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SURVIVAL ZONES FOR WILDLAND FIREFIGHTERS

A CASE STUDY AT VINE CREEK IN JASPER NATIONAL PARK

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ABSTRACT:

Data was collected within a burned out area on a steep mountain slope as part of FPInnovations's Survival Zone project. The fire was a prescribed burn carried out by Parks Canada in Jasper National Park. The data collected shows that in this one instance, that temperatures and heat flux values fell within survivable range for firefighters wearing PPE. This report does not condone firefighters above a fire on a steep slope, but rather this PB was used as a data collecting opportunity.

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1 INTRODUCTION

FPInnovations is investigating firefighter survival in forest fires based on the dimensions of an opening and the fire behaviour in the surrounding vegetation. To date, data have been collected in openings in grass (ten cases) and in the forest on flat terrain (four samples). An opportunity arose to collect data on a steep slope site in Jasper National Park in 2015. This would be our first attempt at collecting data to determine human survivability in an opening on a steep slope.

Jasper National Park staff carried out a prescribed fire along Vine Creek on May 23, 2015. One of the objectives of this burn was to create a capping unit designed to prevent fire spread to keep fires inside Jasper National Park—a landscape-level firebreak. FPInnovations was contacted about the prescribed fire by Parks Canada and both parties agreed that such a planned fire could be used to provide valuable data for FPInnovations' survival zone project (figure 1).

Three elements of this prescribed fire interested us:

- It was a prescribed fire, meaning that Jasper National Park staff would have an influence on when and where the fire would be ignited.
- The fire was to take place on steep terrain, something we have not yet been able to collect data on.
- We were able to use a previously burned area, which was 0.38 ha in size, to simulate an area of refuge similar to that used by Wag Dodge during the 1949 Mann Gulch Fire in northwestern Montana (Alexander, Ackerman, & Baxter, 2009).

The ignition pattern was managed so that extreme fire behaviour would challenge our study area and provide the best possible opportunity for data collection. We will refer to the area where our equipment was placed (a previously burned area) as the "burned-out area." This area was burned earlier in the spring by Jasper National Park staff to protect white pine in the area.

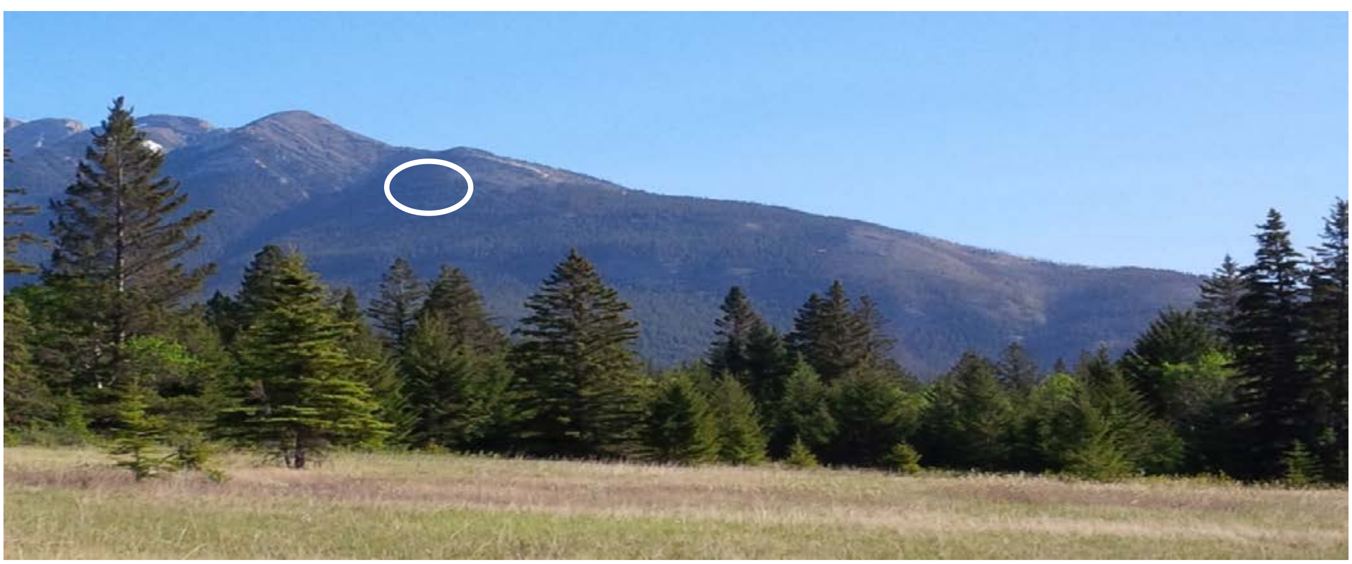

Figure 1. Overview of the Vine Creek prescribed burn location. The white circle indicates the location of the survival zone test.

