt Ingersoll, and Okanagan Mountain Part fires. As a result of these incidents, a procedure was developed in the Southern Interior Forest Region for analysing post-wildfire risks. Further information on the causes of post-wildfire hazards, and on the analysis procedure, is given in Curran et al (2006) and Jordan et al (2006).

The recommended procedure for conducting post-wildfire risk assessments in British Columbia is outlined in Dobson Engineering Ltd (2006), and the procedure was substantially followed in this project.

The definitions and general framework for the risk analysis given in Wise et al (2004) were used. In particular, *risk analysis* is "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 analysis (unlike *risk assessment*) does not include determining whether a risk is acceptable or tolerable.

This risk analysis was conducted in a short time frame, beginning as soon as it was safe to do field work in the fire, in order to communicate risk information and recommendations to stakeholders in a timely manner. Therefore, some aspects of this analysis are preliminary, and some recommendations are made to do more detailed work in the coming months.

Methods

An aerial reconnaissance and preliminary mapping of burn severity was done on August 15-17. Ground traverses were conducted on August 23-24 to collect data on soil burn severity and water repellency. Some field work was done adjacent to the burned area, in the course of assisting Fire Centre staff in preparing rehabilitation plans. Additional field work was done inspecting the Sitkum Creek channel and fan, and tributary channels below the burned area.

Vegetation burn severity mapping

Vegetation burn severity, or fire severity, refers to the effects of the fire on the forest canopy and understory. For this assessment, 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 map is appended to this report. 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 can be prepared from Landsat satellite imagery. At present, a processed image has been obtained from the US Forest Service, but a final burn severity map has not yet been completed. The image shows very good correlation with the preliminary severity map.

Soil burn severity and water repellency – field methods

Soil burn severity refers to the effects of the fire on soil hydrologic function. 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 assessment, two teams of 2-3 people spent two days doing ground traverses in the areas considered to be of greatest concern. 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. Strong repellency is present if the drops stay on the surface longer than 40 seconds, over 70% or more of the trench.

Watershed boundaries

The boundaries of the Sitkum Creek watershed above the fan apex, as well as 14 tributaries in the area affected by the fire were identified on the 1:20,000 TRIM contour map, and digitized. These watershed boundaries and area may differ slightly from those reported elsewhere. Some of the tributary stream locations and watershed boundaries are uncertain, and should be confirmed in the field.

Risk analysis

A qualitative scale of High-Moderate-Low is used for rating hazard, consequence, and risk. At the simplest level, *risk* is the product of *hazard* (or probability of occurrence) and *consequence*. Consequence is a combination of spatial probability, temporal probability, and vulnerability. Further information on these concepts is given in Wise et al (2004) and Jordan et al (2006). Although the rating scale is subjective, there is general agreement amongst engineers and geoscientists in British Columbia, based on many past risk analyses and incident investigations, as to the meaning of the qualitative rating terms (see Wise et al, 2004, for more details and references). For this risk analysis, a simple risk matrix combining hazard and consequence is used (Figure 1).

Information reviewed

- air photos and orthophotos
- fire perimeter maps and other information in the Southeast Fire Centre database
- terrain stability map (see below), soil maps, and bedrock geology maps
- streamflow data for nearby watersheds
- research studies on the hydrology of nearby Redfish Creek
- mining claim status
- engineering study on alluvial fan hazards in the area (see below).

The Sitkum Creek watershed is covered by terrain stability mapping at TSIL B (Banting Engineering Ltd, 1996). This is useful for identifying areas subject to landslide and soil erosion hazards. The mapping uses the detailed system of terrain stability classification:

V – high likelihood of landslides; unstable
IV – moderate likelihood of landslides; potentially unstable
III – low likelihood of landslides; stable
II, I – very low likelihood of landslides; stable

A study of hazards on alluvial fans on the West Arm of Kootenay Lake, including Sitkum Creek, was done for the Regional District of Central Kootenay (Northwest Hydraulic Consultants Ltd, 1990). It includes detailed maps of the fan, a description of flood and debris flow hazards, and estimates of peak flows.

Description of the Sitkum Creek Watershed

The Sitkum Creek watershed covers an area of 27 km^2 on the north side of the West Arm of Kootenay Lake, about 15 km northeast of Nelson. Some summary information on the watershed is given in Table 1.

The upper 2/3 of the watershed, in the area affected by the fire, is a long, narrow, generally U-shaped valley, ranging in elevation from about 1300 m, to 2359 m on the alpine ridge at the head of the valley. On the west side of the valley, slopes are relatively gentle (mostly 20-60%), and are largely blanketed by glacial till. In steeper areas, soils are shallow, with bedrock-derived colluvium and frequent rock outcrops. A series of about 11 small, parallel, tributary creeks drains the west side of the valley. They are quite similar, with each one headed by a shallow cirque-like bowl. Most of the cirques contain areas of coarse blocky colluvium in their upper elevations, with little soil or vegetation. The middle and lower part of the drainages are covered with glacial till, and were heavily forested; most of this area has been burned. In the valley bottom, bordering Sitkum Creek, there are some deep deposits of ice-contact glaciofluvial material, which is quite erodible and has caused several small landslides along the road.

