# Fire Behaviour in Mulch Fuel Beds: Observations from Experimental Fires at Pelican Mountain

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## Abstract

FPInnovations collaborated with Alberta Agriculture and Forestry and other research agencies to conduct two experimental fires in mulched fuels under very high fire hazard conditions.

This study documented fire behaviour and compared it to other experimental fires in mulch fuel beds at other independent study sites. Documentation of fire behaviour in this novel fuel type can inform wildfire managers of potential fire behaviour and suppression challenges.

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Data for this technical report was extracted from a case study written by Louis Price, Wildfire Technologist, Alberta Agriculture and Forestry

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# INTRODUCTION

Vegetation management is one of the seven key disciplines advocated by FireSmart Canada™ to address the threat of wildfire. “Vegetation management addresses the wildfire reality by decreasing the amount of vegetation that can fuel a wildfire” (Partners in Protection, 2003). Commonly prescribed fuel reduction strategies for the wildland–urban interface include stand thinning, pruning, and surface debris removal. Applying these strategies in the wildland–urban interface at a stand level is typically achieved with manual labour using motorized hand tools. The cost of these motor–manual fuel treatments is high relative to mechanical treatments and prescribed burning.

Harvesting equipment can be used during mechanical forest fuel treatments to remove commercially viable fibre in order to reduce the crown fuel load and increase crown separation. However, when timber harvesting is not economically viable or socially acceptable, other mechanical fuel reduction techniques and equipment are used to achieve fuel treatment objectives. Mastication (mulching) of forest fuels is a mechanical process where a purpose-built machine knocks down aerial fuel (stems and branches) and processes it into chips in order to thin a forested stand. Simultaneously, the mulcher processes surface vegetation and downed woody debris and can incorporate the resulting chips into the soil layer.

The flammability of mulched fuels has been examined extensively in laboratory and field settings (Schiks and Wotton 2015). FPInnovations has collaborated with wildfire management agencies to document the behaviour of experimental fires in fuel treatments including mulching. These experimental fires, conducted over a broad range of weather conditions with varying fuel characteristics, have provided insights into potential fire behaviour in mulched fuels.

# OBJECTIVES

FPInnovations researchers collaborated with personnel from Alberta Agriculture and Forestry and other research agencies, including Canadian Forest Service, Environment Canada, and McMaster University, to observe and measure fire behaviour in mulched fuel under very high fire hazard conditions, which was the primary objective of this study. These fire behaviour data were compared to those from experimental burns in other mulch fuel beds under different fire weather conditions.

A secondary objective was to observe suppression and mop-up operations in order to evaluate resistance to control and identify suppression resources that would be required to control and extinguish mulched fuels burning under high hazard conditions.

## STUDY SITE

The Pelican Mountain FireSmart Fuel Management Research Site[1] was developed by Alberta Agriculture and Forestry to conduct wildfire research that will contribute to the development of scientifically based community protection strategies and enhance knowledge about the effectiveness of forest fuel treatments in modifying fire behaviour. The research site is located in central Alberta, 35 km southeast of the town of Wabasca (Figure 1).

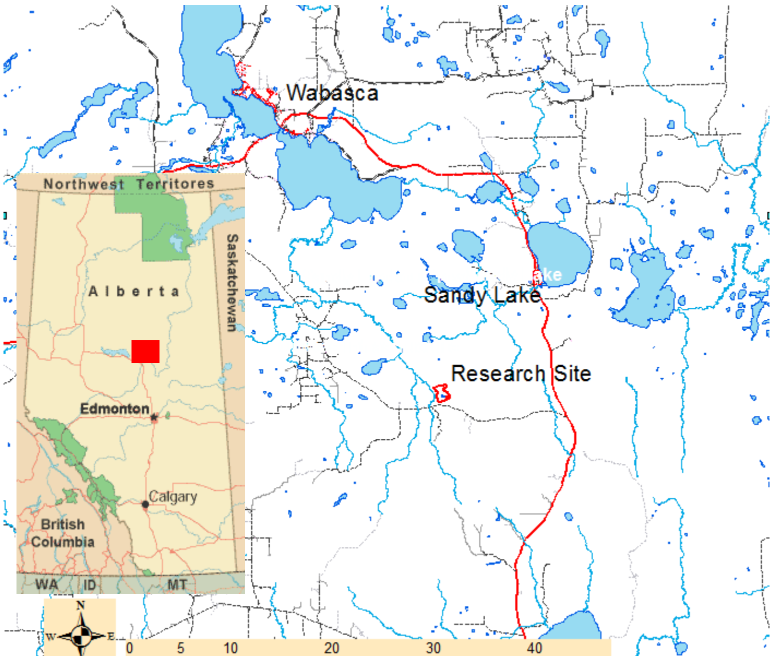


Image courtesy of Alberta Agriculture and Forestry (red square indicates general area).

