Appendix 1: Summary table of water repellency and burn severity data

A: Detailed water repellency data collected at severely burned sites

Fire	Date	Site	GPS	Transect [a]	Plot	Depth [b] Inf. test	Inf. test, [c] first bubble	Inf. test, [d] mean rate	WDPT, % [e] of trench	WDPT, [f] depth	Repellency [g] category	Soil Burn [h] Severity
Sleetsis	2005-10-04	SL1	51	T1	0	0	4	0.50	30	2	H	
Sleetsis	2005-10-04	SL1	52	T1	10	0	3	0.63	40	2	H	
Sleetsis	2005-10-04	SL1		T1	30	2	2	1.74	10	1	L	
Sleetsis	2005-10-04	SL1		T1	60	3	3	1.44	0	1	M	
Sleetsis	2005-10-04	SL1	53	T1	100	0	2	2.38	0	1	L	
Sleetsis	2005-10-04	SL1	54	T2	0	0	5	0.29	20	1	H	
Sleetsis	2005-10-04	SL1		T2	10	0	4	0.42	40	1	H	
Sleetsis	2005-10-04	SL1		T2	30	0	2	2.62	5	1	L	
Sleetsis	2005-10-04	SL1		T2	60	3	1	3.74	0	1	L	
Sleetsis	2005-10-04	SL1		T2	100	3	2	1.59	5	1	M	
Sleetsis	2005-10-05	SL1	55	T3	0	0	4	1.14	10	1	M	
Sleetsis	2005-10-05	SL1		T3	10	3	3	2.32	5	1	M	
Sleetsis	2005-10-05	SL1		T3	30	0	2	0.79	70	2	M	
Sleetsis	2005-10-05	SL1		T3	60	3	3	0.91	50	2	M	
Sleetsis	2005-10-05	SL1		T3	100	2	1	2.82	0	2	L	
Sleetsis	2005-10-05	SL2	56	T4	0	2	3	0.91	70	2	M	
Sleetsis	2005-10-05	SL2		T4	10	3	5	0.63	60	2	H	
Sleetsis	2005-10-05	SL2		T4	30	2	3	1.50	20	2	L	
Sleetsis	2005-10-05	SL2		T4	60	2	3	0.67	40	2	M	
Sleetsis	2005-10-05	SL2	57	T4	100	3	13	0.17	50	2	H	
Sleetsis	2005-10-07	SL2	67	T5	0	1	5	0.46	70	1	H	
Sleetsis	2005-10-07	SL2	68	T5	10	0	9	0.10	90	1	H	
Sleetsis	2005-10-07	SL2		T5	100	0	10	0.46	70	1	H	
Sleetsis	2005-10-07	SL2	69	T6	0	3	25	0.46	90	1	H	
Sleetsis	2005-10-07	SL2	70	T6	50	2	99	0.10	90	1	H	

Notes:

a. This table is a summary of 300 infiltration measurements. Each plot included 3 replicates at 4 depths.
b. Depth in cm, at which the lowest infiltration rate was observed.
c. Mean (logarithmic) time in seconds, at which first bubble was observed in the infiltrometer, at depth noted. (99 = never)
d. Mean (logarithmic) infiltation rate at depth noted, in ml/min.
e. Water drop penetration test: % of trench over which time exceeded 10 seconds (moderate to strong repellency).
f. Water drop penetration test: depth of test in cm.
g. Repellency category: a subjective rating based on infiltration test and water drop penetration test. (0 = no repellency)
h. Soil burn severity: a subjective rating based on the 6 soil parameters on the field form. (U = unburned)

B: Reconnaisance data

Fire	Date	Site	GPS	Transect [a]	Plot	Depth [b] Inf. test	Inf. test, [c] first bubble	Inf. test, [d] mean rate	WDPT, % [e] of trench	WDPT, [f] depth	Repellency [g] category	Soil Burn [h] Severity
Sleetsis	2005-09-20	SR1	37		1	3	29	0.17	90	3	H	L
Sleetsis	2005-09-20	SR1	38		2	1	76	0.74	35	1	H	M
Sleetsis	2005-09-20	SR1	39		3	1.5	32	0.25	80	1.5	H	M
Sleetsis	2005-09-20	SR1	40		4	2	1	1.91	15	2	L	U
Sleetsis	2005-09-21	SR2	51		5	2	1	2.00	70	2	M	H
Sleetsis	2005-09-21	SR2	42		6	2	6	0.39	10		M	L
Sleetsis	2005-09-21	SR2	43		7	0.5	0	9.00	0	0.5	0	U
Sleetsis	2005-09-21	SR3	44		8	2	0	1.50			L	M
Sleetsis	2005-09-21	SR3	45		9	1	13	0.17	90		H	M
Sleetsis	2005-09-21	SR4	46		10	1	0	5.66	10	1	L	M
Sleetsis	2005-09-21	SR4	47		11	0.5	0	5.50	15	0.5	L	M
TownCr	2005-09-22	TR5	48		1	1	99	0.10			H	M
TownCr	2005-09-22	TR5	49		2	1	5	0.40			H	M
TownCr	2005-09-22	TR5	50		3	1	3	0.45			H	L
TownCr	2005-10-06	TK1	58		1				85	0	H	M
TownCr	2005-10-06	TK1			2				80	1	H	
TownCr	2005-10-06	TK2	59		1				15	0.5	L	H
TownCr	2005-10-06	TK3	61		1				15	0.5	L	
TownCr	2005-10-06	TK4	62		1				10	0.5	L	L
TownCr	2005-10-07	TK5	63		1				45	0.5	L	M
TownCr	2005-10-06	TK5			2				0	1	0	
TownCr	2005-10-06	TK6	64		1				80	0.5	H	M
TownCr	2005-10-06	TK6	65		2				30	0.5	M	
TownCr	2005-10-06	TK6	66		3				40	0.5	M	
Kuskonook	2005-07-28		9								H	H
Kuskonook	2005-07-28		27								H	H
Kuskonook	2005-07-28		28								H	M
Kuskonook	2005-07-28		29								M	H
Kuskonook	2005-07-28		30								H	L
Kuskonook	2005-07-28		31								H	H
Kuskonook	2005-07-28		32								H	H
Kuskonook	2005-07-28		33								0	L
Kuskonook	2004-09-13		8								H	

Notes: This table includes data collected on various recconaisance traverses.
For heading notes, see previous page.

