

Post-wildfire natural hazards and risk analysis in British Columbia

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ABSTRACT

Several damaging debris flow and flood events occurred in areas burned by severe wildfires in 2003 and 2007. The BC Forest Service has developed a procedure for analyzing risks to public safety and infrastructure from such events. Each fire season, for wildfires which present potential risks, burn severity is mapped and sites of potential hazards are identified. The results are communicated to local governments and other stakeholders, who are responsible for evaluating risks, warning residents, and applying mitigation strategies. The 2009 Terrace Mountain fire near Kelowna is presented as an example of the procedure.

RÉSUMÉ

Plusieurs coulées de débris et d'inondations néfastes sont survenues en 2003 et en 2007 dans des endroits impactés par des incendies forestiers d'intensité sévères. Le Service Forestier de la Colombie-Britannique a mis au point une procédure d'analyse de risque que de tels événements pourraient avoir sur la sécurité publique et sur les infrastructures. Pour chaque incendie forestier qui présente des risques potentiels, l'intensité du feu est cartographiée et les sites de dangers potentiels sont identifiés. Les résultats sont communiqués aux gouvernements et représentants locales, qui sont responsables d'estimer les risques, avertir les résidents et d'appliquer de stratégies d'atténuation. L'incendie de forêt de 'Terrasse Mountain' qui a eu lieu en 2009 près de Kelowna est présenté comme un exemple de la procédure.

1 INTRODUCTION

Wildfire can cause significant changes to soil physical properties, as well as loss of vegetation cover and forest floor material. These changes in hydrological and geotechnical properties can result in increased runoff and surface erosion, and increased incidence of landslides. Many instances of post-wildfire landslides and increased erosion have been documented in the western United States (Cannon and Gartner 2005) and elsewhere in the world (Shakesby and Doerr 2006).

Several effects of wildfire can increase the likelihood of post-wildfire hydrologic and geomorphic events. These include the loss of forest floor litter and duff, which reduces water storage capacity and increases the susceptibility of the soil to erosion by raindrops (Robichaud et al. 2000); soil water repellency (DeBano 1981); sealing of surface soil pores by ash and fine particles (Larsen et al. 2009); and loss of forest canopy, which reduces the interception capacity and can cause increased snow accumulation and melt rates. The extent and significance of soil water repellency and other affected hydrologic properties is dependent on soil burn severity (Doerr et al. 2006).

Following several damaging debris flow and flood events which occurred in areas burned in 2003, the British Columbia Forest Service developed a procedure for analyzing risks to public safety and infrastructure from post-wildfire natural hazards. The procedure is loosely based on the Burned Area Emergency Response (BAER) program in the United States (Robichaud et al. 2000; Napper 2006), with some important differences. Our procedure focuses on identifying risks and warning affected parties, not on mitigation activities such as broadcast erosion control treatments.

2 LANDSLIDES AND FLOODS FOLLOWING WILDFIRE IN BRITISH COLUMBIA

The wildfire season of 2003 was exceptionally severe in southern British Columbia (Filmon et al. 2004). Several debris flow and flood events following the 2003 wildfires caused significant damage to private property and infrastructure (Jordan and Covert 2009).

Before 2003, post-wildfire landslides and floods were rarely observed in British Columbia. Several small debris flows and debris slides were reported following severe wildfires near Salmon Arm in 1973 and 1998 (BC Forest Service, Kamloops Forest Region engineering files), but few details are available. Elsewhere in the southern Interior, there are only anecdotal accounts of isolated small events.

2.1 Events Following the 2003 Wildfires

A total of 16 significant events, including 8 debris flows, 6 debris floods, and 2 debris slides were documented after the 2003 fires. Detailed descriptions are given in Jordan and Covert (2009); a summary of the events is given here. Most of these events occurred as a result of high-intensity mid-summer rainstorms, although some events occurred during a long-duration fall rainstorm. In addition, a number of minor events were observed, such as localized flooding and gully erosion.

In October 2003, debris floods occurred on two creeks draining the Okanagan Mountain Park fire, and caused some damage to residential areas on the southern periphery of the city of Kelowna. The floods were triggered by a severe rainstorm, with an estimated 20 mm of rain in 20 minutes. The peak discharges on the two creeks were estimated at five to 15 times the pre-fire 200-year

discharges (Dobson, 2006). The flood events were attributed to overland flow in areas of moderate to high burn severity. Most of the sediment carried by the floods was apparently derived from the channel bed and banks in the lower reaches of the creeks, rather than from erosion in upland areas.