The east side of the valley, which was not burned, is much steeper (50-100%) and consists of a series of steep bedrock ridges and shallow gullies, with evidence of frequent snow avalanches and small debris flows.

The lower 1/3 of the watershed is a more confined, V-shaped valley. Below 1300 m, Sitkum Creek becomes steeper (12-15%) and flows in a narrow gorge, as it descends to Kootenay Lake. A large alluvial fan, about 40 ha in area, is at the mouth of the creek.

The entire watershed is underlain by granitic rocks of the Jurassic Nelson Batholith. Colluvial soils have coarse, sandy texture with a high content of angular stones. Soils derived from morainal and glaciofluvial deposits are loamy sand to sandy loam texture.

Most of the watershed is heavily forested. The upper valley, including the area of the fire, is mostly in the ESSFwc biogeoclimatic subzone, with a small area of ICHmw below 1500m, and alpine tundra on the high ridges above 2000m. The burned area was mostly balsam with a lesser amount of spruce, and a dense understory of rhododendron and vaccinium.

A road enters the valley from the southeast, crossing the creek on a bridge at 1310 m elevation, and continuing to an old mine at the head of the valley. It is narrow and rough, but has had some water barring and culvert replacement in the last 10 years or so and is currently in reasonably good condition. No logging has taken place in the upper valley, except for a small cutblock just east of the bridge. Most of the Sitkum Creek watershed is in the chart area of BCTS, who recently acquired it from Canfor. Other than some small-scale salvage logging, no significant forest harvesting was underway or planned in the watershed at the time of the fire.

Resources at Risk

The main elements at risk from possible post-wildfire hydrologic or mass movement events are:

- public safety, houses, and private land on the Sitkum Creek alluvial fan;
- the highway, bridge, secondary roads, and utilities on the fan;
- water quality in Sitkum Creek; and,
- the community water intake and other smaller water intakes on Sitkum Creek.

There are approximately 50 houses or similar buildings on the Sitkum Creek fan (from air photos, and the map in Northwest Hydraulic Consultants Ltd, 1990). Many of these houses are near the abandoned channels or points of potential avulsion noted in the above report, and so are considered to be vulnerable in the case of any flood which causes the creek to overflow its channel. Highway 3A crosses the creek by a bridge, at a point where the channel is of limited capacity and is not deeply incised, so this bridge and the adjacent highway are also considered to be vulnerable.

An old gold mine is located in the upper part of the Sitkum Creek watershed, including the ruins of the mill site which are in a low severity burn area. The immediate area of the mine and mill is covered by crown-granted claims, and some newer mineral claims. (Information on ownership of the crown-granted claims is not readily available at present.) To the best of our knowledge, no significant mining exploration or development work has been done for many years. The mill site is in a state of total ruin, and so is not considered to be a consequence at risk.

The road accessing the mine is also at risk of damage from post-wildfire runoff or mass movement. Deactivation works which have been prescribed to minimize sedimentation impacts to Sitkum Creek will also be effective at minimizing potential damage to the road.

Results of burn severity mapping and field checking

The preliminary vegetation burn severity map is shown in Figure 2. (A full-size version in paper or digital form is available on request.) The areas of high, moderate, and low vegetation burn severity are 270, 290, and 504 ha respectively. A summary of the burned areas as percent of watershed area for Sitkum Creek and its tributaries is given in Tables 1 and 2.

Two traverses were made through the burned area, in the north and south parts of the fire, and a total of 63 plots were measured. In the areas mapped as high vegetation burn severity, about 60% had high soil burn severity, and about 50% of sites had strong water repellency. This is a somewhat lower proportion than other fires we have examined this year (including the Springer Creek fire) and less than some of the 2003 fires (including Kuskonook). However, it is still a significant amount of severe soil burn, and it indicates that about half of the areas mapped as high vegetation burn severity may be subject to producing overland flow in a heavy rainstorm.

For areas of moderate vegetation burn severity, about 15 to 20% of sites had high soil burn severity and strong water repellency. Overland flow might occur in some of these areas, although it is likely to be mitigated by the patchy nature of the burn, and natural mulching by needle fall.

At many of the sites inspected on the field traverses, a thin crust of charred duff covers the mineral soil. A thin water repellent layer was found underneath this, at the top of the mineral soil. Possibly, this crust exists because the pre-fire duff layer was quite thick in most of the burned area. Also, soil moisture might have been relatively high in some areas, due to the high elevation and northeast aspect. The burned duff layer at Sitkum has some moisture storage capacity, and is a natural mulch which should protect the mineral soil from rain drop erosion and enhance infiltration. As a result, the amount of overland flow produced might be less than in severely burned areas in other fires where this duff crust is lacking, and it is possible that the water repellency effects of the fire might recover relatively quickly.

Hazards due to the burn

It is well established through research and experience that wildfire can result in significant changes to watershed hydrology and geomorphology. These can include (Scott and Pike, 2003; Cannon and Gartner, 2005; Curran et al., 2006):

- Combustion of the forest floor produces hydrophobic compounds which accumulate below the surface, resulting in a water repellent layer which inhibits infiltration and can produce overland flow during heavy rainfall;
- Loss of litter and duff by burning removes the water storage capacity which normally exists on the forest floor;
- The interception capacity of the forest canopy and understory shrub layer is removed;
- The vegetation and forest floor layers which protect the soil from raindrop energy are removed, exposing the underlying mineral soil to erosion;
- Loss of the forest vegetation results in less evapotranspiration, increased snow accumulation, and potentially higher groundwater levels.