Appendix 2. Field form used for the Sleetsis and Town Creek fires, 2005.
(next page)

_____ FIRE – BURN SEVERITY ASSESSMENT 2005 **PJ Sept 2005**

Plot Number_____ GPS #_____ Crew/date:_____

Soil and Litter Parameter	**Burn Severity**		
	Low	**Moderate**	**High**
Litter	Scorched, Charred, Consumed		Consumed
Duff (FH layers)	Varies: intact – consumed in few locations,		Consumed in most locations
Woody Debris – Small	Partly Consumed, Charred or consumed		Consumed
Woody Debris – Logs	Charred		Many consumed, others deeply charred
Mineral Soil Exposure	0 – 40%		>40%
Depth in mineral soil to live roots or rhizomes.	0 - 5 mm		> 5mm

	Burn Intensity			
Tree canopy	Mostly alive	Mostly dead; needles remaining	Dead; no needles; some twigs & cones	Dead; trunk and large branches only

SLOPE up and down _____ % _____%

% COVER green vegetation _____%

Size of surrounding area similar to plot: _____ ha

Evidence of runoff/overland flow?(circle):
Puddle terracettes, rilling, miniature hoodoos, sand deposits

Water Repellency Guidelines

DIG A 50 CM TRENCH INTO THE LIGHTER COLOURED MINDERAL SOIL, TYPICALLY ABOUT 1 TO 2 CM INTO THE MINERAL SOIL, DRIP WATER ALONG THE TRENCH AND OBSERVE THE % OF THE TRENCH IN THE FOLLOWING CATEGORIES (EG, 60 % STRONG, 40 % WEAK):

1. Degree of **Water-Repellency**. The degree of **water-repellency** is based on the time required for the absorption of a drop of **water** on a dry soil surface:

i. None – absorbs immediately _____% of trench
a. Weak - Less than 10 seconds. _____% of trench
b. Moderate - Between 10 and 40 seconds. _____% of trench
c. Strong - Longer than 40 seconds. _____% of trench

Appendix 3

Burn severity maps

Figures 1 and 2 below show two types of burn severity maps, for the Kuskonook and Sleetsis fires. The first map in each pair is the severity map based on Landsat imagery. The second map is preliminary sketch map made from photos taken from the helicopter, during the reconnaissance trip.

Following these figures are examples of the burn severity maps prepared by the Selkirk Geospatial Research Centre: Sleetsis, Botanie, Town Creek, and Okanagan Mountain Park (Kelowna) fires, made in 2005-06 as part of this project; and Kuskonook, made in 2004-05. These are followed by a location map.

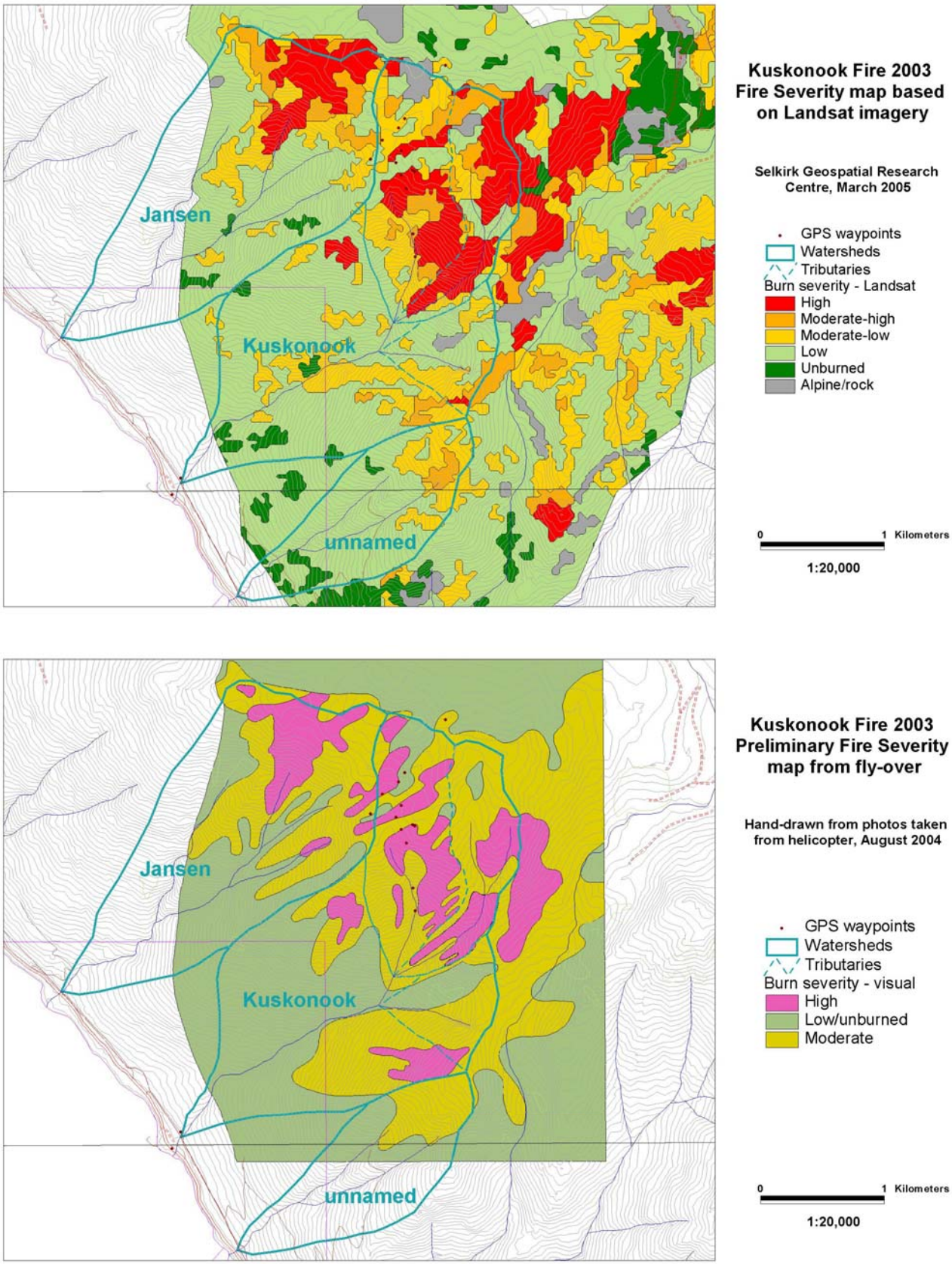


Figure 1. Kuskonook fire: Satellite-based burn severity map (top) and preliminary hand-drawn severity map (bottom).