**Figure 1. General area of research site.**

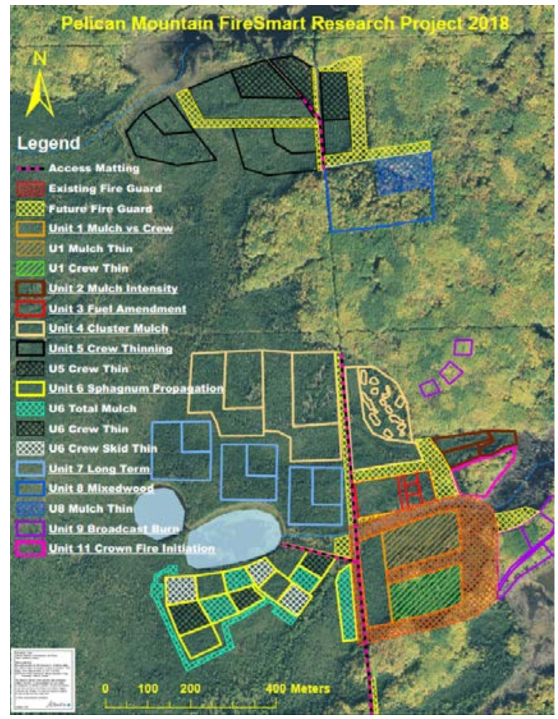


**Figure 2. Research area plot layout.**

Unit 1 (Figure 2) was developed to study the cost-effectiveness of two fuel treatment techniques. In the winter of 2016/17, a motor–manual fuel treatment[2] was applied in the southern portion of the burn unit while a semi-mechanized fuel treatment[3] was applied in the northern portion. In the winter of 2015/16, a containment zone (fire guard) was created by mulching aerial and surface fuels on the north, east, and south sides of the treatment areas. In May 2017, two experimental fires were conducted in the mulched fire guard in the northeast corner of the containment zone for unit 1 (Figures 3 and 4).

The slope of the mulch fire guard that was burned during this study was less than 10%. The mulch that was burned was a mixture of black spruce (*Picea mariana*), aspen poplar (*Populus tremuloides*), and a small component of white spruce (*Picea glauca*). Organic soil depth ranged from 10 to 20 cm.

[1] For more information about the Pelican Mountain FireSmart Fuel Management Research Site, see the Canadian Wildland Fire & Smoke Newsletter.
[2] http://wildfire.fpinnovations.ca/155/TR2017N51.pdf
[3] http://wildfire.fpinnovations.ca/155/TR2017N50.pdf

**Figure 3. May 30, 2017 burn (red square) with line ignition indicated by dashed line.**

**Figure 4. May 31, 2017 burn with point ignition indicated by red dot.**

The mulched debris on the fire guard was not categorized by size class; however, fuel inventories by Alberta Agriculture and Forestry indicated that average debris loading was 8.2 kg/m$^2$, and bulk density was 91.9 kg/m$^3$. The average mulch depth was 9.6 cm. Visual reference with other measured mulch fuel layers can provide a relative characterization by size class (Figure 5). Characterization of the mulch debris analyzed at the study sites at the BC Hydro Northwest Transmission Line right-of-way (NTL ROW), Horse Creek research area, and Canadian Boreal Community FireSmart (CBCFS) research area is detailed in Table 1. A coarse visual comparison of these mulch fuel environments indicated that the mulch particles in the Pelican Mountain burn and the CBCFS burn had a greater proportion of larger material than what was observed in the Horse Creek and NTL ROW study sites.


**Figure 5. Visual comparison of mulched debris at burn site (top) relative to that in three other study sites: (a) Northwest Transmission Line right-of-way, (b) Horse Creek research area, and (c) Canadian Boreal Community FireSmart research area.**