In the Cedar Hills fire near Falkland, an intense rainstorm occurred in June 2004, and caused erosion in approximately 50 small gullies along a 2.5 km slope (Grainger 2005). In an area of convergent gullies that had a combined contributing area of 30 hectares, eroded sediment bulked into a debris flow, and then turned into a debris flood before reaching the fan below. The event crossed the highway, and flowed into two residential yards. On the upper part of the slope, high soil burn severity and strong water repellency were extensive.

The most destructive events occurred in the Kuskonook fire, about 25 km north of Creston. On the night of 6-7 August 2004, a heavy rainstorm occurred in the area, triggering large debris flows in the channels of Kuskonook and Jansen Creeks (Jordan et al 2004; VanDine et al. 2005). Two houses were destroyed, and a large part of the Kuskonook Creek fan was covered with debris (Figure 1). Field investigations after the events found extensive high soil burn severity, water repellent soils, and evidence of overland flow in a plateau area draining into the steep channels. Although shallow surface erosion was widespread, relatively little debris was produced in the source area. The debris flow initiated from failure of the bed and banks, at a point where the channel steepens to about 29 degrees and enters a confined gully in glacial deposits. Most of the estimated 20,000 to 30,000 m³ of debris originated from the channel.



Figure 1. Kuskonook debris flow, August 2004. Photo: Peter Jordan.

In the Lamb Creek fire near Cranbrook, a heavy rainstorm on 19 August 2004 affected the severely burned upper drainage basin of Gold Hill Creek, and caused a large debris flood. Overland flow from the burned slopes in the headwaters accumulated in a wetland and spilled over an escarpment of deep glacial till, causing several meters of incision along the creek channel. Most of the

4.5 km channel has slopes (about 5 to 10 degrees) which are not steep enough to support debris flow, and although there is some evidence of debris flow processes, fluvial transport is predominant in the channel. The volume of eroded debris is estimated at 30,000 to 50,000 m³, which was deposited on a small fan at the creek mouth, and further down the larger Lamb Creek channel.

The Ingersoll fire burned a very steep, bedrock-dominated slope, and a plateau above, bordering Lower Arrow Lake. In October 2005, two years after the fire, a heavy 2-day rainstorm triggered 15 debris flows and debris slides (Figure 2). Most of the events were debris flows which initiated in the upper parts of steep gullies incised in bedrock, and apparently were triggered by overland flow spilling from the plateau into the gullies. This incident differed from the others in that the rainfall was of low intensity and long duration. It is likely that snowmelt contributed to the supply of water, and it is possible that lingering water repellency or other effects of high soil burn severity reduced the infiltration capacity.



Figure 2. Debris flows of October 2005, Ingersoll fire. Three debris flows (left, centre left, and extreme right) started high in gullies below the burned upper slopes. Two events (lower right) began as debris slides in a cutblock logged before the fire. Neither logging nor the deactivated backspare trail (accentuated by the burn) were implicated in the slides. Photo: Peter Jordan.

At most of these events (Ingersoll being the exception), extensive strong water repellency was observed in the headwaters of the affected drainage basins, and this was probably a major cause of overland flow generated during intense rainfall. Most of the debris flows (except for the Cedar Hills event) originated in the channels, due to exceptionally high peak discharge from overland flow, and the vast majority of debris was derived from the channels, not from surface erosion of burned slopes.

Smaller mass movement and erosion events were reported in several of the 2003 fires, including Strawberry Hills near Kamloops, and McLure near Barrière.

2.2 Events Following More Recent Wildfires

The fire season of 2007 was unusually severe in south-eastern BC, with drought conditions almost as severe as in 2003. Several large wildfires occurred near populated areas. In the two years after the fires, several significant debris flows occurred in the Springer fire near Slocan.

In the channel of Middle Van Tuyl Creek, a debris flow triggered by snowmelt in May 2008 crossed Highway 6 and caused one fatality. A drainage diversion from an old landing, as well as increased snowmelt rate in severely burned forest, contributed to the event. A second, smaller, debris flow occurred in the same channel in May 2010.