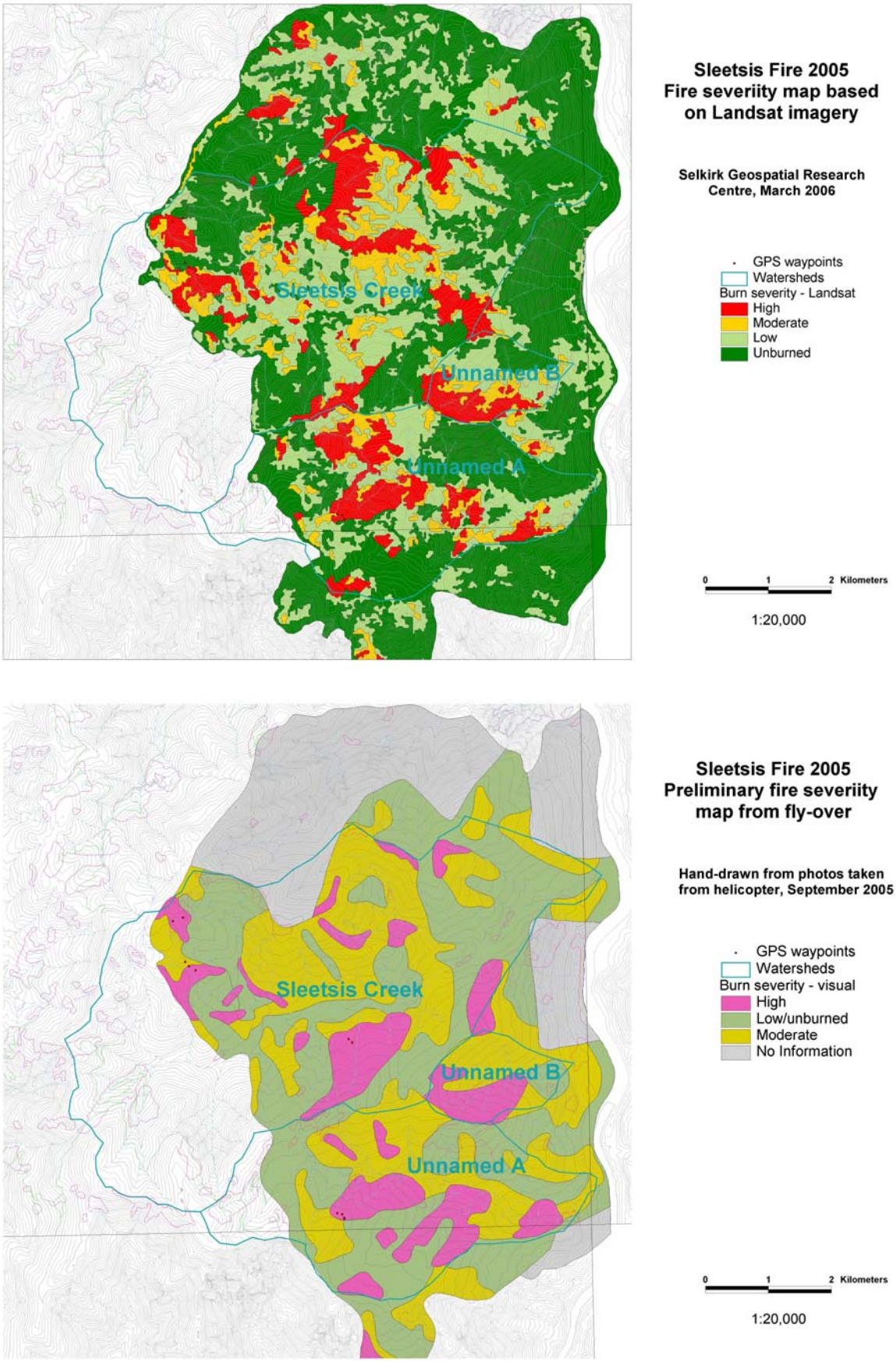
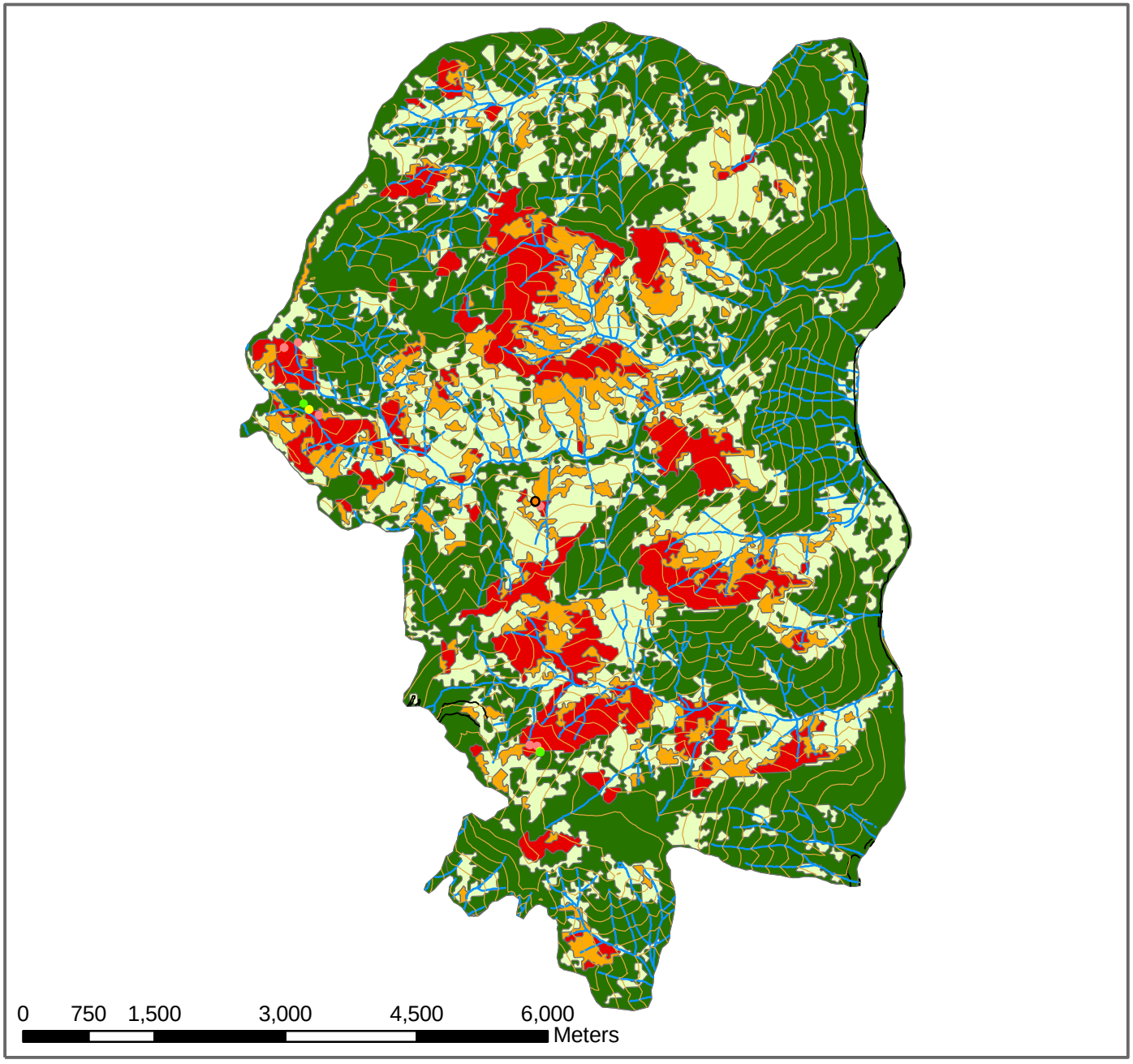
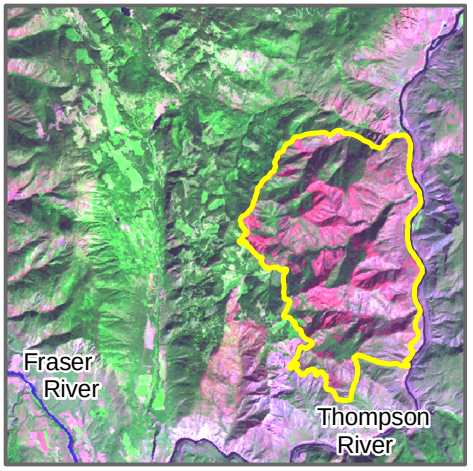