The hydrologic changes include both short-term and long-term effects. The most severe effects are short-term, including flooding, erosion, and debris flows caused by surface soil hydrologic changes, including water repellency. Severity of effects depends on the extent of forest floor loss and water repellency, and also the extent of exposed mineral soil and depth of root kill. The short-term effects typically last for about 3 to 5 years. Long-term effects are similar to those of clearcutting. This risk analysis is primarily concerned with short-term effects.

<u>Flooding</u>

In burned areas affected by water repellency and other soil hydrologic changes, large amounts of overland flow can be generated. Forest soils normally have very high infiltration capacities, and overland flow due to high-intensity rainfall is rare, so this represents a significant change. The effect is most serious during dry conditions and high rainfall intensities (i.e. rainstorms in summer with dry antecedent soil moisture). The water repellency effects tend to become less with prolonged contact with wet snow and water in spring, so the effect is minimal during spring snowmelt.

Only a small portion of a watershed needs to have water repellent conditions in order for overland flow and flooding to occur, especially if it is located in the headwater area of a drainage. The Kuskonook Creek debris flow of 2004 occurred in a drainage in which only 15% of the area had high vegetation burn severity (although another 29% of the area was moderate). Several of the small tributary watersheds have over 40% high (and over 75% combined high and moderate) vegetation burn severity.

High-intensity summer rainstorms typically affect relatively small areas, so it is more likely that only one or several small tributaries would experience flooding. Discharge at the Sitkum Creek fan would be unlikely to reach peak flows levels from these events. However, frontal storms which can produce prolonged, moderate-intensity rainfall in October or November could produce extensive flooding over the entire burn area, especially if antecedent soil moisture conditions were dry, or it fell on early-season snow. Extreme peak flows on Sitkum Creek could be generated by such an event.

Soil erosion

Rainfall and overland flow in burned areas is likely to cause soil erosion. This will increase turbidity if eroded sediment reaches stream channels, and is a water quality concern. The effect should last only for a few years, until surface soil recovers, the water repellency breaks down and vegetation becomes established.

Debris flows

The most significant mass movement hazard due to the burn is debris flows in the gullies on the west side of Sitkum Creek. All ten of the small tributary streams have some debris flow potential, as they all have a steep lower channel below a severely burned headwater basin. All the streams have about 50% or more of their catchment areas occupied by high or moderate severity burn. Some of these streams have a higher debris flow hazard than others, due to more confined lower channels and more abundant debris sources in their watersheds.

All the streams were inspected at the points where they cross the road, or for the most downstream channels (T1 and T2), at their confluences with Sitkum Creek, and the results are summarized in Table 2. Streams T1, T2, T8, and T9 are considered to be high hazard due to evidence of past debris flows in their lower channels.

T1 and T2 are both debris flow prone gullies, and appear to have experienced small debris flows (several 100 m^3) about every 50 to several hundred years, and larger events (up to a few 1000 m^3) at less frequent intervals. Based on observations of the channel condition and debris deposits, it appears that neither gully has experienced a large debris flow in at least the last century. At the mouth of T2 there is a substantial area of old debris deposits, which confine Sitkum Creek against the left valley wall. This area would probably store most of the debris from small events, although a large event could enter the creek. T1 enters Sitkum Creek at a more confined location, and the creek steepens to about 18% for a short distance, immediately below the confluence. It appears that past debris flow events have blocked the creek at this location. There is a possibility that a large event in T1 could temporarily dam Sitkum Creek, causing a debris flood when it breaks, even at moderate or low flow conditions. A debris flow entering the creeks at either T1 or T2 could, if it occurred at peak discharge of the creek, generate a debris flood which could travel the length of the creek.

Tributary T0 is immediately south of the fire. It is a debris flow gully similar to T1 and T2. It is not affected by the burn, but contains some fireguards. These are not likely to contribute to the debris flow hazard if they are properly deactivated.

Channels T8 and T9 have experienced small (several 100 m^3) debris flow events recently. These buried or washed out the road, but do not appear to have reached Sitkum Creek. Although there is no evidence of recent events, the other six tributary channels all appear capable of carrying debris flows. It is likely that an event in any of the channels from T3 to T10 would deposit most of their debris on gentle slopes above the creek, or in the riparian zone adjacent to the creek. As Sitkum Creek flows in a relatively unconfined, low-gradient (7-8%) channel, it is unlikely that a debris flow from these tributaries would block the creek, or that the creek would carry a lot of coarse debris downstream in the short term. Debris flow events entering the creek in this low-gradient reach would cause water quality impacts, and could contribute coarse sediment which could affect channel stability by being carried downstream over a longer term (decades to centuries).

Likely maximum debris flow magnitudes, based on the length of channel, the apparent amount of debris which could be mobilized, and the volume of old deposits, are estimated to be about 3000 m^3 for T1 and T2, and about 1000-1500 m^3 for the other channels.

In summary, debris flows in the tributary gullies T1 and T2 may present a significant downstream hazard, due to their potential for adding large quantities of debris to Sitkum Creek, and possibly blocking the channel and generating a debris flood. Debris flows in other tributaries may occur, but are primarily a water quality concern.