Four large debris flows and several smaller ones occurred in the nearby Enterprise Creek drainage, in very steep, bedrock-dominated, gully systems, during moderate rainfalls in August 2007, August 2008, and September 2009 (Figure 3). Three of these occurred in the same channel. These channels were subject to occasional debris flows before the fire, with return periods of probably several decades. However, the likelihood of debris flows was substantially increased after the fire, probably by the loss of large woody debris in the channels and on adjacent steep slopes, and possibly by water repellency on slopes above the gullies.



Figure 3. Steep, gullied face burned by the 2007 Springer fire in Enterprise Creek valley. Debris flows which reached the valley bottom occurred in the large gully at left (2007, 2008, and 2009) and the right gully (2008). Smaller events also occurred in the intervening gullies. Photo: Peter Jordan.

In the Sitkum fire near Nelson, a debris slide occurred on a mine road during snowmelt in May 2008. High groundwater level caused by increased snow accumulation and snowmelt rate on the burned slopes

above was the most likely cause. This slide affected water quality in a community watershed.

Several debris flows and debris floods occurred in August 2010 in the area burned by the 2009 Kelly Creek fire near Clinton in the Cariboo region (T. Giles, BC Forest Service, Kamloops, personal communication).

2.3 Factors Contributing to these Events

All of these landslide events occurred in large fires with extensive high soil and vegetation burn severity. Water repellency was observed in the 2007 burns, although it was not as extensive as in the 2003 fires, and is not believed to be a significant cause of the 2007 and later events. It appears probable that fires which burn under extreme drought conditions, as in 2003, are likely to have relatively high soil burn severity, one manifestation of which is water repellency. Consequently such fires are likely to have a significantly increased hazard of post-wildfire landslides and flooding.

3 THE POST-WILDFIRE NATURAL HAZARDS RISK ANALYSES PROCEDURE

Because of the landslide and flood incidents which followed the 2003 fires, the BC Forest Service began development of a procedure to identify risks from post-wildfire natural hazards (Jordan et al. 2006). In 2005 the Forest Service received a grant from the Natural Hazards Mitigation Fund, a one-year program of the BC government, to undertake this work. A result of this project was a technical document (Dobson Engineering Ltd. 2007) which reviewed available methods for analysing hazards and risks following wildfires, and proposed suitable methods for conducting risk analyses in British Columbia. At the same time, Forest Service science and engineering specialists conducted field work on the 2003 fires and some fires which burned in 2004 and 2005, to test suitable field methods for identifying changed soil properties which can affect post-wildfire hazards (Curran et al. 2006).

The risk analysis procedure was tested for the first time in the summer of 2007 on six wildfires in the West Kootenay region, two of which proceeded to detailed risk analysis reports (Nicol et al. 2007; Jordan et al. 2007) and ultimately to mitigation treatments.

The procedure follows the Canadian Standards Association decision-making framework for risk management (Wise et al. 2004). This has several steps: identification of risk, risk analysis and estimation, evaluation of risk tolerability, developing control or mitigation strategies, and acting on these strategies. The procedure deals only with the first two steps. The objective of the procedure is to identify and analyze risks to public safety and infrastructure resulting from wildfire. The results of the procedure are passed on to authorities such as the Provincial Emergency Program and local governments, who are responsible for evaluating risks, warning residents, and applying mitigation strategies if appropriate.

3.1 Mapping and Field Work

Each fire season, wildfires are screened by size and proximity to values at risk such as populated areas. For selected fires, when the fire is largely contained, the procedure begins with an aerial overview of the fire, and reconnaissance field work in areas where risks are suspected. The next steps include mapping catchment boundaries, field traverses to collect data on soil burn severity and water repellency, and identification of hazard features. Our objective is to make a preliminary risk analysis available about one week after the fire is contained, followed by a more thorough report for large or high-risk fires, when time and resources permit. Risk analyses are done by a team of qualified specialists, including soil scientists, geoscientists, and geotechnical engineers.

An important component of the procedure is the mapping of burn severity. A simple preliminary map can be prepared with the aid of high-elevation photographs taken from an aircraft (for example, see Figure 5 in section 4.1). However, a much better map can be prepared using LANDSAT satellite imagery acquired before and after a fire. These burned area reflectance classification (BARC) maps are more accurate and are much preferred, especially for large fires, but their preparation must wait until a suitable post-wildfire image is obtained, which may take a month or longer. The raw BARC data must be calibrated to field observations of actual burn severity, since it can be affected by forest age and type, recent logging, aspect, and atmospheric conditions (Parsons et al. 2010). An example of a completed BARC map is given at the end of this paper. The BARC maps give a good representation of loss of the forest canopy (or vegetation burn severity), but to evaluate potential hydrologic effects caused by changes to soil properties, it should be converted to a map of soil burn severity (Parsons et al. 2010). To do this, it is necessary to collect field data on post-wildfire soil and vegetation conditions, as well as comparable data in adjacent unburned forest.