Figure 2. Sleetsis fire: Satellite-based burn severity map (top) and preliminary hand-drawn severity map (bottom).

2005 Sleetsis Fire Severity Mapping





Severity Levels

- High Severity
- Moderate Severity
- Low Severity
- Unburned
- Roads
- Rivers and Streams
- Contours

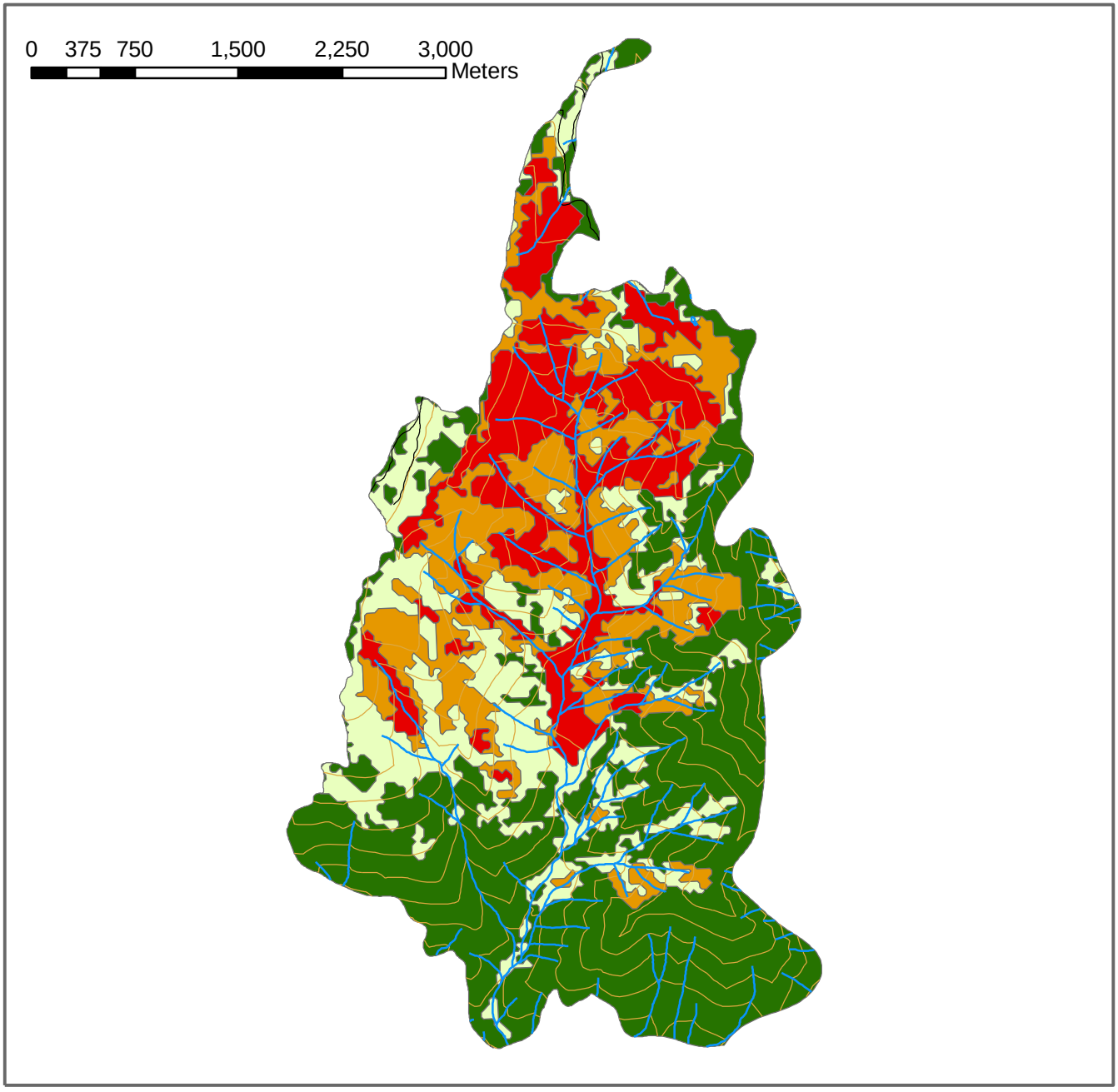
Classification based on Landsat 5 satellite images (path 45, row 26).
Date pre-fire image: August 18, 2004
Date post-fire image: September 06, 2005

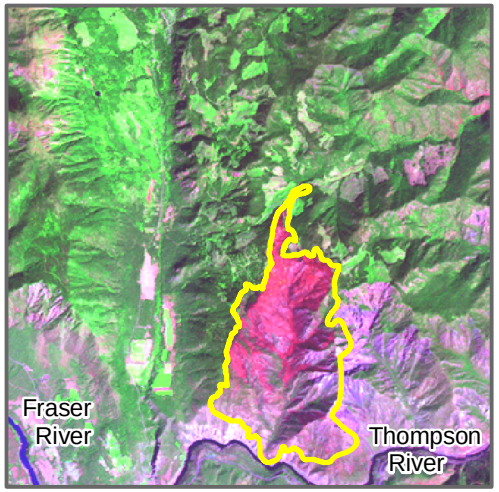
Map Created by:
Robert Magai and Rhian Davies
Selkirk Geospatial Research Centre
Selkirk College
Castlegar

February 10, 2006

5

2004 Botanie Fire Severity Mapping





Severity Levels

- High Severity
- Moderate Severity
- Low Severity
- Unburned
- Roads
- Rivers and Streams
- Contours