2 OBJECTIVE

FPInnovations set out to determine if a particular sized (0.38 ha) burned-out area on a steep slope could be used as a potential survival zone for entrapped firefighters. Wildfire engagement procedures outline the extreme hazard of operating upslope from an advancing wildfire due to accelerated fire behaviour, and should be actively avoided. Historical accounts, such as the Mann Gulch fire of 1949, demonstrate how quickly conditions can deteriorate and result in firefighters in an up-slope entrapment. The Vine Creek prescribed burn presented an ideal scenario to collect data on a slope in a previously burned area.

3 FIRE ENVIRONMENT

3.1 Fuels

C-3 (mature jack pine or lodgepole pine) was the primary Canadian Forest Fire Behaviour Prediction System (FBP) fuel type (Taylor and Alexander 2016) on the upper slopes. C-2 (boreal spruce) was more common at the lower elevations, although both fuel types were present within the prescribed fire unit.

Surface fuel loading was light and the organic layer was less than 10 cm thick in most of the unburned areas at the elevation of the research site. Within the burned-out area, the organic layer was less than 2 cm thick.

The site selected to act as a survival zone was burned earlier in the spring. It was blackened and most trees had been stripped of all needles and small branches. The site was surrounded by trees that had needle kill, but were still attached to the trees (Figure 2(A)).

3.2 Topography

The topography was considered steep, with slopes ranging from 36% to 119% (Figure 2(B)). The site was primarily covered in timber, but there were open rock outcrops and grass areas interspersed over the prescribed fire unit. The survival zone lay on a 50% slope inside the prescribed fire unit. The site had a southwest aspect or slope exposure and was situated at an elevation of 1800 m above mean sea level (MSL).

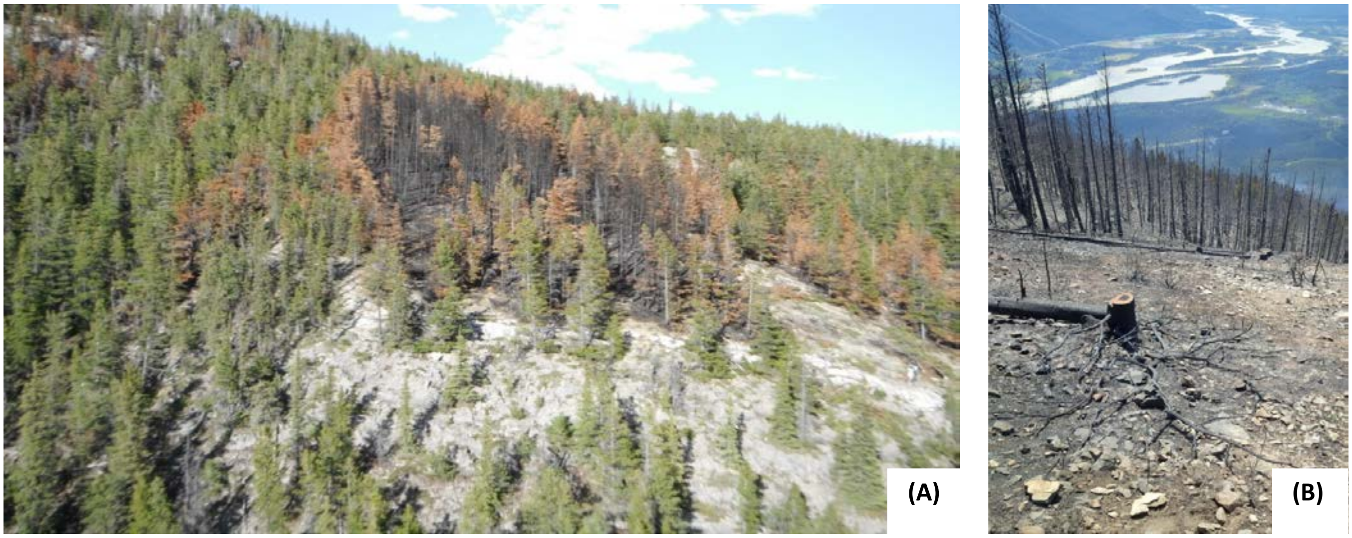

Figure 2. Burnt area that served as the safe zone for the experiment (A) and looking down the exposed, rocky slope beneath the survival zone (B).