The first step in conducting the analysis is to identify the values at risk. These may include dwellings and other buildings, infrastructure such as highways and utility lines, and domestic water intakes. Field work is normally concentrated in areas which can affect the values at risk, which may be only a small portion of the total burned area. The main priorities in field work are to obtain a representative set of data on soil burn severity in a range of forest types and burn conditions, and to identify and assess potential hazard features, such as alluvial fans, channels and gullies subject to debris flows, and potentially unstable slopes.

Watershed areas in the fire are outlined on a topographic map, and a working map produced which includes burn severity (preliminary or BARC), and the locations of field data points. It is useful to tabulate the burned areas by watershed; the proportion of each watershed burned at high and moderate severity, and the distribution of burned areas within the drainage area, are important factors in estimating the likely post-wildfire hydrologic impacts.

3.2 Risk Analysis

For each identified value at risk and/or watershed area, the increased hazard due to the fire, and the risk, are estimated qualitatively as low, moderate, or high, and tabulated. Risk refers to the *partial risk*, which if the risk were to be calculated quantitatively, is the probability of occurrence of a hazardous event times the probability of it reaching or affecting the site of the value at risk (Wise et al. 2004). Other components of consequence, such as the value or vulnerability of the elements at risk, are not considered at this level of risk analysis; however, they would be addressed if a more detailed risk assessment is subsequently done for specific high-risk sites.

3.3 Risk Evaluation and Mitigation

If high risks to public safety or infrastructure are identified, we may make recommendations for mitigation measures to be considered; however, acting on these recommendations is the responsibility of local land managers, local government, or landowners. Mitigation measures can fall into three general categories:

- engineering treatments to reduce the hydrologic impact of logging roads or other development in the burned area (Foltz et al. 2009);
- protective structures such as dykes or berms (Hung et al. 1987); and
- broadcast treatments such as straw mulching to reduce runoff and erosion on severely burned areas (Robichaud et al. 2010).

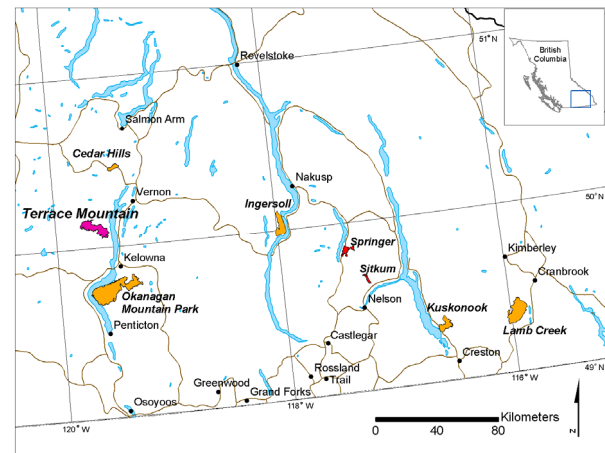


Figure 4. Location map of south-eastern BC, showing the 2009 Terrace Mountain fire. Other fires referred to in this paper are also shown (2003 in orange, 2007 in red).

4 THE 2009 TERRACE MOUNTAIN FIRE

The Terrace Mountain Fire near Kelowna is presented as an example of the application of the risk analysis procedure. This fire burned an area of 9300 ha above the west shore of Okanagan Lake (Figure 4) in July and August of 2009. The east part of the fire burned areas

above a number of rural residences near the small community of Fintry, a secondary highway (Westside Road), and a provincial park and campground. The fire also burned part of the large Bear Creek drainage, which is the community watershed supplying West Kelowna.

4.1 Risk Analysis Mapping and Field Work

In mid-August, a three-person team of Forest Service specialists conducted field work for four days in the burned area, when the fire had been contained and firefighting operations were in the mop-up stage. A set of oblique air photos was taken from a helicopter (Figure 5) which was used to draw a preliminary map of vegetation burn severity. This initial reconnaissance identified farms in the lower Shorts Creek valley, and the east side of the fire above Okanagan Lake, as the main areas of interest. Field data on soil burn severity were collected throughout the fire (Figure 6), with most points located in the main area of concern in the east part of the fire.