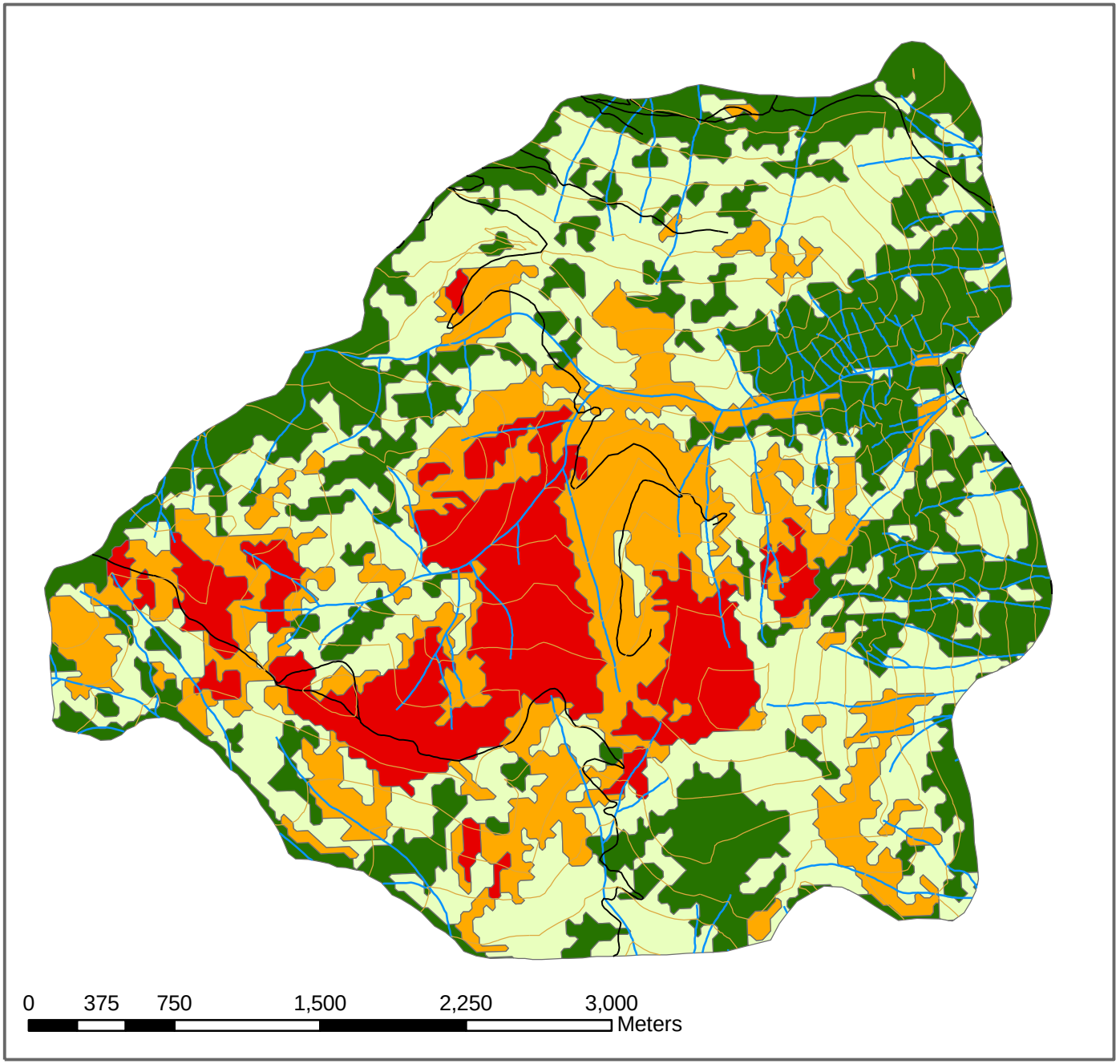
Classification based on Landsat 5 satellite images (path 45, row 26).
Date pre-fire image: July 12, 2002
Date post-fire image: August 18, 2004

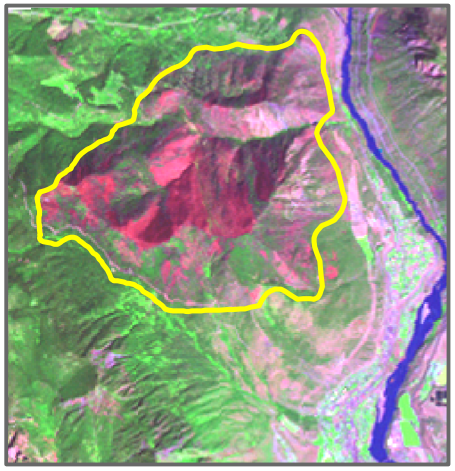
Map Created by:
Robert Magai and Rhian Davies
Selkirk Geospatial Research Centre
Selkirk College
Castlegar

