Forest Fire Victoria Inc.

Forest Fire Victoria *is a group of forest and fire professionals who share more than 250 years of fire experience.*

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The Problem of Quantifying Fuel and Correlating with Fire Behaviour; Defining Limits to Fire Suppression

Horizontal distribution of fuel is highly variable and very difficult to quantify in a meaningful way and relate to changes in fire behaviour. There are a couple of exceptions, such as hummock grassland (e.g. spinifex and mallee in semi-arid zones) where fuel clumps are separated by bare ground and the wind speed at which continuous spread is possible is related to the fraction of grass cover. However, for most fuels the impact of fuel distribution, which may be obvious on fires of low intensity, changes as the intensity of fire increases with increasing wind speed: the fire then integrates much of the variation in the fuel complex and fire spread is determined by some average and undefined characteristic.

Interpreting Fire Intensity

$$I = H\,w\,R$$

The concept of line fire intensity was introduced by Charlie Van Wagner in the 1960s.

H is the Heat Yield of the fuel in kilojoules per kilogram (kJ/kg). Heat Yield is assumed to be the heat released by burning a kilogram of fuel under field conditions. It is lower than the heat of combustion which is the heat released when all fuel is combusted to CO_2 and water as measured in a laboratory, in a bomb calorimeter. Under field conditions not everything in a hydrocarbon fuel is converted to CO_2 and water; many products such as a myriad of hydrocarbons as gasses or solids such as ethane, tars etc. and carbon still contain thermal energy when they are released into the convection column.

The amount of heat in fuel is related to a number of factors and heat yield can vary from around 16 000 to 20 000 kJ/kg. A figure of 18 000 kJ/kg has been generally accepted as a constant value for practical application.

R is the rate of spread in metres per second (m/sec). R is measured normal to the fire front and is the rate that new fuel is involved in the fire. An elliptical model is a common way of describing fire spread around the perimeter of a moving fire, although spread on the flanks is a combination of heading and backing fires which has a much wider range of intensity than when spread is calculated normal to the fire-line. However, this variation has been considered of minor importance as calculated fire intensity reflects the average flame height around the perimeter reasonably well.

w is the weight of fuel consumed by the fire front in kilograms per square metre (kg/m^2). And here is where the issue becomes really challenging.

The relationship **I = HwR** was used to demonstrate that doubling the fuel load resulted in a fourfold increase of intensity. The relationship is technically sound but it postulates that the heat is released at the very front edge of a fire perimeter.

We know that total fuel consumption does not occur at the fire edge but occurs by different modes of combustion and different rates over a prolonged period and at a considerable distance behind the leading edge of the fire depending of the size and nature of the fuel being burnt.

Therefore, it was assumed that "large fuel" that burnt slowly well behind the fire front had no impact on the characteristics at the leading edge of the fire. So the next assumption was that we could define "fine fuel" as the material that is burnt in the continuous flaming zone behind the fire edge and we would further define fine fuel as that < ¼" (USA) or <6mm (Aus.), and it was this material that contributed to the heat release in the flames at the leading edge of the fire. Correlations of calculated line fire intensity (I) with flame height, and scorch height seem reasonable and repeatable in a particular fuel type.

However, we have no idea what fraction of the "fine fuel" is burnt by flaming combustion and what fraction is burnt by smouldering combustion in or behind the zone of continuous flames. The Project Vesta)[1] fires burnt over cameras and recorded the duration of tall and short flames for intense fires in an open dry Jarrah forest fuel. Tall flames at the front of the fire lasted around 13 seconds whilst continuous flames behind the front lasted a little over a minute. Smouldering combustion lasted anywhere between 5 to 15 minutes and prolonged combustion of logs and patches of deep organic layers produced enough heat to prevent prolonged access of normally clad people onto the recently burnt ground for up to 45 minutes. It would seem then that Line Fire Intensity is not as useful as we would like for describing moving fires; well not quite.

- The fact that you can draw reasonable correlations between flame height and fire intensity over a quite wide a range of fine fuel (<6m) loads and burning conditions for a dry eucalypt forest fuel type is useful, and suggests that the proportion of material burnt by flaming and smouldering combustion remains relatively consistent over a range of fuel loads and burning conditions and is a function of the average fuel structure in that fuel type.
- The equation helps to illustrate the role of fine fuel load over a range of burning conditions

[1] Gould JS, McCaw WL, Cheney NP, Ellis PF, Knight IK, Sullivan AL. (2007) – *Fire in Dry Eucalypt Forest: fuel structure, fuel dynamics and fire behaviour.* Ensis-CSIRO, Canberra ACT, and Department of Environment and Conservation, Perth WA.