Debris floods

Debris floods can occur when the entire channel becomes mobilized during a flood, resulting in very high transport rates of sediment and large organic debris. This can happen if an extremely high peak flow (for example, from breaking of a temporary dam) causes bank undercutting or erosion of normally-stable log jams or sediment accumulations in the channel. Debris floods can also be caused by a landslide or debris flow which enters the stream at a time of peak discharge; the sudden input of debris can result in the entire stream bed becoming mobilized. A local example of this was the Coffee Creek debris flood on November 1999. On Sitkum Creek, the most likely scenario which could cause a debris flood would be a debris flow from tributary T1 or T2 entering the channel during a major fall rainstorm when discharge is near its peak.

The likelihood of debris flows occurring in the main channel of Sitkum Creek which could reach the fan is very low, due mainly to the low slope of the channel (compared to the 20-40% slopes more typical of debris flow channels). On the Sitkum Creek fan (as well as other fans in the West Arm area) there are a number of large levée-like deposits of large boulders, which have sometimes been interpreted as debris flow deposits. On Sitkum Creek, the watershed size is much greater, and the channel gradient and fan gradient are lower, than streams which are typically capable of carrying debris flows. It is likely that these deposits have resulted from debris floods, which may have occurred during discharge events of very long return periods (such as 1000 years). On streams which originate in granitic rocks, it can be difficult to distinguish debris flow deposits from normal flood deposits. In considering risks on alluvial fans, the main difference between debris flows and debris floods is that the former can have peak discharges in the order of 10-100 times as great as streamflow floods, and are very destructive. Debris floods are not likely to have peak discharges much greater than “normal” floods; their main effect is that the large amount of sediment they deposit on the fan make it likely that avulsions (changes in stream course) will occur.

Landslides (other than debris flows)

Most of the area of the burn is mapped as terrain stability class III, with some areas of class IV on steeper slopes and in the gullies of several tributary streams. Some areas of class IV are found along the road in the first 1 km past the bridge, in deep glaciofluvial and morainal deposits, where several landslides have occurred in the past.

Landslides caused by overland flow or increased groundwater levels due to the burn are possible in two areas. The steep slopes above the road between creeks T6 and T11 lie below a large area of severe burn. Small debris slides could be triggered on these slopes by overland flow coming off the burned slopes, bute would likely stop on the road, or less likely, reach the riparian area bordering the creek. Along the first 1 km of road past the bridge, landslides originating in the road fill could be caused if the road intercepts surface or groundwater flow from slopes above. This hazard can be reduced by properly deactivating the road.

Any landslides in these two areas are likely to be a water quality concern, due to introduction of fine sediment to the creek, but otherwise are unlikely to significantly affect the creek channel, nor contribute to debris flood hazards downstream.

Triggering events:

Two types of rainfall event are most likely to cause landslide or flood events following wildfire. These are:

- Short-duration, high-intensity rainstorms in summer. These convective storms may cover only a small area, and so are often unrecorded by weather stations and are difficult to forecast. Examples of post-wildfire events caused by this type of event are the 2004 Kuskonook Creek debris flows, and the October 2003 floods at Kelowna. Most post-wildfire events documented in the western USA are of this type.
- Long-duration frontal rainstorms which typically occur in fall or early winter. These can produce 50-100 mm of rain over several days, and may fall on an early-season snowpack at high elevations. An example of this type of event is the October 2005 debris flows in the 2003 Mt Ingersoll burn near Burton.

In the Sitkum burn, the first type of rainstorm is the most likely to cause debris flows in the small tributary streams, although the second type also could cause them. The second type of rainstorm is more likely to cause widespread flooding which could result in high peak flow or a debris flood on the Sitkum Creek fan.

Short-duration, high-intensity rainstorms typically affect only a small area, and therefore would probably cause debris flows in only one or two of the tributary gullies. Long-duration, moderate-intensity frontal rainstorms, although less likely than summer thunderstorms, could cause widespread debris flow activity over much of the Sitkum Creek watershed (as in the Mt Ingersoll example). The likelihood of both types of rainfall event triggering debris flows has been increased by the fire, due to increased overland flow that could be produced in the burned area.

Debris flows in unburned areas in this region commonly occur during the spring snowmelt season. Higher than normal runoff, and possible debris floods, could be produced in the tributary streams in the spring, due to the hydrologic effects of the burn (see below). The likelihood of debris flows in the spring may also be increased, but not to the extent as in the summer and fall.

Post-wildfire changes in soil hydrology are less likely to significantly increase flood flows resulting from spring snowmelt or late spring rain-on-snow rainfall, compared with summer and fall events. This is mainly because water repellent layers in the soil become inactive following prolonged contact with the wet snowpack, and become reactivated as the soil dries out in mid-summer. In Sitkum Creek, an increase in peak spring streamflow is likely, but this is due to the ECA effect of the fire (see discussion below), not to soil hydrologic effects. The reason for the relatively lower impact of spring hydrologic events is that the runoff increase due to ECA effects is in the order of 10-20%, while the runoff increase due to high-intensity summer rainstorms on areas of high soil burn severity can be 10 to 100 times.