The team completed its risk analysis report four weeks after field work was finished (Jordan and Curran 2009). The report included a table of vegetation burn severity by watershed, based on the preliminary map, as well as a summary of partial risks in areas of concern.

On September 26, a suitable LANDSAT image was acquired, and soon after, a BARC map was prepared (Figure 9, at end of paper). The initial BARC map was calibrated using data collected on our field traverses, and further revisions were made to account for recent cutblocks, which have a lower burn severity than indicated by the raw BARC data (Parsons et al. 2010). The map is presented as "calibrated vegetation burn severity". In the main area of interest, we found that it correlated well with soil burn severity, but in some other parts of the fire, soil burn severity was lower than vegetation burn severity. Despite collecting data at 52 field points, we had insufficient information to produce an accurate map of soil burn severity for the entire fire.

4.2 Detailed Risk Assessment and Mitigation Works

During field work, it quickly became apparent that high risks were present in the lower Shorts Creek valley, where several houses are located on small fans at the base of steep creek channels and gullies, with extensive areas of high soil burn severity in the contributing drainage areas. Therefore, we recommended that a detailed risk assessment be done of this area. The Kamloops Fire Centre retained Westrek Geotechnical Services Ltd. to conduct this assessment, which was completed concurrently with work on the risk analysis report.

The detailed risk assessment identified high partial risks to residences located at two sites. Both were potentially at risk from increased hazard of debris flows, which could be triggered by high intensity rainfall on burned areas upslope. It made recommendations for mitigative works to reduce the risk at these sites, including protective berms above the houses (active measures), straw mulching of the drainage area contributing to a steep gully above one house, and drainage improvements to logging roads above the gully (passive measures).



Figure 5. Aerial photos help identify hazard locations. Shorts Creek valley, Terrace Mountain fire. Photo: Peter Jordan.



Figure 6. Field inspections to assess soil burn severity. Terrace Mountain fire, August 2009. Inset: water drops showing strong repellency. Photo: Peter Jordan.

As a result of these recommendations, mitigative works were completed in October 2009. They included deactivation of an old, abandoned, logging road above one of the houses (Figure 7a), construction of berms on the steep fans to divert any future debris flows away from the houses (Figure 7b), and additional culverts on the active logging road above the area at risk. This road was further deactivated by the forest licensee in the summer of 2010, with all culverts in the contributing drainage area replaced with large cross-ditches. The drainage area contributing to the high-risk gully was demarcated, and areas of high soil burn severity were identified on the ground. These areas were treated with straw mulch, spread manually by a Wildfire Management Branch firefighting crew (Figure 8).

5 CONCLUSIONS

The landslide and flood incidents which followed the 2003 and 2007 fires show that damaging events can occur in spring, summer, or fall, in response to snowmelt, localized high-intensity rainstorms, and low-intensity frontal rainfall. Although relatively rare, debris flows triggered by high-intensity rainstorms are of particular concern due to their unpredictability.

The 2009 Terrace Mountain fire illustrates the application of the BC Forest Service's risk analysis procedure for post-wildfire natural hazards, and of more detailed risk management methods at identified high-risk sites. The mitigation measures applied to reduce risks at these sites include all three categories of common treatments: engineering treatments (road deactivation and drainage upgrading), protective structures (berms), and broadcast treatments (straw mulching).



a



b

Figure 7. Mitigation works constructed to protect dwellings from increased debris flow hazard, Terrace Mountain fire. a) Constructing cross-ditches on abandoned logging road crossing gully. b) Berm on Wilson Creek fan. Photos: Tim Smith.

In the first year after the fire, no high-intensity rainstorms have occurred in the burned area. No fire-

related erosion events have been noted in the burned area, and the mitigation works therefore have not been tested. Monitoring in 2010 confirmed that the mitigation works were completed as specified and were functional. Further monitoring is planned for at least one more year.

The post-wildfire natural hazards risk analysis procedure continues to evolve. It has now been applied to 24 wildfires in the 2007, 2009, and 2010 fire seasons. About half of these fires have BARC burn severity mapping, and about one-third have had detailed reports completed. Many of the reports are available on the internet, presently at this location: ftp://ftp.for.gov.bc.ca/RSI/external/publish/Wildfire_Risk_Analysis.



