

Report on activities and results for Phase 2 of “Engineering Study of Post-wildfire Natural Hazards”, 2005-NHMF-024.

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The main objectives of Phase 2 were to test the proposed field methods for assessing post-wildfire hazards on one or more recent wildfires, and to test methods of preparing maps of burn severity based on remote sensing.

The purpose of the field work described here was to investigate the feasibility of standardizing the collection of vegetation and soil burn severity data, and to test the proposed methods by analysing wildfire areas that burned in 2004 and 2005. Two methods of preparing burn severity maps were tested, and GIS methods were tested to apply the mapping and the field data to produce summary data for affected watersheds. The intention of the study team is, following discussion of the results of this study, to standardize the mapping and field data collection methods, and include them in the risk analysis procedure.

A complete risk analysis was not done as part of this project, since the work on Phase 2 was done before completion of the proposed risk analysis procedure (under contract to Dobson Engineering Ltd.).

1. Field work on the Sleetsis and Town Creek fires

The fire season of 2005 was unusually inactive. The Sleetsis fire, near Spences Bridge, was the only large wildfire in the region in 2005. It was not an interface fire; however, several creeks which drain the burn area cross the CN railway, so it does provide an example of a wildfire that would be assessed under the risk analysis procedure.

The other notable fire that occurred in 2005 was an interface fire (McKinney Camp Fire, Osoyoos Indian Reserve). However it was small (500 ha) and was mostly grassland and bedrock cliffs and therefore of little value in terms of mapping vegetation burn severity, so we decided not to include it in our field program.

The Town Creek fire, immediately above the town of Lillooet, was an important interface fire which occurred in 2004, and it has several risk management issues related to public safety, community water supply, and salvage logging. This was a fire with areas of severe and moderate burn covering significant portions of two community watersheds, with high-risk elements below that could be affected by debris flows or debris floods. Extensive salvage logging is being conducted in the burned areas, so we decided to undertake field work on this fire.

The field work was done in September and October of 2005 by SIFR staff, primarily Peter Jordan (research geomorphologist) and Kelli Giest (auxiliary research technician), with participation by Tim Giles (research geomorphologist), Graeme Hope (research soil scientist),

and Kevin Turner (geotechnical engineer). The work was done with the cooperation of the Lillooet Fire Zone staff, who provided useful assistance with respect to access, logistics, maps, and knowledge of the fire history.

The initial field work on the Sleetsis fire took three days in September, several weeks after the fire was largely contained. This is somewhat later than work would be done in applying the procedure operationally; for high-risk interface fires, response within a week of containment would be expected. The work included a helicopter reconnaissance during which photographs were taken for preparing a severity map, and a landing was made to do several ground test plots in a remote area of the fire. Three other areas of the fire which are road-accessible were visited for measurements. The field sites are marked on Figure 2 of Appendix 3. The Sleetsis fire is large and complex; if it were an interface fire involving high-value elements at risk, this amount of field checking would not have been adequate, and probably two or three times as much ground work would be done on a fire this size. However, for a relatively low-risk fire such as this, three days spent on field work by a crew of two or three is probably reasonable.

The first field trip was followed by a week of field work in October, during which we conducted more detailed measurements of soil water repellency, in order to test and refine our field methods, and to collect data which will help us assess the variability of soil water repellency at various scales.

Field work on the Town Creek fire consisted of a brief aerial reconnaissance, followed by one day of work on the ground, during which we made observations of burn severity and soil water repellency, primarily in the Dickey Creek watershed which was most affected by the fire. At the time of our visit, salvage logging was underway, and our field work was limited to some small areas which had not been disturbed since the fire.

The locations of field sites on both fires were recorded using handheld GPS receivers, photographed, and marked in the field, to facilitate further observations next year, if work on the project continues. We also located potential sites to install rain gauges in the spring of 2006, in case funding is available to monitor these fires for future flooding and erosion events.

2. Further field work on the Kuskonook fire

In July 2005 we did one day of further field work on the 2003 Kuskonook fire, with UBC researchers who were doing work on water repellent soils. The purpose of our field work was to collect further data on water repellency at sites we had marked during previous field trips, and to provide field checks to verify the burn severity classes used in the Landsat-based fire severity map for the Kuskonook fire, which was prepared in the winter of 2004-05. A summary of the burn severity data is included in Appendix 1.

On this field trip, we tested and revised the field form which we are considering for operational use in the risk analysis procedure. This form was originally developed during our work on the Kuskonook fire in 2004.