**Table 1. Comparison of mulched fuel bed characteristics**

| Study area | Debris loading (kg/m$^2$) by size class (SC) and percentage (%) of total | | | | | Overall bulk density (kg/m$^3$) |
|---|---|---|---|---|---|---|
| | SC 1 (< 0.5 cm) | SC 2 (0.50–0.99 cm) | SC 3 (1.00–2.99 cm) | SC 4 (3.00–4.99 cm) | Total | |
| Northwest Transmission Line right-of-way[a] | 13.0 (76.6) | 2.3 (13.6) | 1.7 (9.8) | 0.0 | 17.0 | 170.0 |
| Canadian Boreal Community FireSmart[b] | 1.0 (26.3) | 0.6 (15.8) | 1.3 (34.2) | 0.9 (23.7) | 3.8 | 135.0 |
| Horse Creek[c] | 8.2 (52.2) | 2.1 (13.4) | 4.0 (25.5) | 1.4 (8.9) | 15.7 | 152.6 |
| Pelican Mountain[d] | n/a | n/a | n/a | n/a | 8.2 | 91.9 |

[a] http://wildfire.fpinnovations.ca/120/BCHydroNTLMulchReportFINAL.pdf
[b] http://wildfire.fpinnovations.ca/119/TR2017N24.pdf
[c] Estimated from graph in Schiks (2014)
[d] Debris loading and bulk density were calculated by Alberta Agriculture and Forestry.

## RESULTS

A remote automatic weather station southwest of the experimental fires collected weather data prior to and during the two experimental fires. Weather data and Fire Weather Index (Van Wagner, 1987) values recorded during the burning window are presented in Table 2.

**Table 2. Weather data and Fire Weather Index (FWI) values for May 30 and May 31, 2017[a]**

| Date | Weather[a] | | | | Fire Weather Index values[b] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Temp. (° C) | RH (%) | WS (km/h) | WD | FFMC | DMC | DC | ISI | BUI | FWI |
| May 30 | 29 | 26 | 12.2 | S | 93 | 57 | 182 | 12.3 | 64 | 25 |
| May 31 | 33 | 27 | 11.6 | SSE | 93 | 63 | 190 | 11.8 | 69 | 25 |

[a] RH = relative humidity; WS = wind speed; WD = wind direction (cardinal direction).

[b] FFMC = Fine Fuel Moisture Code; DMC = Duff Moisture Code; DC = Drought Code; ISI = Initial Spread Index; BUI = Buildup Index; FWI = Fire Weather Index.

## May 30 – Line ignition trial

On May 30 at 1613, a line ignition was initiated in the northeast corner of the containment zone (Figure 3). The average flame height during this burn was 0.5 m (Figure 6); maximum flame height was 2 m (Figure 7). The overall rate of spread during the burn was 3.1 m/min; the maximum rate of spread was 4.6 m/min. The wet lines established along the flanks and along the marsh limited the fire spread to an area of approximately 30 × 40 m.

**Figure 6. Average flame height of 0.5 m.**

**Figure 7. Two-metre flame height observed at the head of the fire on May 30.**

## May 31 – Point ignition trial

On May 31 at 1444, a point ignition was used to start the experimental fire south of the area burned the previous day (Figure 8). The overall rate of spread was 1.1 m/min; the maximum rate of spread was 2.2 m/min. The average and maximum flame height were 1 m and 2.5 m, respectively. The final size of the burned area was approximately 40 m wide × 95 m long.

**Figure 8. Initial fire growth from May 31 point ignition.**

**Figure 9. Difficult suppression conditions created by high-intensity fire and smoke.**

During this trial, fire whirls were observed, and firebrand transfer ignited spot fires up to 80 m ahead of the fire front in unburned fuel in the area burned the previous day. These spot fires were easily extinguished. High-intensity fire and smoke created suppression challenges for firefighters (Figure 9). Fire control with backpack pumps and small-diameter 5/8 inch hoses was very difficult.

To evaluate the resistance to control, firefighters along the east flank were equipped with a water delivery system comprised of a WATERAX Mark-3® pump, a 1.5-inch hose, and two fog nozzles. Along the west flank, firefighters used two Hanson nozzles with an identical water delivery system and the same pump pressure. Hanson nozzles were more effective than fog nozzles. In order for the fog nozzles to be effective, firefighting personnel needed to open the fog nozzles quite wide, which reduced the water stream distance and pressure. Class A foam was not used in this water delivery system.

Two minutes after open flame along the fire's flank was suppressed, a small spot in the mulched fuel bed re-ignited. This is not unusual since knocking down the open flame is the objective of the first stage in controlling a fire, with subsequent passes along the fireline focused on mop-up and patrol. However, this is an indication of how low fuel moisture content and the amount of available fuel in a mulch fuel bed create difficult control and mop-up conditions.

The measured depth of burn (Table 3) indicated an average fuel consumption of 3.2 and 3.6 kg/m$^2$ for the two fires. With an average pre-burn mulch depth of 9.8 cm, it follows that approximately two-thirds of the mulched debris remains as a potentially combustible surface fuel layer. This layer of residual fuel in the May 30 burn area was reignited from firebrand deposition during the May 31 fire.