- The equation does illustrate the huge range of heat release of a forest fire and does illustrate the limited range of suppression effectiveness by any means and is much better than comparing bushfires with historical nuclear detonations.

The relationship only applies to a specific fuel type and different relationships are needed for significantly different fuels e.g. tall wet forests, heaths, pastures. It is only that dry eucalypt forests and woodlands represent a fairly large proportion of our southern forests that the equation has been applied widely; perhaps more widely than it should without qualification.

Table 1 Limits of direct suppression of fire in a dry eucalypt forest with a high spotting potential.

Byram Line Fire Intensity (Kilowatts/metre)	Conditions and Limits
500	Upper limit to prescribed burning in production forest; suppression with hand tools easy; spotfires 1-5m.
2,000 – 2,500	Limit of direct fire line attack in forests. Heavy short distance spotting to 50m; isolated spotfires to 500m.
10,000	Fire reaches into and ignites crowns, and a crown fire starts and is maintained by surface fuels; spotfires to 5 km.
40,000	Typical high intensity disaster scale bushfire. Increasing damage to tree crowns by fire induced wind; spotfires to 20+ km.
150,000	Possibly the maximum for forest fire in Australia. Fire tornadoes may be generated with widespread blow-down and stem breakage in the burnt forest.

Let us look at Table 1 "Limits of direct suppression of fire" taken from the Peoples Review of Bushfires in Victoria 2002 – 2007. Final report – 2009.

Limits of direct suppression of fire without stipulating the forest type/fuel type is not particularly helpful. The table needs to define the type of fuel under consideration in each case.

500 kW/m. This was recommended as the upper limit for prescribed burning for fuel reduction in a tall dry Eucalypt forest which limited the scorch height to approximately10% of the burnt area. Higher limits could be set if higher scorch height or damage was accepted. Many forests with thin bark require lower intensities to avoid cambial damage. This has largely proved to be impractical. There is a case to use higher intensities for fuel reduction to reduce the spotting potential in some fibrous-barked forests. Of course, much higher intensities of prescribed fire are used to regenerate some forests.

1000 kw/m. This represents the upper limit for experienced fire crews using hand tools[13]. It was determined during experiments to measure the physiological stresses of firefighters carried out in jarrah/marri dry forests in Western Australia and mixed stringy bark forest in the Nowa Nowa district of East Gippsland

2000 – 2500 kW/m. Limit of direct fireline attack using dozers or air tankers in dry Eucalypt forests with a moderate spotting potential. This was determined from fires in a dry forest in WA and mixed stringy bark forest in the Nowa Nowa district of East Gippsland under Moderate fire danger (see photos). It was the point where spotting in that forest went beyond the capacity of bulldozers and aircraft to build continuous fire line and control spotfires. The limit would be lower in forests with a very high spotting potential e.g. E. obliqua; the limit would be somewhat higher in tall, smooth-barked forests with a low spotting potential e.g. spotted gum.

10 000 kw/m. This represents a fire burning in a dry forest with a fuel load of 12.5 t/ha and a speed of 1600 m/hr. Crowning of course depends also on fuel structure, forest height and wind speed. The following photos are some illustrations of calculated fire intensities.

45 kW/m

- ROS ≈ 0. 5 m/min
- Flame height ≈ 0.2 m
- Fuel burnt ≈ 3 t/ha

200 –300 kW/m

- ROS ≈ 0. 1 m/min
- Flame height ≈ 0.5 m
- Fuel burnt ≈ 7-10 t/ha

1000 kW/m

- Flame height ≈ 1-2 m
- ROS ≈ 0.2 km/h
- Limits of suppression by hand tools

2500 kW/m

- Flame height ≈ 4-6 m
- ROS ≈ 0.4 km/h
- Limits of suppression by dozers and aerial suppression