Most of the sites at which strong water repellency was observed after the debris flow event in 2004 were still water repellent, two years after the fire. We plan to monitor these sites over the next several years, to track the recovery of vegetation and soil hydrologic properties over time.

We also prepared a preliminary burn severity map based on hand-held photos taken from the helicopter in 2004, to compare with the Landsat-based burn severity map made previously (see discussion below).

3. Burn severity and water repellency observations

3.1 Methodology

In four areas of the Sleetsis fire, and one area of the Town Creek fire, we recorded observations on burn severity, using the field form developed for the Kuskonook fire. (See Appendix 2.) In each area, observations were made at several plots, which included a range of burn severities where possible. At each plot, a test was made for water repellency using the water drop penetration test. Measurements with the mini-disk infiltrometer were also made at some sites. Photos of some of the plots are shown in Appendix 4.

These observations serve two purposes. One is to test for the presence of water repellent soils. The other is to create ground-checked control points, for calibrating the severity classes used in preparing a burn severity map from remote sensing images.

On the field form, soil and forest floor burn severity was rated by using 6 visual observations on a low-moderate-high scale. For the purpose of calibrating the burn severity maps, these were combined to produce a weighted numerical score from 0 to 30. (The method used to do this is preliminary, and requires further development.)

On the second field trip, a set of measurements was made of water repellency using the mini-disk infiltrometer. The purpose was to collect data according to a systematic design which is suitable for statistical analysis, to investigate the variability of water repellency at various scales. The results of this analysis will help determine how many measurements need to be made, and how to structure the measurements, in order to determine water repellency to a consistent and optimal level of precision. The design was based on one used by the US Forest Service (Sarah Lewis, Rocky Mountain Research Station, Moscow, ID, pers. comm.). Measurements were made on 6 transects, each consisting of 5 plots at set distance intervals. In each plot, 3 replicate measurements were made with the mini-disk infiltrometer at 4 standard depths, 0, 1, 2, and 3 cm. The data set includes 300 measurements.

The ethanol drop (MED) method was not used for any water repellency testing in this trial.

3.2 Results

The transects measured during the October field trip were in areas judged as severely burned on the basis of the appearance of the soil and vegetation. The field work was conducted in poor

weather. The soil was wet, and at times it was raining, which probably affected the measurements. However, water repellent soils were still observed at many locations. It is possible that the observed extent of water repellency would have been greater, if the field work had been done under dry conditions.

The table in Appendix 1 gives a summary of the burn severity and water repellency data at all the plots in the Sleetsis and Town Creek fires. The burn severity data were used as calibration points for the burn severity mapping. At present, statistical analysis of the water repellency data is still in progress. However, from the summary data in Appendix 1, there are indications that for the Sleetsis fire, water repellency and burn severity are poorly correlated, while for the Kuskonook fire, they are well correlated.

4. Burn severity mapping

As part of this project, the Selkirk Geospatial Research Centre of Selkirk College in Castlegar (Robert Magai, his coworkers, and students) made burn severity maps based on Landsat imagery. Maps were made for the following fires: Sleetsis, Town Creek, Botanie, and Okanagan Mountain Park fires. The maps are shown in Appendix 3, and were also provided as GIS files. In addition, maps are in progress for the Cedar Hills, Lamb Creek, and Ingersoll fires. These maps support the field studies and research work that has been done, or is ongoing, on these fires by SIFR research staff, UBC researchers (David Scott and students), and consultants. We are also continuing to work with the Selkirk Geospatial Research Centre on the methodology for preparing these maps, and on correlating the remote-sensing burn severity indices with water repellency and burn severity data collected on the ground.

Appendix 3 includes a location map and a table of summary data for these fires. The Sleetsis (2005) and Town Creek (2004) fires were mapped as part of the field and mapping program described above. The Botanie fire (2004), adjacent to the Sleetsis fire, was included because it experienced a debris flow in 2005 which blocked the CNR tracks and reportedly caused a derailment. The Ingersoll (2003) fire is being mapped because in October 2005, it experienced several debris flows during a rainstorm. We plan to do further investigations of these events as part of our continuing research program on post-wildfire erosion. The other 2003 fires, for which severity maps are being prepared, are the ones which had major erosion or mass movement events in 2004.

4.1 Methodology for preparing burn severity maps from Landsat imagery

(This section is written by Robert Magai, Selkirk Geospatial Research Centre.)