February 20, 2006

5

2004 Town Creek Fire Severity Mapping





Severity Levels

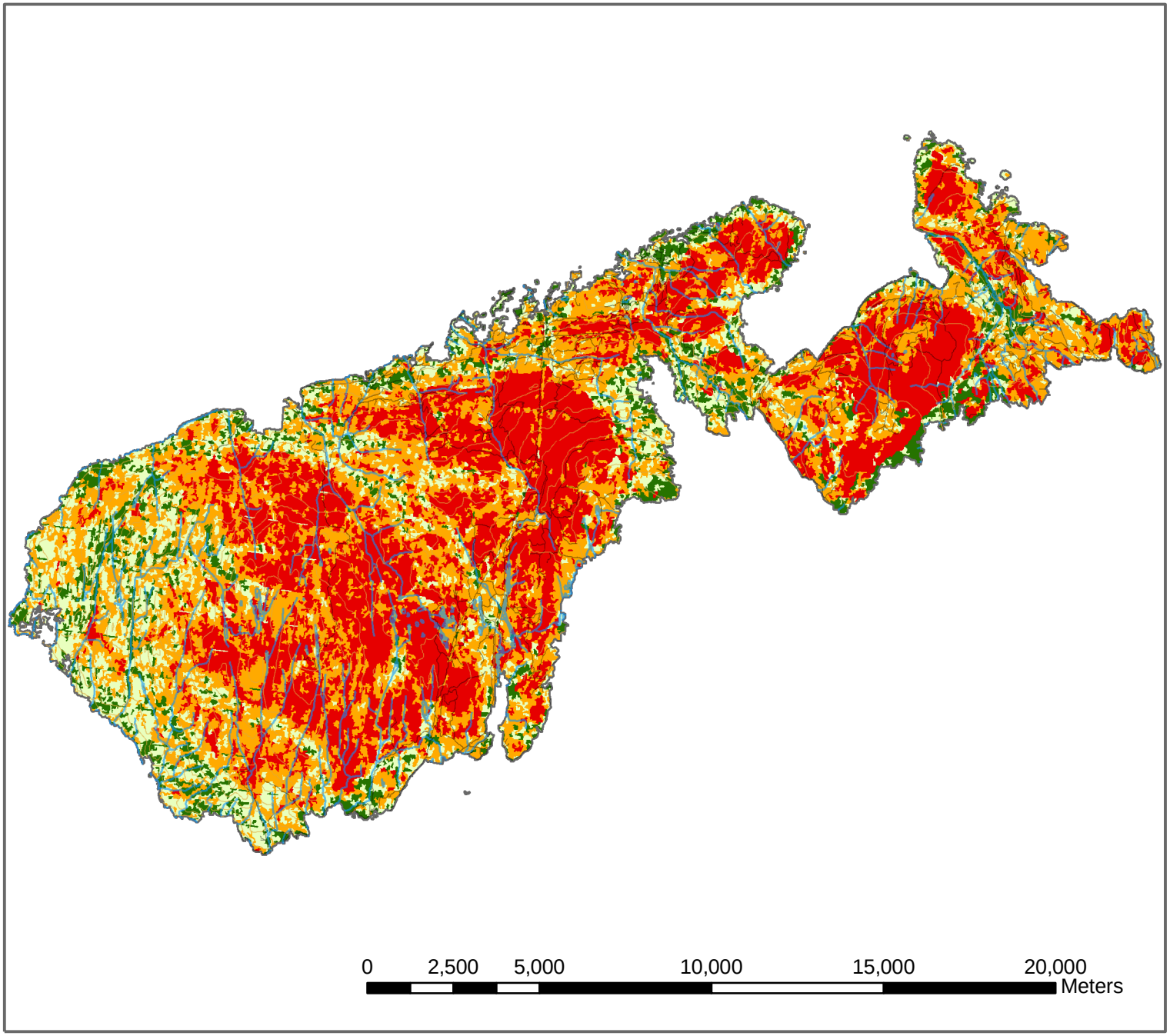
- High Severity
- Moderate Severity
- Low Severity
- Unburned
- Roads
- Rivers and Streams
- Contours

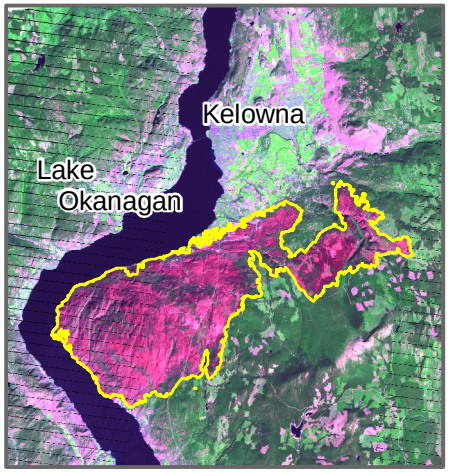
Classification based on Landsat 5 satellite images (path 45, row 26).
Date pre-fire image: July 12, 2002
Date post-fire image: August 18, 2004

Map Created by:
Robert Magai and Rhian Davies
Selkirk Geospatial Research Centre
Selkirk College
Castlegar

February 10, 2006

2003 Kelowna Fire Severity Mapping





Severity Levels

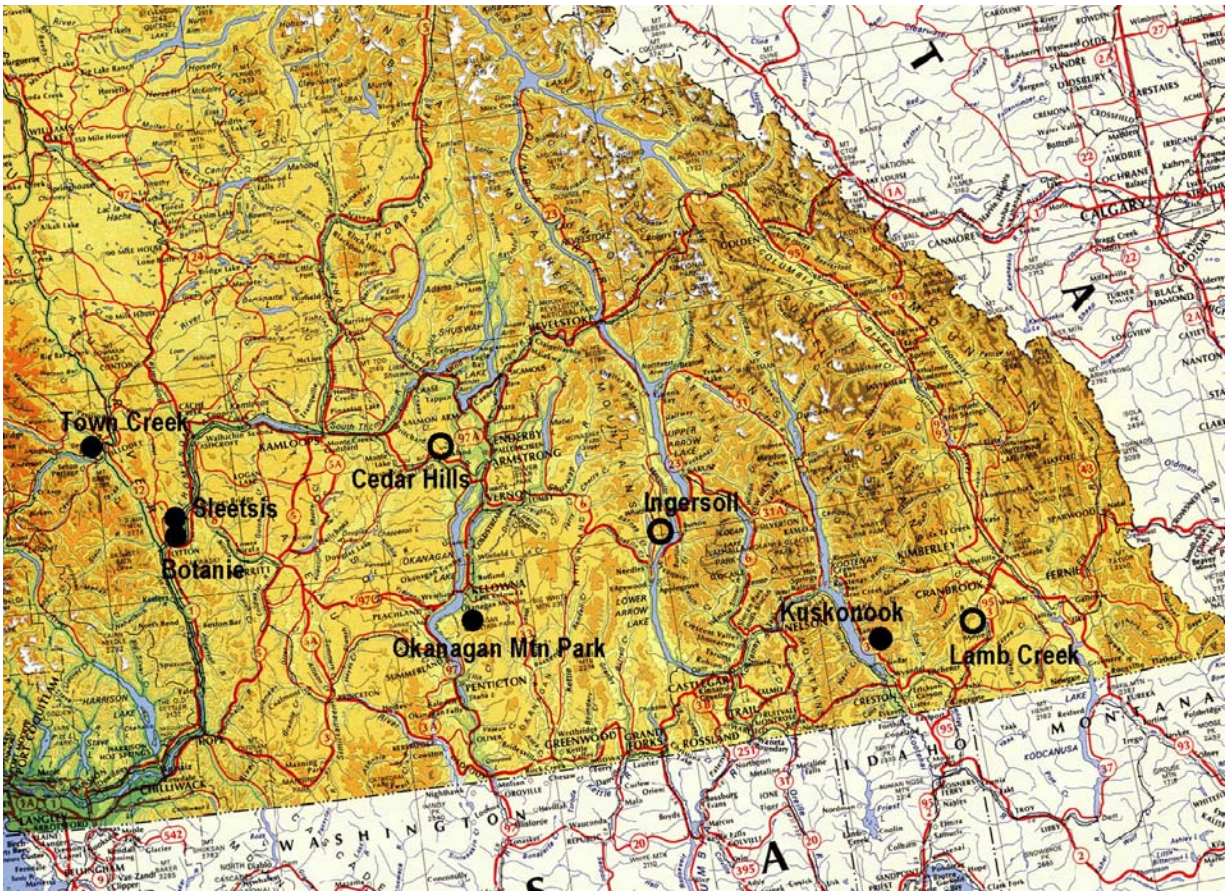
- High Severity
- Moderate Severity
- Low Severity
- Unburned

- Contours
- Roads
- Rivers and Streams

Classification based on Landsat 7 satellite images (path 45, row 25)
Date pre-fire image: Aug 23, 2002
Date post-fire image: Sept 27, 2003

Map Created by:
Robert Magai and Rhian Davies
Selkirk Geospatial Research Centre
Selkirk College
Castlegar

February 24, 2006



Location map and summary of fires

Map showing the location of fires on the preceding pages (closed circles), and other fires referred to in this project (open circles).