Hydrologic effects on the Sitkum Creek watershed

This section focuses on watershed-scale changes, rather than effects on local hillslopes and small tributary channels.

<u>Peak flows during spring freshet</u>

The area of the Sitkum Creek watershed is 27 km^2 (2700 ha), of which 1064 ha or about 39% was burned by the fire (Table 1). High and moderate severity burn cover about 10% and 11% of the watershed respectively.

If we assume that the high and moderate severity burn areas are equivalent to a clearcut condition (or will be, when the dead needles fall off in the moderate areas), then the burn contributes 21% to the ECA of the watershed. Very little logging has occurred in the watershed. Existing cutblocks total only about 15 ha, and fireguards built to contain the fire cover about another 15 ha, for a total ECA of about 1%. (These are very rough estimates made from photographs and Landsat images.)

The H60 (the elevation above which 60% of the watershed area lies) is 1620 m. Research in the nearby Redfish Creek watershed has shown that, at the time of peak flow, approximately 65% of the watershed is covered in snow (Gluns, 2001). The implication of this on snowmelt hydrology and the generation of peak flows is that any changes to the forest canopy in this zone can have an influence on the timing and magnitude of peak flow. Local research on the effect of forest removal on the snowpack has shown it to increase the amount of snow water equivalent available for melt and increase the melt rate (Toews and Gluns, 1986). While this research did not measure changes in snowpack as a result of fire, the principles behind the removal of forest canopy are the same. The removal of forest cover can change the process of streamflow generation.

Almost the entire burned area lies above the H60, and therefore all the area in the burn which has lost canopy cover will alter the snow accumulation and melt and consequently the timing of the contribution to streamflow. It is expected that the effect of snowmelt from burn area will be such that the peak flow of water from this elevation band will be earlier by up to 10 days, and that this would show up in the earlier rise of the hydrograph. Instantaneous peak flows could be increased as the melt synchronizes with contributing areas at lower elevations; however, there is no quantitative means of measuring this. Hydrological modeling allows us to investigate this.

Most of our inferences as to what the effect of wildfire will be on hydrology of the watershed can be drawn from past research on the effects of vegetation removal on streamflow, and hydrological modeling. One such study is in nearby Redfish Creek where the DHSVM watershed model was applied to investigate the effects of various forest harvesting scenarios on streamflow (Whitaker et al, 2001; Schnorbus and Alila, 2004). The model was driven by a locally derived climate data set within the watershed. Applying the results of harvesting 13% in the upper portion of the watershed, the model predicted a 10% increase in flows.

Their conclusion that harvesting at elevations above 1500m can cause a significant increase in peak flows suggests that the 21% severe and moderate burn in Sitkum Creek could cause a 10-20% increase in peak flow. Most of the burn occurs above H60. The desynchronizing effect on snowmelt compared to similar unburned elevations could also cause an earlier snowmelt runoff peak.

<u>Peak flows during summer/fall</u>

To assess storm events we applied the Fire Hydrology Version 1.3 program which is a simplified rainfall-runoff hydrology prediction program developed by the USDA. We assumed water-repellent soils in all areas of high vegetation burn severity. The model resulted in a predicted increase in discharge of 3 times above normal for a 2-year return period rain event. However this is well below the discharge expected during spring runoff and would not have an impact in terms of altering stream characteristics associated with higher flows, (i.e. increased sediment movement or lateral channel erosion). The effect for longer return period events is less certain, but there is likely to be some increase.

Sitkum Creek has no useful record of stream gauging (there were a few years of miscellaneous data in the 1930s and 1940s), but there are two active Water Survey of Canada stations on nearby comparable watersheds. Redfish Creek, 11km to the east, has 34 years of record beginning in

1968, and Duhamel Creek, adjacent to Sitkum Creek on the west, has 12 years of record beginning in 1995.

Redfish and Sitkum Creeks have the same watershed area (within 1 km^2) and the same maximum elevation (2360 m). Redfish Creek has a slightly higher average elevation and slightly more alpine and subalpine area, and therefore may be somewhat more dominated by alpine snowmelt, but otherwise the two watersheds are very similar. In the Northwest Hydraulic Consultants (1990) report, the estimated 200 year flood is the same for both creeks, 13 m^3/s (daily) and 18 m^3/s (instantaneous). Historically, peak discharge events invariably occurred in the spring. However, in two recent events on Redfish Creek (November 1999 and October 2005) the highest discharge of the year resulted from a fall rainstorm. It is possible that climate change might be causing an increased probability of coastal-type fall peak runoff events.

It is expected the fire in Sitkum will have an effect on the hydrology of the watershed. Increased peak flows and an increase in the duration of higher flows may occur, in the order of magnitude of 10-20% for spring peak flows. The effect of fall peak flows is more uncertain; however the result will probably be a decrease in the return period of the flow for any given storm. These changes will decrease over time as the burned area becomes revegetated.

Water quality issues

Another concern with wildfires in domestic consumption watersheds is water quality. Wildfires and water quality have been reported on extensively in the literature. A good review has been done by Tiedemann et al (1979). Effects vary widely due to severity of burn, vegetation, geology, soils, and geographic location within the watershed. In a study following wildfire in a drainage to the east of Sitkum Creek (Matthew Creek near Kimberley) which burned a similar proportion of the drainage area, there was little significant change in water quality with the exception of true color and turbidity which exceeded Canadian drinking water standards. (Gluns and Toews, 1989). There were notable changes in some of the nutrients, particularly nitrate-nitrogen but they changes were minor compared to the standards. These changes were attributable to reduction in the nitrogen cycling following fire.