3.3 Fire weather, fire danger and fire behaviour potential

The forecasted fire weather and fire danger indices for May 23, 2015 at 1300 h are shown in Table 1.

Table 1. Actual weather observations and forecasted Canadian Forest Fire Weather Index System components fire weather indices at time of ignition. Weather observations are from a valley bottom station

Temperature (°C)	Relative humidity (%)	Wind direction	Wind speed (km/h)[1]	24-h rain (mm)	
23	17	SE	10 - 15	0	
FFMC	DMC	DC	ISI	BUI	FWI
94	37	231	13	53	27

[1]As measured at a height of 10 m in the open

The predicted fire behaviour based on the above burning conditions and FBP System fuel types (Taylor and Alexander 2016) were:

- C-2 boreal spruce: continuous crown fire, forward rate of spread (ROS) of 22 m/min, head fire intensity class 6.
- C-3 mature lodgepole pine: intermittent crown fire, forward ROS of 14 m/min. head fire intensity class 4.

These values are indicative of high to extreme fire behaviour potential.

The atmosphere was super-adiabatic on the day of the prescribed fire, producing unstable conditions. Super-adiabatic is defined by a vertical temperature lapse rate greater than 10°C/1000 m. This type of lapse rate produces an atmosphere that facilitates turbulence due to aggressive mixing and is capable of contributing to extreme fire behaviour scenarios. The lapse rate on May 23, 2015 was 12°C/1000 m from Stony Plain sounding data which is located about 250 km to the east.

4 METHODS

4.1 Study site

The survival zone was located directly above a rocky slope that increased the size of the survival zone. The total size of the burned-out and rocky area was roughly 82 x 56 m (i.e., 4592 m^2 or 0.46 ha).

We selected four data collection points (labelled 1, 2, 3, and 4 in Figure 3). Three points (1, 2 and 3) were located within the previously burned area, while the remaining point (4) was situated at the top of the rock outcrop adjacent to the lower part of the burned-out area.

Each data collection point had an in-fire camera box recording high definition video, a temperature sensor (°C), and a heat flux sensor (kW/m^2). The study site also contained three flat heat flux sensors placed approximately 10 m below and above the four data collection points so that data were collected from a larger area within the burned-out area. These sensors sat flat on the ground and collected heat flux data occurring above them (180° field of view). Two cameras were placed on the ground to simulate a firefighter lying prone, whereas the other two cameras were placed a metre above the ground. .

The burned-out area containing points 1, 2, and 3 was 3 823 m^2 (0.38 ha) in size. The rocky out-crop clearing in front of the burned-out area was 769 m^2.

Figure 3. Post-fire view of the data collection points within the survival zone site.

4.2 Ignition

Ignition of the site began on May 23, 2015 at 1450 h by initially burning off some higher elevation areas behind the research area. This was achieved using an aerial drip torch (helitorch) to deploy strips of fire across the upper slope and allowing the fire to run to the ridge line. This acted as a fireguard in the upper reaches of the prescribed fire unit. Once this was completed, ignition moved downslope using wider strips. To ensure the survival zone would be challenged by extreme fire behaviour, at 1517 h a strip of fire was ignited about 100 m downslope of the research site. The ensuing flame front gained sufficient momentum to run up to, and challenge the research area, as indicated in figure 4.