7,500 kW/m

- Flame height ≈20-35 m
- ROS ≈ 1.2 km/h

10 000 kW/m

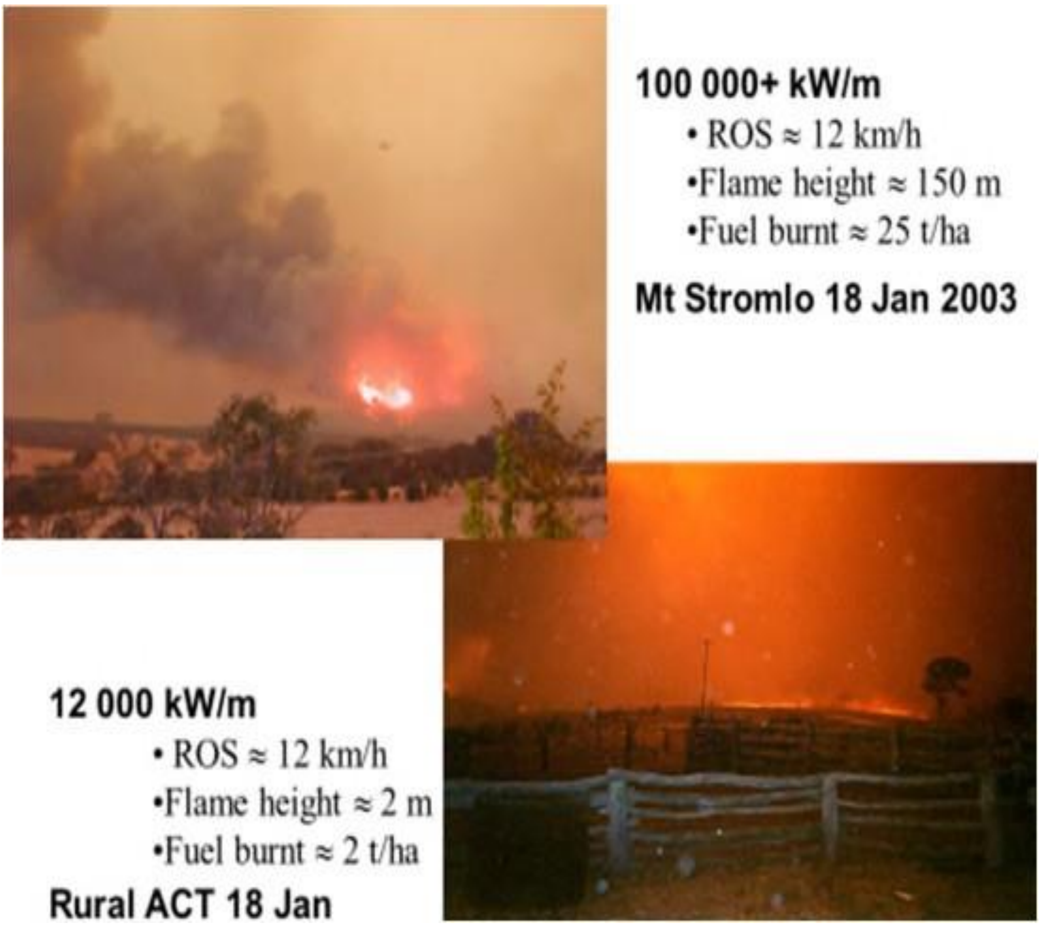
- Flame height ≈ 40 m
- ROS ≈ 1.6 km/h

Limit of Direct Suppression

A description of the fire characteristics and several operational limits are presented in Table 1
The limit for hand tool suppression was well documented and consistent with the experience of firefighters in forestry crews. The limits for bulldozers and air tankers were more difficult to measure and was based on about 3 fires in a forest at Nowa Nowa under moderate to high fire dangers.

However, during these experiments it became obvious it was not the width of the barrier roads and firebreaks) but rather the number and distance that spotfires developed ahead of the fire that could not be quickly controlled.

The fire intensity of 2500 kW/m that is the limit of suppression in a dry Eucalypt forest is only 6% of the intensity of a typical disaster scale bushfire and less than 2% of the possible maximum intensity of a forest fire in Australia. This is why rapid initial attack is vital to attack the fire before it builds to its full potential under the prevailing weather conditions.