It is expected in the Sitkum Creek drainage that there will be changes in chemical water quality but they will be well within acceptable standards. Sedimentation and turbidity may be the only parameters that would be expected to have a large change. Most of this would occur due to erosion from severely burned areas, and from debris flows in tributary streams. Erosion from fire guards and roads could result in increased turbidity where there is a direct connection to streams; however, this can be mitigated by proper deactivation. In the short term, ash and charcoal can be expected to enter the water.

It is possible that if the mill ruins and waste deposits were to be further damaged by debris flows or flooding, that this could cause contamination which could affect water quality downstream. At present we have no information on whether there are any contaminated materials at the mill site which could cause a problem. Debris flow hazard at the site appears to be low, but there might be some potential for flooding from adjacent creeks, as a result of increased runoff from burned areas upslope.

Risk analysis

According to the Northwest Hydraulic Consultants (1990) report, the channel of Sitkum Creek at the bridge has a capacity of about 36 m^3/s, double the estimated 200 year peak instantaneous flow of 18 m^3/s. However, historic observations of past floods suggest that Sitkum Creek is likely to overflow its banks at the highway bridge in the 50 year flood (D Boyer, personal communication). During a major flood, debris and sediment carried by the floodwaters can partially obstruct or aggrade the channel, reducing its capacity. This is especially the case during a debris flood event. There are several abandoned channels on both the left and right sides of the present creek channel which have been active in historic time (Northwest Hydraulic Consultants, 1990). Field observations confirm that there are potential points of avulsion leading into these abandoned channels, especially if debris jams occurred during a flood.

Post-wildfire hydrologic changes are likely to cause the return period of peak streamflow events to be reduced, for both spring snowmelt peaks, and possibly to a greater extent for summer and fall rainstorm peaks. For example, the 50 year instantaneous flood of about 16 m^3/s (under pre-wildfire conditions) could be changed to perhaps 25 years (as an initial estimate from inspection of flood frequency curves for Redfish Creek).

Based on the discussion above, the incremental flood hazard on the Sitkum Creek fan due to post-wildfire effects is considered to be moderate. The consequence to both the highway and to residences if a major flood caused a partial or complete avulsion is high. Therefore the risk is high. There is a risk to public safety as well as to structures, since the fan is densely populated, and a flood due to post-wildfire effects is possible in summer or fall, when it would not normally be expected.

The authors of the Northwest Hydraulic Consultants indicated that their identification of hazards was based on the condition of the watershed at the time, and recommended that the report be updated if there were any significant changes in the watershed.

The risks from debris flows on the Sitkum Creek fan are low. However, the debris flood hazard as a result of post-wildfire conditions is probably moderate, especially in the fall season. Since the consequences of stream avulsions or debris deposits on the fan are high, the risk is high.

Risks to water quality are primarily due to increases in turbidity which are likely due to post-wildfire erosion. For the first several years, the probability of this (i.e. the hazard) is high. The consequence is high because it is a community watershed; hence the risk is high. Risks due to effects on chemical water quality are moderate to low.

Recommendations

(It is not the purpose of this risk analysis to determine whether risks are acceptable, or if they should be mitigated, or which agencies should be responsible for risk management. The recommendations below are intended to draw attention to the most significant risks, promote awareness and discussion of risks, and suggest where further study or action is warranted.)

1. Information on the post-wildfire hazards and risks should be communicated to stakeholders, including local residents, landowners, and owners of the mine.

2. The 1990 study on alluvial fan hazards should be updated, to reflect changed hydrologic conditions in the watershed, as recommended by the authors. This should include further study and recommendations (if appropriate) on the return periods of floods on the Sitkum Creek fan, the capacity of the present channel and highway bridge to pass these floods and the associated debris, investigation of possible protective works or other improvement on the fan, and flood preparedness.

3. Mitigation treatments, such as aerial mulching, should be considered in the tributary watersheds of T1 and T2, to reduce the debris flow hazard in these drainages.

4. Deactivation of the Sitkum-Alpine road, from the bridge to the mine, should take place, to reduce the hazard of stream sedimentation due to debris flow or erosion events. (It is our understanding that deactivation prescriptions have been completed, and that work will begin soon.)

5. Reforestation should be considered as a treatment to promote hydrologic recovery in the burned areas.

6. A comprehensive watershed risk mitigation and restoration plan should be developed, including a communications plan, to ensure coordination of activities.

7. Consideration should be given to applying hydrologic models to assess the post-wildfire hydrologic changes to Sitkum Creek, and to produce better estimates of probable streamflow.

8. Streamflow and water quality on Sitkum Creek should be monitored for several years, or until substantial recovery of hydrologic processes in the watershed have occurred. Real-time monitoring of discharge should be considered, to assist in forecasting the occurrence of damaging floods.

9. The mill site and mine waste should be inspected for possible sources of contamination that might be affected by the fire or by post-wildfire flooding.