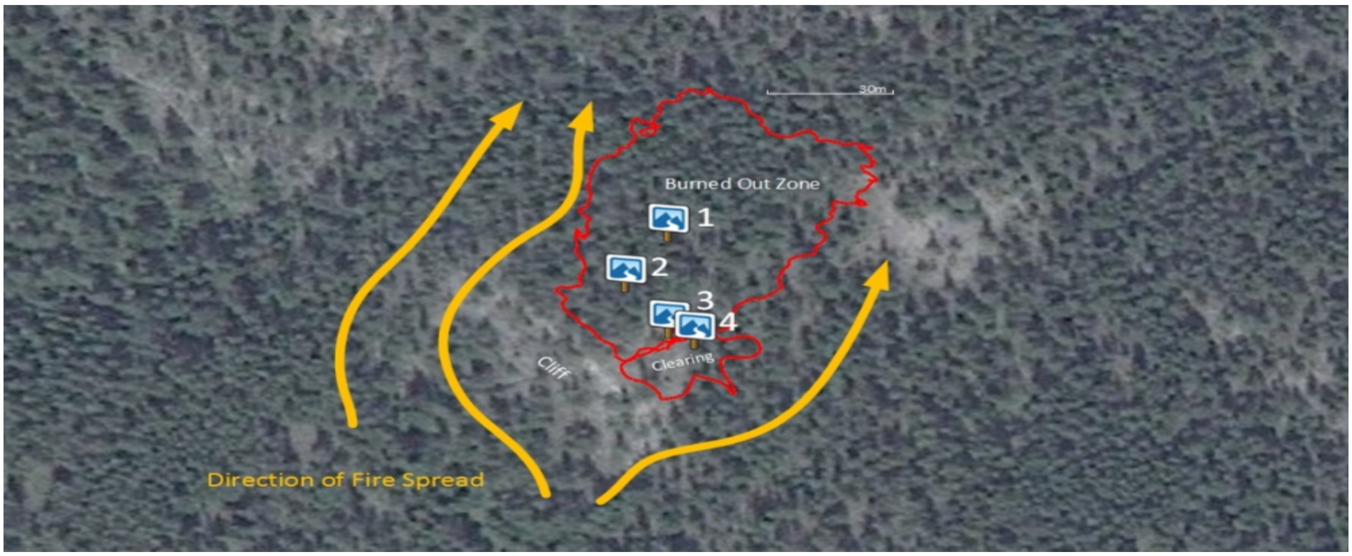

Figure 4. The path of the flame front around the survival zone resulting from the line of fire established by aerial ignition below the site.

5 RESULTS

5.1 Fire behaviour

The area surrounding the survival zone was completely burned by high-intensity crown fire. Because aerial ignition was used in a stripping manner across the mountainside to control fire growth, head fire rates of spread could not be determined. However, it did not take long for the burning gel fuel dropped from the helicopter to develop into a crown fire and begin travelling upslope. Observed flame heights reached a minimum of 2.5 times tree height but at times were estimated by the Incident Commander from a helicopter to be occasionally as high as 150 m. FPInnovations estimated that the head fire intensity immediately adjacent to the left of the survival zone to be at least 10 000 kW/m.

5.2 Temperature and heat flux

Table 2 shows the maximum temperature and heat flux collected by each in-fire camera box.

Table 2. Temperature and heat flux values

Camera box number	Maximum temperature (°C)	Maximum heat flux (kW/m^2)
1	40	2.8
2	43	2.8
3	69	3.2
4	24[2]	16.4

[2]This temperature appears low for this location.

The flat sensors recorded the following values:

- #F1 : 17.4 kW/m^2 (located 10 m below data collection point 4)
- #F2 : 3.2 kW/m^2 (located 10 m to the right of data collection point 1)
- The third sensor failed to collect useable data

The temperature and heat flux values recorded suggests survivable conditions. The 16.4 kW/m^2 heat flux measured at point 4 lasted for 13 seconds. Ackerman (2010) showed that in full personal protective equipment (PPE), a firefighter can endure around 15 kW/m^2 for about 22 seconds before second-degree burns occur.

Flat sensor #F1 recorded the heat flux of the longest duration. The sensor was located 10 m below data collection point 4 in the lower rock opening and, thus, was the most exposed to crown fire. It recorded values of 5 kW/m^2 for 6 minutes.

6 DISCUSSION

The weather on May 23, 2015 and the extended dry spell leading up to the burning of Vine Creek, created fuels that were very receptive to ignition, fire spread and crown fire development. Atmospheric soundings from Stony Plain showed the potential for blow-up fire behaviour as evident by the very steep lapse rates (approximately 12.0°C/1000 m) on May 23. The environmental conditions – i.e., the weather ("cross-over" conditions), fuel (amount and dryness), and topography (aspect and slope steepness) -- were favourable for intense burning during the Vine Creek prescribed fire (Figure 5).

The standing timber surrounding the survival zone was severely burned by high-intensity crown fire. The surface fire coverage was quite complete and all the small-diameter canopy fuels (needles, twigs, and branches) were consumed.