**Table 3. Depth of burn and fuel consumption**

| Date | Average depth of burn (cm) | Average fuel consumption (kg/m$^2$) |
|---|---|---|
| May 30 | 3.4 | 3.2 |
| May 31 | 3.9 | 3.6 |

Prior to the May 31 burn, suppression crews applied water for 55 minutes using the Mark-3 pump at optimal throttle level and a 1.5-inch hoselay to saturate a 2- to 2.5-m wide strip of mulched fuel surrounding the area to be burned. The saturated mulch and vegetation along both flanks provided a good barrier to fire spread with no breaching of the wet line. Wet lines were also applied in preparation for the May 30 burn.

During mop-up operations, firefighters experienced increased exposure to smoke (Figure 10) relative to the active flaming stage. An increased level of smoke production with elevated levels of carbon monoxide and other harmful smoke components is generally encountered during mop-up operations in smouldering fuels (Fowler, 2003).

**Figure 10. Intense smoke conditions encountered during mop-up operations.**

# DISCUSSION

## Comparative fire behaviour in diverse fuel environments

Documentation of these experimental fires provides insights and data that will contribute to a better understanding of fire behaviour in mulch fuels and, potentially, to a data set that is essential to developing a model for mulch fuels. However, in order to model fire behaviour in mulch fuels, it will be important to characterize the fuel type (CIFFC, 2003) to define “an identifiable association of fuel elements” that is inclusive of the broad range of “species, form, size, arrangement, and continuity” that comprise each unique mulch fuel complex. Defining a mulch fuel type is a challenge given the broad range of fuel environments resulting from different mulch treatments.

The characteristics of mulch fuel beds vary considerably depending on site conditions and treatment objectives and techniques. Variations in mulch fuel size and shape, distribution, bulk density, and age, and presence of other surface fuels (larger debris, mosses, lichens, and/or grass) result in variations in fire behaviour in these fuel environments. For example, the presence of dry feathermoss combined with an overlay of mulch debris at the Red Earth Creek experimental fire likely exacerbated fire behaviour (Hvenegaard et al., 2016).

With so much variability in fuel attributes, it is often difficult to find consistent mulch fuel environments for experimental fires that can contribute reliable fire behaviour data to the development of a mulch fuel model. Since 2013, FPInnovations has collected fire behaviour from three experimental fires in open mulch fuels (no overstory fuels) in which mulch was the primary fuel component. Even though there were differences in the mulch fuel size class characterization (Table 1), there was an apparent trend of increasing rate of spread and flame length with increasing Initial Spread Index (Table 4). Additional data from experimental fires conducted by other research agencies and future experimental fires can be used to augment this limited data set and develop a fire behaviour curve for a mulch fuel model.

**Table 4. Comparison of fire behaviour from line ignition in three study areas at different Initial Spread Index values**

| Study area | Date | Initial Spread Index | Maximum rate of spread (m/min) | Maximum flame length (m) |
|---|---|---|---|---|
| Northwest Transmission Line right-of-way | Sept. 6, 2013 | 3.3 | 1.5 | 0.30 |
| Horse Creek | Aug. 14, 2014 | 5.2 | 1.9 | 0.50 |
| Pelican Mountain | May 30, 2017 | 12.3 | 4.6 | 2.00 |

Observations of fire behaviour in mulch fuel compared to fire behaviour predictions in other Fire Behaviour Prediction open fuel types (Forestry Canada Fire Danger Group, 1992) (Table 5) provide an indicator of relative fire behaviour for these fuel types.

**Table 5. Observed fire behaviour during May 31 trial, with predictions for other Fire Behaviour Prediction (FBP) open fuel types**

| Weather and Fire Weather Index values | | | | Fire behaviour | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Observed[a] | FBP predictions[b] | | |
| FFMC | Average wind speed (km/h) | ISI | BUI | | Mulched fuel | O-1a | O-1b | S-2 |
| 93 | 11.6 | 11.8 | 69 | Rate of spread (m/min) | 0.9 (average) 2.2 (maximum) | 36 | 39 | 8.5 |
| | | | | Fire intensity (kW/m) | 1 875[c] | 3 255 | 3 553 | 29 578 |
| | | | | Fuel consumption ($kg/m^2$) | 3.6 | 0.3 | 0.3 | 11.8 |

[a] Fire behaviour values are based on the observed maximum rate of spread and maximum flame height.
[b] FBP predictions for O-1a (matted grass) and O-1b (standing grass) are based on a default fuel loading (Taylor et al., 1997) of 3 tonnes/ha (0.3 $kg/m^2$) with a 100% curing rate.
[c] Calculated using Byram's fire intensity equation $I = 300 L^2$ where I = fire intensity and L = flame length. Maximum flame height recorded for the May 31 fire was 2.5 m. Minimal flame tilt was observed on the flame front, and flame length was considered to be equivalent to flame height.