10. Burn severity mapping based on pre- and post-wildfire Landsat imagery should be completed. (This is now underway.)

11. Acquisition of high-resolution satellite imagery, or aerial photography, should be considered, to facilitate planning of reforestation or other rehabilitation activities in the watershed, and to facilitate monitoring of post-wildfire erosion events and recovery.

12. Rainfall, erosion events, revegetation, and the effectiveness of any mitigation treatments in the burned area should be monitored for several years, to assist with assessment or risks on the fan, and to improve our understanding of post-wildfire hydrologic processes.

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References

Cannon, S.H. and Gartner, J.E. 2005. Wildfire-related debris flow from a hazards perspective. In: Jakob, M. and Hungr, O. (eds.) Debris-flow Hazards and Related Phenomena. Praxis-Springer, Berlin, Heidelberg: 363-385.

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., 2006

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, MOFR, SIFR February 2006.

Gluns, D.R. 2001. Snowline pattern during the melt season: evaluation of the H60 concept. Pp. 68-80. In: Watershed assessment in the Southern Interior of British Columbia. Res. Br., B.C. Min. For., Victoria B.C. Work. Pap. 57/2001.

Gluns, D.R. and D.A.A. Toews. 1989. Effect of a major wildfire on water quality in Southeastern British Columbia. Pp 487-499 *In* Woessner, W.W. and D.F. Potts (eds.) Symp. Proc. On Headwaters Hydrology. Amer. Water Resour. Tech. Publ. Series, TPS-89-2. 708p.

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 BC.

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., 2006

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.

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

Tiedemann, A.R., C.E. Conrad, J.H. Dietrich, J.W. Hornbeck, W.F. Megahan, L.A. Vierech, and D.D. Wade. 1979. Effects of Fire on Water: A state of the Knowledge Review. USDA For. Serv. Gen. Tech. Rep. WO-10.

Toews, D.A.A and D.R. Gluns. 1986. Snow accumulation and ablation on adjacent forested and clearcut sites in southeastern British Columbia. 54th Western Snow Conference, Phoenix, Arizona.

Whitaker, A., Y. Alila and D.A.A. Toews. 2001. Modelling of Peak Flow Change Using DHSVM Model. Pp 95-111. In: Watershed assessment in the Southern Interior of British Columbia. Res. Br., B.C. Min. For., Victoria B.C. Work. Pap. 57/2001.

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.

P(HA), annual probability (likelihood) of occurrence of a specific hazardous landslide and it reaching or otherwise affecting the site occupied by a specific element		**P(S:H) × P(T:S) Probability (likelihood) that the landslide will reach or otherwise affect the site occupied by a specific element, given that the landslide occurs**		
P(HA) = P(H) × P(S:H) × P(T:S)		**High**	**Moderate**	**Low**
P(H), annual probability (likelihood) of occurrence of a specific hazardous landslide	Very high	*Very high*	*Very high*	*High*
	High	*Very high*	*High*	*Moderate*
	Moderate	*High*	*Moderate*	*Low*
	Low	*Moderate*	*Low*	*Very low*
	Very low	*Low*	*Very low*	*Very low*

Figure 1. Example of a simple qualitative risk matrix. This example is for partial risk (probability of the hazard affecting a specific element) of a landslide. From Wise et al (2004).

Table 1. Sitkum Creek: physiographic and hydrologic summary

Drainage area	27.0 km^2 (2700 ha)	
Elevation range	560 – 2360 m	
Melton ratio [1]	0.35	
H60 elevation	1620 m	
Fan slope: mean; range [2]	8%; 5 – 11%	
Typical slope, lower channel [3]	12 – 15%	
Typical slope, middle channel [4]	7 – 8%	
Burn severity [5]: H	10%	
M	11%	
L	19%	
Peak flow estimates (m^3/s): [2]	daily	instantaneous
mean annual flood	6.2	8.7
20 year	11	15
200 year	13	18

Footnotes:
1 Melton Ratio = relief / √ area. It is an index of average watershed slope. A study by Wilford et al (2004) in northwestern B.C. concluded that watersheds subject to debris flows and debris floods typically had Melton ratios of >0.6 and 0.3-0.6 respectively.
2 Data from Northwest Hydraulic Consultants (1990).
3 From bridge to fan apex.
4 From confluence with T13 to bridge.
5 From preliminary vegetation burn severity map (Figure 2).

Table 2. Tributary watershed characteristics

Watershed	Area (ha)	Burn severity H	Burn severity M	Debris flow hazard[1]	Road diversion potential[2]	Creek blockage potential[3]	Terrain stability IV and V [4]	Remarks
T1	56	27%	22%	H	n/a	H	12%	steep incised lower channel
T2	50	41%	24%	H	n/a	M	15%	steep incised lower channel
T3	66	50%	33%	L-M	H	L	42%	
T4	66	38%	16%	L-M	L	L	31%	
T5	79	36%	14%	M	H	L	23%	
T6	56	37%	30%	L	L	L	8%	
T7	41	30%	34%	L	L	L	16%	
T8	30	40%	42%	H	H	L	0%	
T9	39	43%	36%	H	H	L	6%	
T10	26	23%	32%	M	H	L	5%	
T11	145	23%4	21%	L	H	L	4%	mostly alpine/subalpine; includes unmapped tributary
T12	120	1139%	18%	L	n/a	L	39%	mostly alpine/subalpine
T13	312	1%	5%	L	n/a	L	50%	mostly unburned; mostly alpine/subalpine; snow avalanches
R1	311	11%	28%	n/a	n/a	n/a	24%	face unit between tributaries