While the fire behaviour impacting the area surrounding the survival zone site was extreme, the site had some favourable attributes as a survival zone. The rock bluff in front of the burned-out area that we used as the survival zone had two important influences on the data recorded by our equipment: first of all, it added to the size of the overall site and, second, it acted to shield the site from the heat released by the fire and acted to direct the flow of radiant energy upward. This led to heat flux values and temperatures along the ground that were favourable to the survival of firefighters that become trapped in similar situations. In-fire cameras showed there would be little to no flame contact on firefighters within the pre-burned area. The highest heat flux and temperature values were recorded by the camera box and by the flat sensor located at point 4 in the rocky opening just above the rock bluff (see Table 2, Camera Box 2, flat sensor #F1).

Light wind conditions allowed the heat from the convection column (fire plume) to rise straight up, instead of getting attached to the slope, as indicated by photographic and video footage. If a west wind had been blowing, the heat could have moved up along the slope more than it did on May 23. Therefore, the convection-driven, as opposed to wind-driven, column possibly contributed to more survivable conditions.

Figure 5. Resulting fire behaviour on the Vine Creek prescribed fire associated with the strip-head fires established by aerial ignition (Photo courtesy of Jasper National Park).

Data collection point 1 was chosen as the spot where a firefighter would most likely choose to 'hunker down' (Alexander 2006) as it was in the middle of the previously burned area and near the back. This point recorded the lowest heat flux value and the lowest temperatures by our instruments (a temperature of 40°C and a heat flux of 2.8 kW/m^2).

Because we chose a previously burned area to be our simulated survival zone, there was little to no fuel to burn. Video footage showed many embers blowing into the site but not resulting in any new ignitions. Some pockets of ground fire were ignited by embers, but little open flame was observed. In an entrapment situation, these areas could be avoided as the fire passed by the site. This would be a similar scenario to that of Wag Dodge's actions of burning out the grass and then entering the burned area to hunker down in during the 1949 Mann Gulch Fire (Alexander et al. 2009).

Two and sometimes three or more blasts of radiant heat hit the sensors. Figure 7 shows three times the heat flux increased over a six-and-a-half-minute period at point 4. These increases match up with the video footage[3]. Figures 6 and 7 show the most extreme readings for heat flux and temperatures that our sensors collected. A firefighter would need to remain hunkered down during these.

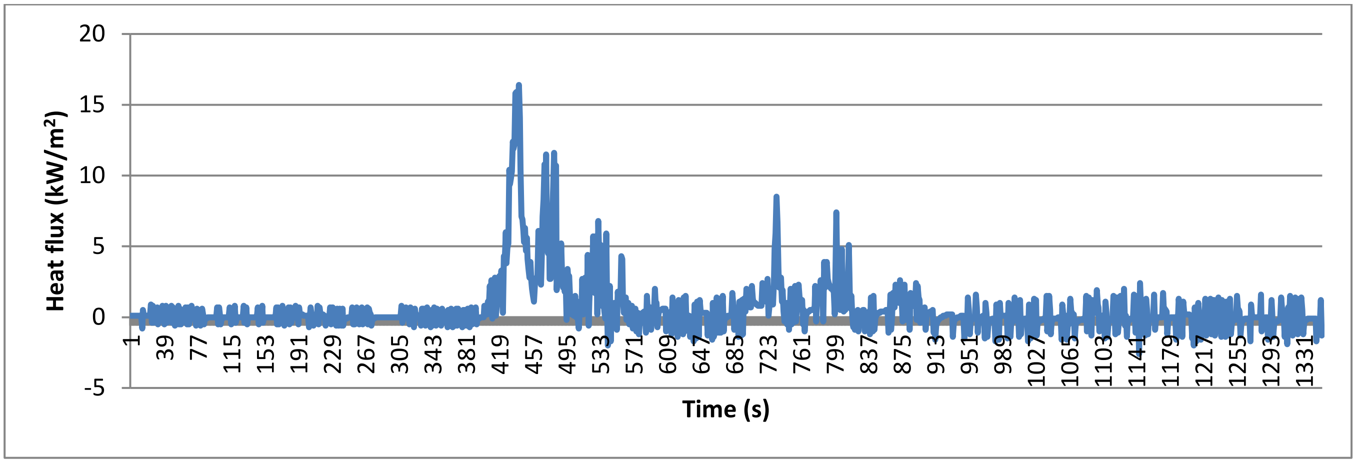

Figure 6. Heat flux data collected at point 4 situated at the top of the rock outcrop.