This section summarizes the methodology for producing the preliminary burn severity maps. The approach was developed by the US Geological Survey in cooperation with the US National Park Service, and includes a comprehensive system for characterization, mapping and monitoring of burn severity and ecosystem recovery following fire. Burn severity mapping is a two part process:

- Mapping burn severity through the use of pre- and post-burn satellite images; and,

- Validation of burn severity mapping classes through field sampling, with accompanying map revisions.

Two satellite images of the burn area are obtained. One image should cover the period prior to the fire and another immediately following the fire. Both pre- and post-fire images need to be cloud free within the area of interest. Preferably the images should cover similar season to eliminate the potential interference of variation in plant growth stages. The immediate post-burn image provides information closely related to the intensity of the burn. The pre-burn represents conditions of the vegetation in its normal state.

Suitable pre-fire and post-fire Landsat images were ordered for the fires listed above. The images covered the period 2002 through 2005. Using a two band combination for each image, the brightness values of the bands were processed mathematically to extract burn severity levels using a specific index called the difference Normalized Burn Ratio (dNBR). This index is derived mathematically by the following formulae:

$$\text{dNBR} = (\text{pre-fire NBR} - \text{post-fire NBR})$$

where

$$\text{NBR} = (\text{Landsat Band 4} - \text{Landsat Band 7}) / (\text{Landsat Band 4} + \text{Landsat Band 7})$$

Classes of burn severity are interpreted from differences in reflectivity between the forest, understory vegetation and soil surfaces prior to the burn and the reflectivity of ash, scorched snags, bare soil and regenerating vegetation in those same areas after the burn. Past studies have shown that differences in the two bands (4 and 7) are quite well correlated with changes in reflectivity that results from wildfires.

Prior to the mathematically processing the images, the Landsat images were geo-rectified with the BC coordinate system. The geo-rectified images were subsequently co-registered to each other so that there would be a good pixel to pixel match. This procedure was followed by correcting the images for variation caused by topographic/aspect variation and the specific angle of the sun and the satellite at the time the images were collected. Following these corrections, the ratios of reflectance in bands 4 and 7 were compared for pre- and post-burn conditions throughout the fire area.

The dNBR results were grouped into preliminary classes of burn severity ranging from unburned, low, moderate, to high severity. Preliminary class thresholds were based on recommendations in the USGS based on information from previous assessments in similar ecosystems, and reconnaissance information of on-the-ground conditions in the Sleetsis and Town Creek fires. The threshold levels were subsequently adjusted to reflect data that were collected in the field.

Recommendation: Since cloud free images are hard to get for the required time period (immediate post-fire) it is suggested that we explore using airborne as opposed to space borne images. We need to look into the possibility of acquiring airborne images that have a range of

bandwidth that include near infrared spectral channels. The airborne images collected at high resolution could also be used in studies of soil water repellency.

4.2 Preliminary hand-drawn burn severity maps

We also prepared preliminary maps of apparent vegetation burn severity based on visual observations, for the Kuskonook and Sleetsis fires. These maps are based on photos taken from the helicopter during our field reconnaissance. The severity classes used for these maps are arbitrary and subjective, and are based on these simple visual criteria:

- High – trees appear black or grey (foliage and small branches consumed)
- Moderate – trees appear red (foliage is killed but not consumed; dead needles remain)
- Low – trees appear mostly green with occasional red patches (mostly alive)

These categories are consistent with generally accepted definitions of fire severity (Appendix 7), with the exception that understory vegetation is generally not visible on the photos taken from the air.

To make the maps, an orthophoto map with contours was plotted at 1:20,000. Polygons were drawn on the map by visually matching burned areas on the photos with corresponding locations on the pre-fire orthophoto. Polygons on the map were then digitized so they could be included in GIS-produced maps. This method depends on the opportunity to take good photos from the air, and on the availability of an orthophoto or high-resolution satellite image for a base map. It may be possible to use an ordinary contour map, but it would be much more difficult, and the results less accurate, than using a photographic base map.

4.3 Comparison of burn severity mapping methods

Figures 1 and 2 of Appendix 3 show both the Landsat-based maps and the preliminary visual maps, for the Kuskonook and Sleetsis fires, for comparison. Appendix 5 gives some summary data on the areas covered by H and M burn severity classes for the watersheds affected by the fires (both methods for Sleetsis; Landsat only for Kuskonook).

Both types of burn severity maps pick out comparable areas for the “H” severity class, but the preliminary visual map shows much more area in the “M” class. There are considerable differences in rating areas that were logged before the fire. It is obvious that the Landsat-based maps are much more detailed and have higher resolution. The positional accuracy of these maps is much better too; the hand-drawn preliminary maps can have considerable inaccuracy in transferring features from the photos to the base map. If the objective is to estimate the approximate area of a watershed covered by severe burn, the preliminary visual map appears to do a reasonable job.