Footnotes:
1 Based on evidence in lower channel of past debris flow activity.
2 Potential for debris flow or flood to be diverted down the road.
3 Potential for a debris flow to block Sitkum Creek; based on channel confinement and evidence of past blockage.
4 There is no class V terrain in tributaries T1 to T10 or R1. T11-T13 have class V terrain in alpine areas.
n/a = not applicable

Report prepared by:

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

David Gluns, R.P.F.
Ministry of Forests and Range
Southern Interior Forest Region

Report reviewed by:

Doug Nicol, P.Eng.
D.R.Nicol Geotech Engineering Ltd.

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

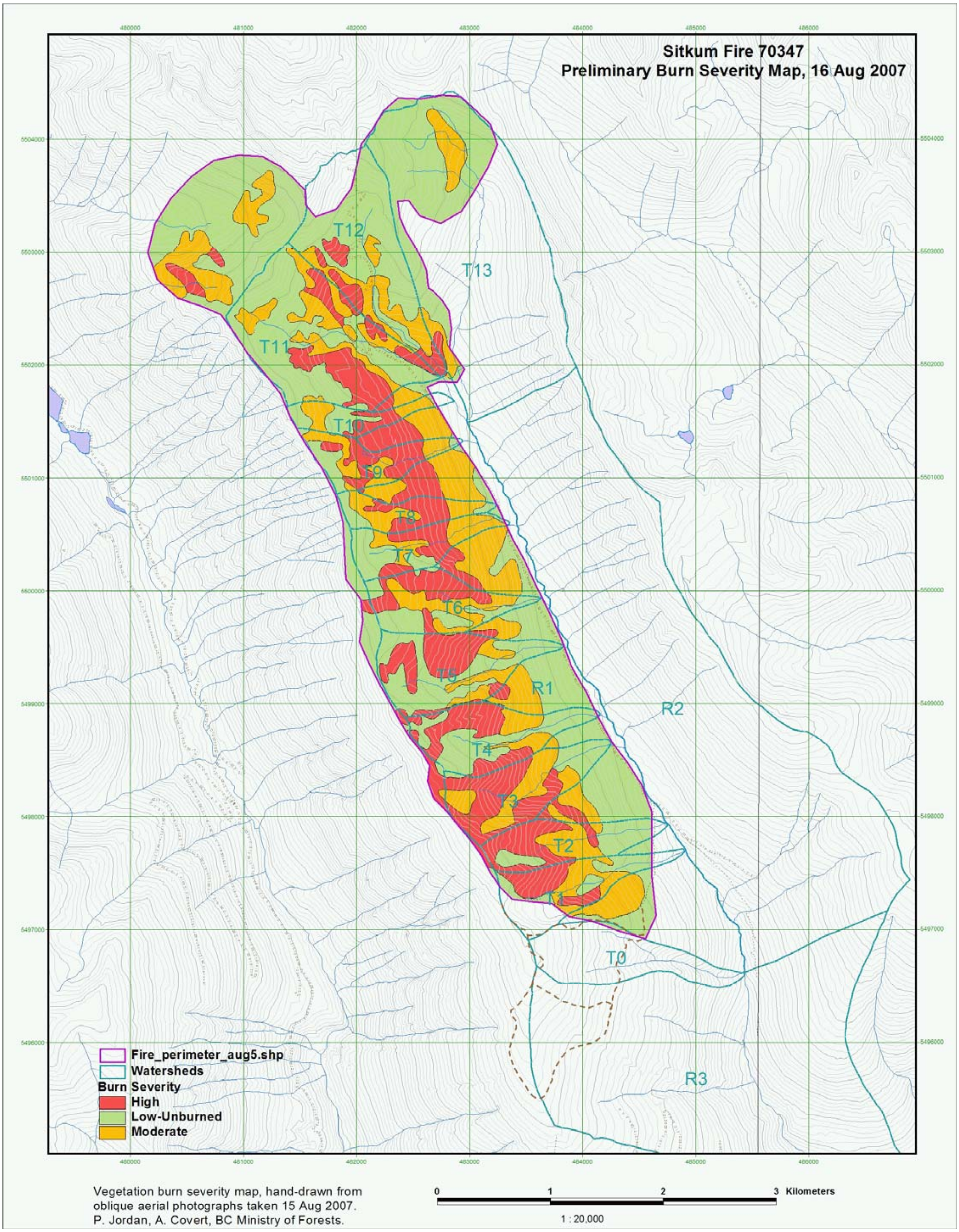

Figure 2. Preliminary burn severity and watershed map (reduced).

Photo 1. Burned area in tributaries T1 to T5 on the west side of Sitkum Creek.

Photo 2. Upper Sitkum Creek watershed, showing continuous area of severe burn, and moderate severity area between this and the road. Two recent small debris flows on streams T8 and T9 are visible. The old mill site is on the extreme right.

Photo 3. Example of a severely burned area, showing a water repellency test plot.

Photo 4. Low-level aerial photo of the Sitkum Creek fan, taken 15 August 2007.