Figure 8. Spreading straw mulch by hand, Terrace Mountain fire. Photo: Peter Jordan.

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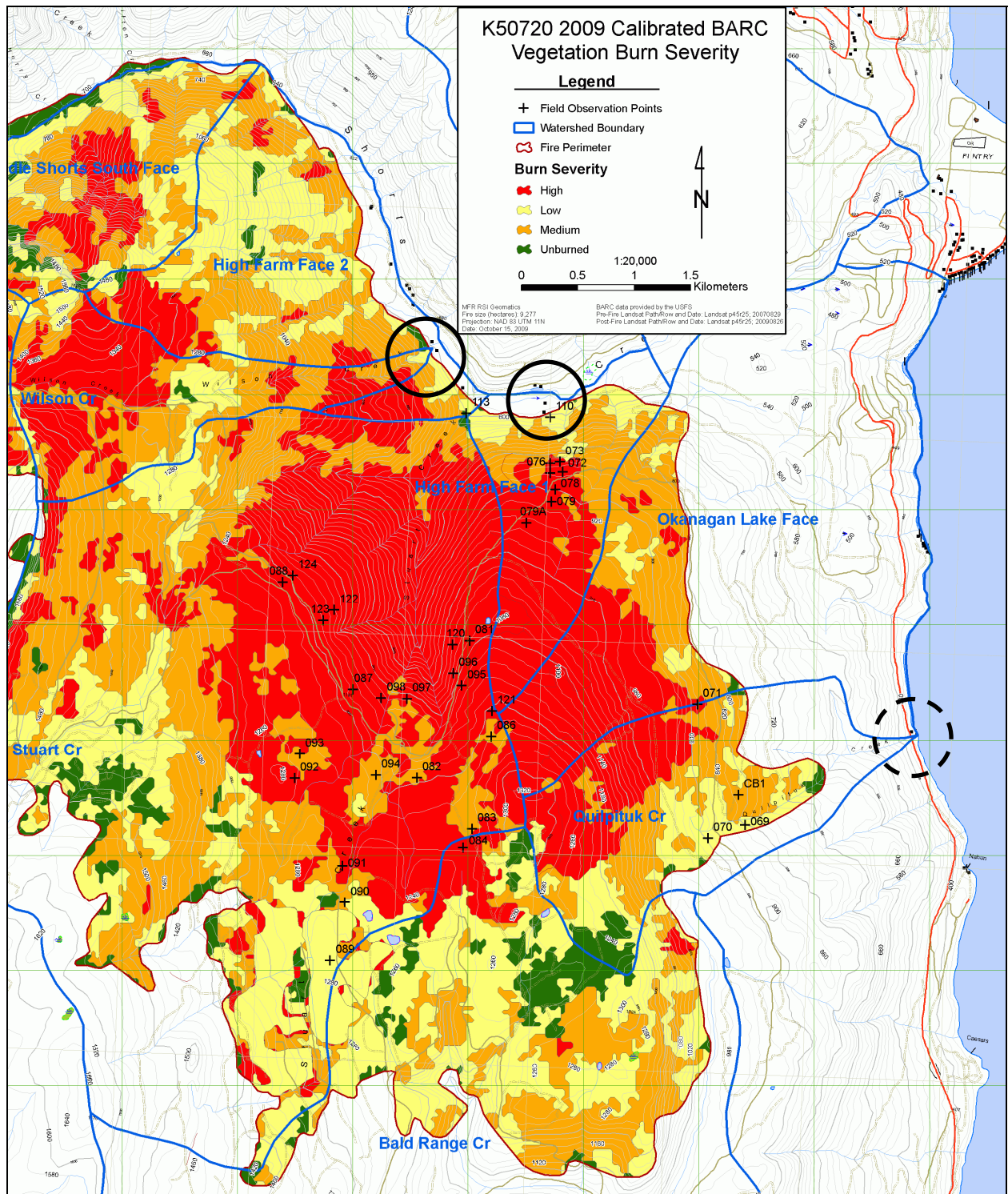


Figure 9. A portion of the BARC burn severity map, Terrace Mountain fire. High-risk locations in the Shorts Creek valley are shown (solid circles); compare with Figure 5. A moderate-risk location is also shown (dashed circle). Map prepared by Will Burt, BC Forest Service, Nelson.