Summary information on the fires:

Fire	number	area (ha)	reported start date	burn severity map complete March 2006
Okanagan Mtn Park	K50628	25 900	16 Aug 2003	yes
Cedar Hills	K40300	1 600	1 Aug 2003	no
Kuskonook	N70820	4 800	27 Aug 2003	yes
Lamb Creek	N10470	11 900	7 Aug 2003	no
Ingersoll	N50617	6 700	10 Aug 2003	no
Town Creek	K70099	1 500	18 June 2004	yes
Botanie	K70172	1 500	24 June 2004	yes
Sleetsis	K70135	5 600	29 July 2005	yes

Appendix 4 Photos

1. Sleetsis fire: Example of one of the photos taken from the helicopter, used to prepare the preliminary fire severity map. The helicopter landing point, and the locations of four field plots, are marked.

Several small debris flows occurred after the fire and before the time of photography (20 Sept 2005), in the lower-right part of the photo (not clearly visible). There is also evidence of older debris flows in the valley bottom.

2. Severe, moderate, and low burn severity near headwaters of Sleetsis Creek. Several plots were located on the ridge, just left of centre.

3. Severe burn along stream channel, headwaters of Sleetsis Creek.

4. Water drop penetration test, at a severely burned plot, Sleetsis fire. Typically, the soil is scraped off to expose surfaces at several depths, and the test is repeated to identify the depths at which repellency exists.

5. Water drop penetration test. Note the drop remaining on the surface, just below the spout.

6. Testing infiltration rate with the mini-disk infiltrometer,

7. Testing infiltration rate at an unburned control plot, Sleetsis fire.

Appendix 5: Kuskonook and Sleetsis fires – Office analysis of watersheds (for discussion as part of the test of post-wildfire risk analysis methods)

1. Kuskonook fire, 2003, N70820

- The three watersheds above Hwy 3A were identified as being at risk from post-fire debris flows, in an overview risk assessment done by Doug Nicol after the fires in 2003.
- Debris flows occurred on Kuskonook and Jansen Creeks in August, 2004. Several of us did field investigations after the events, in 2004 and 2005.
- For documentation see internal MOF memos, Jordan et al (2004), and VanDine et al (2005).
- A landsat-imagery-based fire severity map was made in 2004-05.
- The following table is based on office analysis of the maps, and is intended to address the question, "what would we likely have done, if we did a risk analysis following the fire?"

watershed	Kuskonook	Jansen	unnamed
area (ha)	504	351	135
Elevation range (m)	560-2130	560-2120	560-1700
relief (m)	1570	1560	1140
Melton ratio [1]	0.70	0.83	0.98
Typical fan slope [2]	17%	26%	– [3]
Typical channel slope, mid-watershed	35-50%	35-65%	45-55%
Typical channel slope, headwaters	20-65%	60-70%	50-60%
Terrain stability "U"	0	0	0
Terrain stability "P"	22%	43%	14%
Fan identified in previous mapping as subject to debris flows	yes	yes	yes
Historical or air photo record of recent debris flows	no	no	no
"Gentle-over-steep" (burn on plateau draining into steep channels)	yes	yes	no
Mainstem channel riparian zone severely burned	no	no	no
Fan/channel morphology	subject to avulsion	subject to avulsion	?
Elements at risk	houses on fan (~6), highway, marina, water intakes	houses on fan (~2), highway	highway
Burn severity: H	15%	10%	0
M	29%	19%	21%
burn concentrated in:	headwaters	headwaters	headwaters

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 Fan slope and other slopes are approximate, measured on TRIM maps (20 m contour)
3 – = no information available

2. Sleetsis fire, 2005, K70135

- We chose this fire as an example in 2005, for testing of our risk analysis methods.
- Field work in Sept-Oct 2005 focused on measurement of water repellency.
- Two fire severity maps have been prepared – one is landsat-imagery-based, being done by Selkirk College; the other is a preliminary sketch map based on photos taken during a helicopter overflight.

watershed	Sleetsis	Unnamed A	Unnamed B
area (ha)	2927	1195	220
Elevation range (m)	260-1800	240-1790	340-1390
relief (m)	1540	1550	1050
Melton ratio [1]	0.28	0.45	0.71
Typical fan slope	16%	18%	17%
Typical channel slope, mid-watershed	10-15%	15-35%	30-50%
Typical channel slope, headwaters	20-60%	35-60%	55-65%
Terrain stability "U"	–	–	–
Terrain stability "P"	–	–	–
Fan identified in previous mapping as subject to debris flows	–	–	–
Historical or air photo record of recent debris flows	no	no	no
"Gentle-over-steep" (burn on plateau draining into steep channels)	no	no	no
Mainstem channel riparian zone severely burned	no	no	no
Fan/channel morphology	incised	incised	large dry fan, no active channel, not incised
Elements at risk	railway	railway	railway
Burn severity: H	11%	16%	29%
(Landsat map) M	9%	8%	18%
Preliminary burn severity H	10%	20%	40%
(hand-drawn visual map) M	27%	30%	48%
burn concentrated in:	middle, headwaters (mostly in two tributaries)	middle, headwaters	headwaters

Discussion:

The work on Kuskonook Creek was done after the debris flow event, which occurred one year after the fire. The data in the table, and air photo interpretation and previous mapping, indicates that all three creeks are debris flow dominated, with events on Kuskonook and Jansen occurring infrequently (return period of 100 to several hundred years). Field work on the fans confirmed that the fans are subject to debris flows, which could reach the elements at risk.

Field work in the upper watershed of Kuskonook Creek showed extensive water repellency, persisting one to two years after the fire, which was apparently strongly correlated to burn severity. In hindsight, it's obvious that the extent and severity of burn was enough to greatly increase the debris flow hazard.

I would suggest that this office exercise, combined with reconnaissance field work, shows that the debris flow risk on Kuskonook and Jansen Creeks is high, without the need for more detailed field work. On the small unnamed watershed, further field work would be needed to determine debris flow hazard and consequence (this has never been done); the data in the table suggests the hazard is moderate.

The table for the Sleetsis fire indicates that the two large watersheds (Sleetsis and Unnamed A) are not subject to debris flows. The small watershed (Unnamed B) may be subject to debris flows (which probably formed its large, dry, apparently inactive fan). Sleetsis and Unnamed A may be subject to debris floods, although their channels and watersheds appear to be geomorphically inactive, upon casual observation.