In drawing the preliminary visual map for Kuskonook, there was some “cheating” in that the map was prepared over a year after the fire, and the orthophoto used for a base map happened to be taken after the fire, which made it easy to position the burn severity polygons fairly accurately. The Sleetsis map is more representative of the accuracy that can be expected when making a map soon after a fire.

The categories of H, M, and L on the Landsat-based maps are based on accepted definitions (Appendix 7), but assignment of these classes to dNBR values in preparing the maps is somewhat arbitrary, and depends on calibration with ground plots. Further work is needed on how best to calibrate the maps to on-the-ground plots where burn severity and soil properties have been measured.

The Landsat-based maps are clearly a better product. However, it is not reasonable to expect to get them soon after a fire. The satellite passes overhead only about every 18 days, and many images are useless because of cloud cover. It may take a month or more to get a useable satellite image. It may be possible to obtain (at high cost) other imagery from satellites such as Quickbird which can be aimed to take images on order. It is also possible that custom-flown aerial photography may be an alternative.

For operational use in the risk analysis procedure, if it needs to be completed quickly after a fire, it is likely that we will have to use the preliminary visual maps. They should be adequate to make an initial rough estimate (+/- 10% or so) of the area of a watershed covered by severe burn. If a more detailed analysis of hydrologic changes to a watershed is to be done later, then the more accurate Landsat-based maps should be used. Also, for other purposes such as preparing prescriptions and cost estimates for post-wildfire rehabilitation, and for planning salvage logging, the Landsat-based maps would be much more suitable.

Appendix 6 gives some practical suggestions for making the preliminary visual maps.

5. Watershed characteristics

An important part of the risk analysis procedure is to examine individual watersheds affected by a wildfire, and assess the risk of floods or debris flows in these catchments due to post-wildfire hydrologic changes.

As part of this test of the procedure, catchment areas were delineated for the Kuskonook and Sleetsis fires, and data relevant to flood and debris flow hazard were compiled. The results are given as tables in Appendix 5. The catchment areas are shown on the maps in Figures 1 and 2 of Appendix 3.

In the case of the Kuskonook fire, the purpose of the exercise was to address the question: "If we had done the risk analysis procedure following the fire, what risks would we have identified?" Table 1 shows that a number of indicators for Kuskonook and Jansen Creeks (fan and channel slope, extent of potentially unstable terrain, previous mapping, and water repellency observed in the field) identify a high debris flow hazard. Kuskonook and Jansen Creeks had a substantial area of "high" burn severity (15 and 10% respectively) concentrated in their headwaters. On both creeks, the fans are subject to avulsion, and are occupied by houses and the highway. The results of the procedure for these two creeks would clearly be to identify a high risk of post-wildfire debris flows. In fact, debris flows did occur on both creeks a year after the fire. No debris flow was reported on the small unnamed tributary to the south, which was not as severely burned.

A similar exercise for the Sleetsis fire (Table 2) shows that a small, steep catchment (“Unnamed B”) may have a high debris flow hazard. We did not do any field work in this catchment, and further field work would be necessary to assess the risk of debris flows to the CN Railway. The data shows the two larger catchments (Sleetsis Creek and “Unnamed A”) are not subject to debris flows, but may have a moderate hazard of debris floods. Field work near the headwaters of these watersheds identified some water repellent soils. We did not investigate the main-stem stream channels in the field.

For this exercise, watershed boundaries were mapped in GIS, using the TRIM digital contour maps. The use of GIS facilitates quick and accurate calculation of watershed areas, and overlaying the burn severity maps to calculate the areas of burn. It would be possible to calculate drainage areas and estimate the areas of burn without GIS, by using a planimeter or counting grid squares on paper contour maps. However, having GIS-based maps is a considerable advantage in visualizing the distribution of burned areas in the watershed, and having such maps would probably be valuable for communicating the results of the procedure to affected stakeholders.

6. Discussion and recommendations

The field work and mapping done this year on the Sleetsis, Town Creek, and Kuskonook fires provided a useful test of the field form, field methods for identifying burn severity and water repellency, and methods of burn severity mapping. It was also a useful practice for the Ministry of Forests risk analysis team to assess its capability to conduct an assessment in the event that interface fires occur in the coming year.