## Operational implications

A holdover fire in the residual fuel in the area of the May 30 experimental fire indicated that large volumes of water and/or foam are required to extinguish mulch fuel fires. Backpack pumps and a water delivery system using a 5/8-inch hose may not deliver an adequate volume of water to ensure extinguishment under all conditions.

During the experimental fire on May 31, a firebrand landed in the area burned during the previous day and ignited a spot fire which was easily extinguished. While this demonstrates that residual fuel in burned areas of mulch debris can be ignited, an equally important consideration may be the ease of fire propagation and spread in a previously burned mulched fuel treatment. In this case of spot fire ignition, the moisture content of the residual fuel was not measured. However, it is likely that fuel available for consumption had been consumed in the experimental fire the previous day. This would leave a residual layer of fuel of higher fuel moisture content. Given another day or week of drying, the sustained burning and propagation of this spot fire would likely have been more active.

Prescribed burning in mulch fuel treatments has been proposed as a method of reducing the amount of available fuel. The areas burned during these experimental fires are available for ongoing burn trials to evaluate temporal changes in ignition and spread potential in previously burned mulch debris.

The wet lines established in the mulched fuels and vegetation along the flanks of the fire area provided a very good barrier to fire spread. With an unlimited supply of water, saturation of these fuels was possible. However, often in emergency situations of community protection, water supplies are limited, and watering mulch fuels to create a barrier to fire spread will require a more calculated and conservative application of water and/or the addition of water enhancers.

While the wetted mulch fuels provided a good barrier to fire spread, the barrier could be short-lived. With increased solar radiation and surface winds in an open mulch fuel environment, the drying rate of the uppermost layer (2 cm) of open mulched fuels is higher than that of most fuels in an unaltered forest floor (Schiks et al., 2016).

The mulch fuel bed under study contained a minimal amount of coarse fuels. Mop-up operations could have been more problematic with larger fuels smouldering for a longer duration in the burn area. Water enhancers such as foam increase penetration of water to deeper fuel layers (NWCG, 1993) and expedite extinguishment.

As in all firefighting operations, smoke exposure is a hazard, and firefighting tactics that limit exposure should be implemented (Broyles, 2013). To limit firefighters' exposure to smoke during mop-up operations, alternative strategies such as sprinkler lines could be used.

## MOVING FORWARD

At the Pelican Mountain research site and at other sites, opportunities exist for continued fire behaviour trials in mulch fuel beds in varying stages of vegetation regeneration and debris decomposition.

Another burn unit at Pelican Mountain has been dedicated to conducting burn trials in mulched fuels. This burn unit will allow several trials to be conducted in three fuel environments created by mulching at three different intensity levels.

Opportunities for future research projects include trials to determine the optimum volume of water required to wet mulch fuels and assess the duration of time that a wetted barrier is effective in reducing fire behaviour. Barnes (2017) studied the effect of sprinkler watering duration on fuel moisture changes in moss and duff layers in a boreal fuel environment to provide guidelines for efficient sprinkler operation to enhance the effectiveness of fuel treatments. Expanding this study to consider mulch fuel and quantify the extent to which mulch retains moisture can yield valuable operational guidelines on effective watering of mulch fuels.

# CONCLUSION

The two experimental fires conducted under very high fire hazard ratings in mulch fuels at the Pelican Mountain FireSmart Fuels Management Research site exhibited vigorous surface fire behaviour, including the generation of fire whirls and firebrand production with transport up to 80 m. Mulched debris was the primary fuel component in this fuel environment.

Documentation of other experimental fires in fuel environments dominated by mulch fuels provides comparative fire behaviour data that could be used to enable fire behaviour predictions in mulch fuels along a range of fuel moisture and weather conditions. A trend in the relationship between fire behaviour (rate of spread and flame length) and Initial Spread Index has been suggested through these trials. Future experimental fires will provide additional data for this data set and validate this apparent relationship.

Wildfire operations personnel can benefit from observations and hands-on fire suppression training in mulch fuels in order to develop suppression strategies and confidently assign appropriate resources to these fires.

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