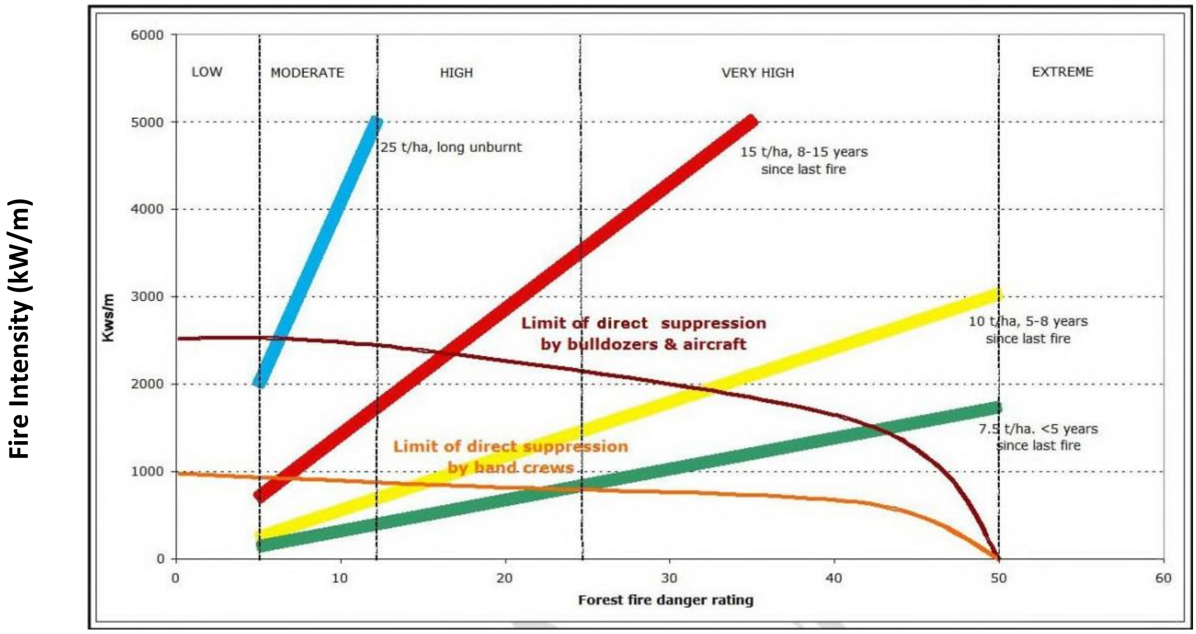
The rate of spread of a fire in a dry forest can be represented by the Forest Fire Danger

Rating as calculated by the McArthur fire danger rating system which is used to quantify fire weather throughout Australia. The Fire Danger Classes ***of Low, Moderate, High, Very High*** and ***Extreme*** are the degree of suppression difficulty assigned by McArthur for a fire burning in a dry Eucalypt forest carrying a typical fine fuel load of 12.5 t/ha.

Figure 8 describes how line fire intensity, increases with increasing forest fire danger rating in forests with fine fuel loads of 7.5 (green), 10 (yellow), 15 (red), and 25 (blue) t/ha that progressively build up with time since the last fire. The limits of direct suppression with hand tools (orange) and aircraft (brown) decrease from the original value with increasing fire danger rating showing that no techniques are effective under extreme fire danger regardless of the fuel load.

Fire suppression in light fuels of 7.5 t/ha should be successful with hand tools at conditions of high fire danger and with aircraft at very high fire danger. In heavy long-unburned fuels of 25 t/ha suppression by hand tools will be successful at only low fire danger, while suppression by bulldozers and aircraft will be successful only at moderate fire dangers.

Figure 8. The relationship between fire intensity (kW/m) and forest fire Danger Rating for a range of fuel loads, and the limits of direct suppression of fire.[2]



2 This graph was re-drawn from a presentation by Phil Cheney, CSIRO Forestry and Forest Products, titled 'Effectiveness of Prescribed Burning on Reducing Fire Behaviour' to a conference 'Bush Fire Prevention: Are we Doing Enough?', Institute of Public Affairs, Melbourne, 11 March 2003.

GRASSFIRES

Grassfires are easier to control than forest fires because they have a low spotting potential and a low burnout time. However, both factors will influence the intensity at which suppression is possible.

The limit of suppression is estimated to around 10 000 kW/m from observations of fires spreading in a grassy fuel with a low spotting potential (say 6 km/h in 4 t/ta fuels) at a moderate wind speed. It is four time greater than the limit for dry eucalypt forests because the characteristic of the combustion zones in the two fuel types are vastly different; e.g. grassfire flame duration 5 – 10 seconds; burnout time <60 seconds; and firebrands burn out before they can be ejected from the convection column.

The fire illustrated in the last picture was burning through eaten-out pasture on 18 January 2003 that was lucky to carry 2 t/ha and would have difficulty carrying a fire at low wind speeds. Mean winds at the time of the photo would be in the order of 60+ km/h and a fire danger index exceeding 80 Extreme. Direct suppression was impossible by any means.

To reiterate; one can draw associations between fire intensity and fire effects including suppression capability but there will be different associations with different fuel types. **The biggest** use is perhaps illustrating the range of fire intensities possible under different fuel and weather conditions and illustrating the very limited capacity for suppression by any means during dangerous weather.

- **Forest fuel characteristic that affect fire behaviour are difficult to measure and are co-correlated with measures of fire spread**
- **Fine fuel load is an adequate measure to describe how fire behaviour changes with increasing fuel age (time since last fire).**
- **Line fire Intensity can be correlated with fire front characteristics such as flame height and spotting distance and difficulty of suppression.**
- **Our capacity to suppress forest fires by any means is very small when measured against the possible intensity of disaster fires.**
- **Reduced fuel loads allow fire suppression to be conducted more safely and more efficiently over a wider range of fire danger classes**