In doing the field work described above, investigating the after-effects of the 2003 fires, and participating in the preparation of the risk analysis procedure over the last 8 months, we have identified several knowledge gaps, which should be the subject of further research and development. These include:

- Rainfall intensity, and variability of rainfall across the region: We have very little data or understanding of rainfall intensity-duration-frequency relations at high elevations. Existing Environment Canada data is almost entirely at valley bottom elevations. There are various weather station networks at mid and high elevations (Ministry of Environment snow survey, Ministry of Transportation highway weather, BC Hydro, MoF fire weather system and research sites), but apart from retrieving data for its immediate use, no analysis of this rainfall data has been done. We need to compile and analyse relevant data, and install recording rain gauges at the sites of wildfires we are studying.
- Our understanding of soil hydrologic changes following wildfire in ecosystems typical of Southern Interior B.C. is incomplete. Research is needed to address several questions, including: How do post-wildfire changes in soil hydrology depend on antecedent weather and soil moisture conditions? How does water repellency in burned areas compare with that in adjacent unburned sites? How long does soil water repellency persist following a fire?

How variable is soil water repellency, at what scale, and how do we design a sampling protocol to adequately measure it? How do the changes in soil hydrology following wildfire compare in different biogeoclimatic zones? Are the conclusions about post-wildfire hydrologic hazards which are typically made in assessments of wildfires in the United States applicable to our region, or are our soil/ecosystem/hydrology conditions substantially different?

- Hydrologic modeling: Very little modeling of watershed processes has been done in forested watersheds in B.C. except at the research level, and we do not have operational models that can be readily applied. Can the US Forest Service models, or some other models, be adapted to meet our needs? (This topic is addressed by Dobson Engineering in their supplementary report.)
- Salvage logging: This is a common practice following wildfires in B.C., and it is applied with very little understanding of the positive or negative effects it might have on hydrologic response of a watershed following wildfire. We need to monitor the effects of various salvage logging practices on soil properties and on hydrologic processes, so that in the future we can make recommendations about salvage logging in high-risk watersheds.

A serious deficiency was noted in the Ministry of Forests' capability to do a risk analysis, which is our lack of in-house GIS support. Unless this situation is corrected, a MOF project team may be unable to do even simple tasks such as digitizing maps in a timely manner. Therefore we will probably have to contract out GIS support for the risk analysis projects in the event of a bad interface fire season. Since Protection already routinely contracts out GIS services for project wildfires, it may be of benefit to utilize their contractors for this task.

A related problem we discovered was the difficulty of getting timely access to common base-mapping products such as TRIM contour maps in GIS form. Largely this was due to problems with the outsourcing of our computer systems, which was happening at the same time this work was being done, and it may also have been due to rapid organizational changes in government agencies such as MSRM and LIBC. This problem may therefore have been a one-time occurrence.

Recommendations that can be made as a result of our work include:

- The burn severity maps based on Landsat imagery have great advantages over preliminary hand-drawn maps. Although the latter may be necessary to do a prompt initial identification of risks following a fire, we recommend that for large, complex, or high-risk fires, that a fire severity map based on Landsat imagery should also be prepared. This will be very useful for a more detailed analysis of longer-term hydrologic risks (i.e. longer than the several months immediately following a fire), and also for purposes such as input to salvage logging plans, planning possible rehabilitation activities, and communicating information about risks to other stakeholders.

- The possibility of using alternative remote sensing products, such as custom digital aerial photography, should be investigated. We see this imagery as being particularly useful for planning salvage logging, as well as for mapping soil burn severity.
- A standard field protocol should be developed for sampling soil water repellency and for assessing burn severity. To date, our investigation of hydrologic changes following wildfire has used unplanned, random field checks simply to detect the presence or absence of repellency. We found that a systematic design for collecting water repellency data had clear advantages, considering the local variability that was observed. In addition to providing better data on soil hydrologic changes, this will be useful for providing field check points for calibrating burn severity mapping.
- Fires which are identified as high-risk should be monitored for several years, to document hydrologic or mass movement events which may happen. This monitoring should include rainfall measurement, observations of changes in streamflow and stream channels, and observation of plots to document revegetation and recovery of soil properties. This will improve our ability to make accurate assessments of post-wildfire risks in the future.

List of appendices

- Appendix 1. Summary table of water repellency and burn severity data.
- Appendix 2. Field form.
- Appendix 3. Burn severity maps.
- Appendix 4. Photos.
- Appendix 5. Kuskonook and Sleetsis fires – Office analysis of watersheds.
- Appendix 6. Practical suggestions for making a preliminary burn severity map.
- Appendix 7. Descriptions of fire and burn severity.