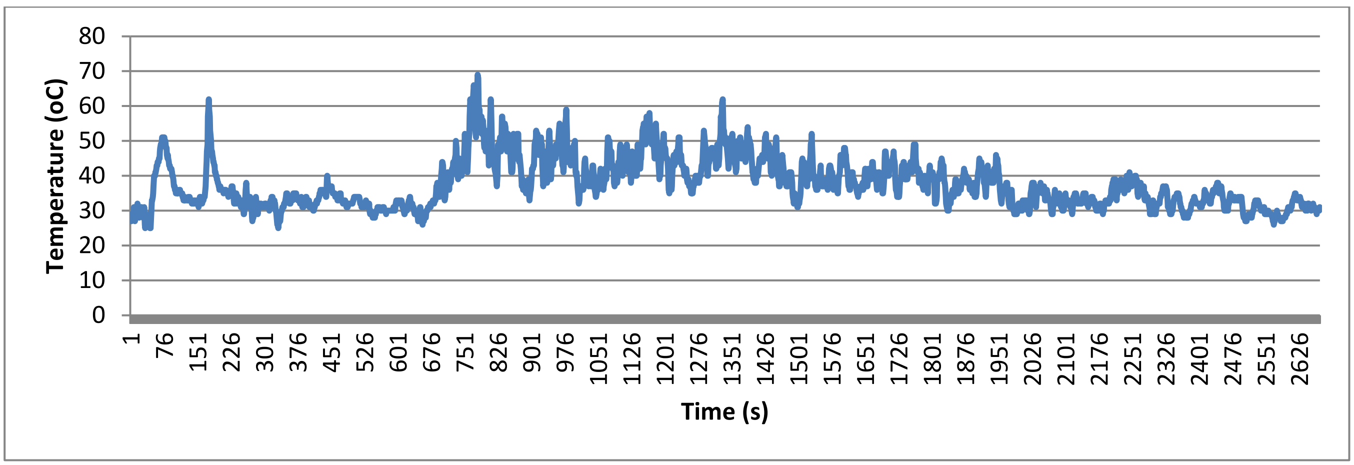

Figure 7. Temperature data collected at point 3. Temperatures were above 40°C for over 21 minutes.

6.1 Smoke

The videos from the four in-fire camera boxes showed that for the majority of time the area was clear of smoke at ground level. Periods of smoky air were regularly interspersed with periods of clear air. There were, however, periods of heavy smoke during the burning at each camera location. The longest smoky period lasted about a minute before fresh air replaced it.

Some video sequences were very dark, but this was due to rising smoke from the prescribed fire as a whole completely blocking out the sun rather than heavy smoke on the ground. The video showed how the ground escaped from most of the smoke.

[3] https://www.youtube.com/watch?v=tGazUvq-Iok

7 CONCLUSION

Heat flux and temperature data collected in the middle of this ‘survival zone’ would be within a range that would permit firefighter survival. Other factors that would need to be considered would be the air quality due to smoke conditions and extinguishing the embers landing on one’s clothing. There would also be the human psychological aspect of being able to remain calm during this situation (Alexander 2006).

In no way does this case study condone working above a wildfire on steep slopes, but for the purposes of research it did provide a number of interesting aspects. The location that we chose as a survival zone had several favourable attributes:

- The rock face in front of, and beside, the burned-out area contributed to a larger, fuel-free survival zone, putting greater distance between firefighters and the fire, itself.
- The steep rock face immediately below the survival zone acted to deflect the flames and radiant energy straight up.
- The previously burned area, which acted as our survival zone, had little to no surface fuel to burn.
- The wind was light and less than forecasted. This allowed the convective energy from the fire to overpower any wind effect, reducing the effect of smoke in the survival zone.
- The amount of smoke and its duration was not determined to be hazardous based on the video footage.

More case studies of steep slope situations are required in order to develop guidelines for firefighters caught in burn-over situations in mountainous terrain. This was the first survival zone case study completed on a steep slope and the site selected had some unique features that contributed to the survivability of a firefighter caught above an upslope fire run. A wider range of situations on steep slopes is required before comparisons with data collected to date on level terrain sites can be reliably made.

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