Field work after the fire showed that water repellent soils were present, but were sporadic in occurrence and not well correlated with burn severity. This observation, and the data in the table, suggest that Sleetsis and Unnamed A may have a moderate post-wildfire hazard of debris floods, especially Unnamed A. Unnamed B may have a significant debris flow hazard due to the extent of severe burn. Further field work on the fans and channels would be necessary to confirm the hazard and consequences on all three watersheds.

P. Jordan, February 2006

Appendix 6: Practical suggestions for making a preliminary burn severity map

These suggestions result from my experience in 2005 making burn severity maps of the Sleetsis and Kuskonook fires, using hand-held photos taken from a helicopter.

1. Taking the photos

It is recommended to base the map on a well-planned series of oblique photographs, rather than trying to draw directly on a map while airborne. (The latter method requires a lot of experience and an iron stomach.)

Use a good quality camera (film or digital) with a wide-angle lens, 24 mm (preferably), or 28 mm. Very few non-SLR digital cameras have wide-angle lenses; most only go to the equivalent of 35 or 38 mm. Add-on wide-angle lenses can be obtained for some cameras. The best choice for a compact digital camera is the Nikon Coolpix 8400, which has the equivalent of a 24-85 mm lens. As the cost of a camera is small compared to the cost of a helicopter flight, it may be worth buying a camera specifically for this task.

Use a fast shutter speed to avoid blurring from the aircraft's vibration. With a digital camera, you may have to use a high ISO setting. You should shoot through an open window; if this is not possible, then it is essential that your camera have an infinity setting (i.e. disable the autofocus.)

With a film camera, you have 3 choices: (a) use print film; (b) use slide film, and make the map while projecting the slides on a screen; (c) use slide film, and if you have a good-quality slide scanner, convert the slides to digital images. A polarizing filter is likely to produce better photos. If using one, you should use ISO 400 film. (It might be worth experimenting with infrared film. I have no experience with this. It is expensive, slow, and contrasty.)

Take the photos from a helicopter or airplane with a window which opens (this is important). Have the pilot fly as high as possible (probably around 10,000 ft). The photos should be taken so the angle of view goes from almost straight down, to just below the horizon.

The best results will be obtained on a clear sunny day, or a high overcast day, at or before mid-day. Partly cloudy conditions are difficult due to strong shadows. For best contrast, the photos should be taken at about right angles to the sun. Also, it is best to be looking upstream in the drainages of interest. Plan your flight lines to take advantage of this. For example, suppose the drainages slope towards the east; you will want to be facing west. Since you will be sitting on the left side of the helicopter (in most machines), have the pilot fly directly away from the sun (i.e. north). Start a bit east of the edge of the fire, and fly the first flight line, taking a photo every 0.5 to 1 kilometre. Then go back to the south end, and fly another flight line about 1 to 2 km further west. The number, orientation, and pattern of flight lines will depend on the size and shape of the fire.

2. Making the map

The objective of drawing the map is to cover the entire area of the burn with polygons delineating severe, moderate, and low burn severity, and unburned areas, based on the appearance of the forest canopy. These categories are identified basically on the colour of the canopy: black/grey, red, or green with red patches. Burned clearcuts are difficult to judge; in my experience, they can look severe when a Landsat-based burn severity map rates them as moderate. Some ground field checks will enable you to draw a better map.

If you took digital photos, you can manipulate the contrast and colour balance to improve the photos.

The best base map is an orthophoto (preferably), or a medium-resolution satellite image (5 m pixel size or better). This should be printed at 1:20,000 on a plotter, optionally with an overlay of contours and hydrographic features. (For small fires, a scale of 1:10,000 may work better.) If there is no imagery available, then use a TRIM contour map; however, it will be much more difficult to transfer information accurately from your photos to the map. Use a red Omnichrome pencil (or equivalent) to draw the polygons, if using a photographic base map.

If you used a photographic base map, you will probably have use a light table to trace the polygons onto another base map for digitizing. Once digitized, the map can be brought into a GIS for further analysis.

P. Jordan, March 2006

Appendix 7.

From Curran, M., Chapman, B., Hope, G., and Scott, D. (under review), Large-scale Erosion and Flooding after Wildfires: Understanding the Soil Conditions. Unpublished technical report, British Columbia Ministry of Forests, Southern Interior Forest Region, November 2005.

Appendix . Descriptions of fire and burn severity

Two terms can be used in assessing fire impacts on hillslopes: fire severity and burn severity (Table 1). Fire severity refers to fire effects on the overstorey and understorey vegetation. Burn severity relates to the severity of the effects of the fire on soil hydrologic function (Table 2), and is a collation of the terms described in more detail in this document.

Table 1. Descriptions of fire and burn severity

Fire severity	A general term describing the combined effects of flaming and smouldering. It is inferred after the fact from fire impacts on a range of attributes, predominantly overstorey and understorey. Three suggested classes are used.	Low: canopy unburned, trunks partially burned, understorey lightly or patchily burned Medium: trees burned and dead, scorched needles remain, understorey burned High: trees blackened and dead, needles consumed, understorey burned
Burn severity	A relative measure describing the effects of the fire on soil hydrologic function. Classes of burn severity are generally high, moderate, low, and unburned.	Low: litter scorched or consumed, FH layers intact, mineral soil unchanged Moderate: litter consumed, FH layers consumed or deeply charred, mineral soil unchanged High: forest floor consumed, ash often thick, mineral soil has altered structure, porosity, etc.

Note: These definitions have been adapted from Canadian Interagency Forest Fire Centre. (2000); U.S. definitions are slightly different.

Table 2. Burn severity classification based on post-fire appearances of litter and soil and soil temperature profiles (adapted from Robichaud et al. 2000, based on DeBano et al. 1998)

Soil and litter parameters	**Burn severity**		
	Low	**Moderate**	**High**
Litter	Scorched, Charred, Consumed	Consumed	Consumed
Duff (FH layers)	Intact, Surface Char	Deep Char, Consumed	Consumed in most locations
Woody debris – Small	Partly Consumed, Charred	Consumed	Consumed
Woody debris – Logs	Charred	Charred	Many consumed, others deeply charred
Ash colour (if still present)	Black	Light Coloured	Fine, white
Mineral soil exposure (may still be covered with loose ash or charcoal)	Little	< 40%	> 40%
Mineral soil	Not Changed	Not Changed; water repellency is slight or patchy	Altered Structure, Porosity, etc. Often reddish, and often strongly water-repellent
Depth to live roots or rhizomes (in mineral soil)	0 mm	0–5 mm	> 5 mm
Soil temp. at 10 mm[a]	(< 50°C)	(100–200°C)	(> 250°C)

[a]Usually assessed by indirect methods.