The Dead-Man Zone - a neglected area of firefighter safety

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Summary

Firefighters engaged in parallel or indirect attack are working in a "dead-man zone" if they do not appreciate the time and space required to find a safe refuge. In this zone, if the wind direction changes, the fire can advance so rapidly that the firefighters have very little time to seek refuge in the burnt area behind a suppressed portion of line, or egress elsewhere, before the fire overwhelms them. We discuss three bushfire incidents in Australia where firefighters were trapped and killed, and the development of fire spread in forest fuels from a line start. A table illustrating the distance that a line fire can travel in five minutes under different fire danger conditions is presented. Factors that affect the speed of the firefighter's reaction to changed circumstances, and safe work practices, are discussed.

Introduction

The three methods of controlling a forest fire are: direct attack on the burning edge; parallel attack by constructing a fire line close to and parallel to the fire edge; and indirect attack by constructing the fire line at considerable distance to the fire edge. These are well described in texts and learning modules for fire control.

Crews most commonly use direct attack when water is applied directly on the fire line or when fires are very small, for example on initiating spot fires when hand tools are used to push the burning fuel directly into the fire. Direct attack is rarely used during dry fire fighting with hand tools over any extended distance, or with machines, because it is difficult to work directly on the fire edge without dragging burning material outside the fire line.

The parallel method of fire control is defined as constructing the fire line just far enough from the fire edge to allow crews and equipment to work effectively away from the heat and smoke (Luke and McArthur 1978). In North America the parallel method is considered to be an indirect fire control technique and the definition above would describe the " 2-foot" method where the fire line is constructed entirely in unburned fuels approximately two feet from the fire edge (Brown and Davis 1959).

In Australia, Luke and McArthur (1978) considered parallel attack can be successful on forest fires spreading at a rate of up to 200 m h^{-1} (corresponding to Byram's fire line intensity of 1500 kW m^{-1}) with the fire line located at a distance ranging from a few metres to 50 m or more from the fire edge. The indirect method of attack in Australia usually involves standing off a considerable distance from the fire and burning out a strip of sufficient width to provide an effective barrier against the main fire (Luke and McArthur 1978). However, as the prime objective of both methods is to ensure that all fuel between the fire line and the main fire is burnt out, it is probably better to consider parallel attack as an indirect method. Also, similar safety problems arise with both methods.

Chandler *et al*. (1983) warn that parallel attack is potentially dangerous if an unexpected wind shift turns the flank into a head fire when there is not enough distance between the fire and the line to permit firefighters an orderly and safe withdrawal. In Australia, insufficient emphasis has been given to this problem. We examine three cases where fatalities have occurred during parallel or close indirect attack. We present new information on the rapid development of a line of fire when the wind change turns a flank fire into a head fire, and provide guidelines for estimating the time required to withdraw safely when constructing fire line under different fire danger conditions.

Case studies

In the following incidents firefighters perished during parallel or indirect attack. We do not discuss all the details of the incidents. Rather, we focus on the fire behaviour that may have influenced the decision-making of the crews and, in particular, the time and space parameters that determined how much time was available for egress before entrapment.

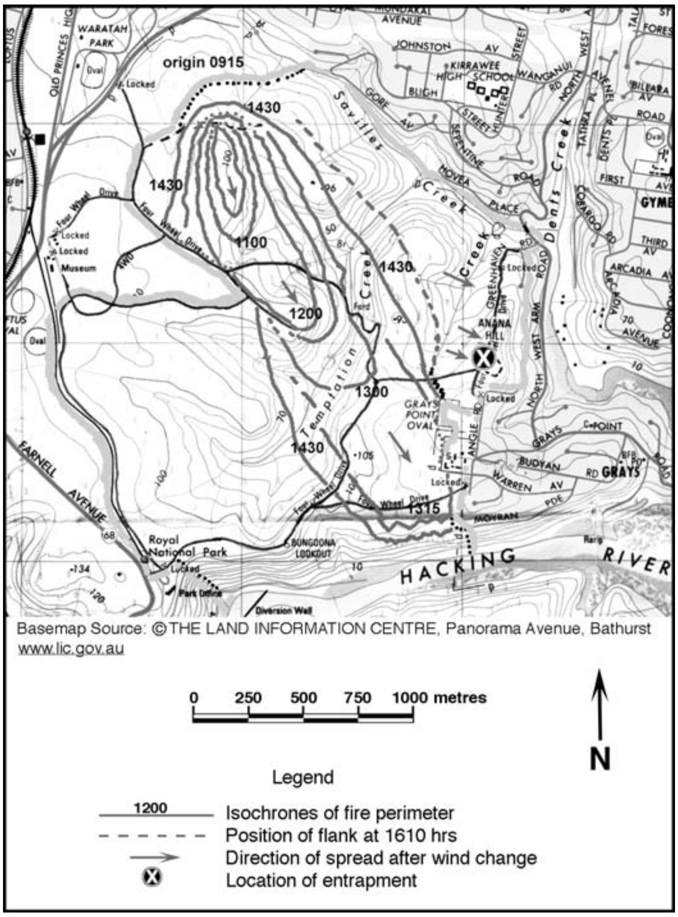
Grays Point Fire, 9 January 1983

On 9 January 1983, three volunteer bushfire fighters died and six were seriously burnt in a bush fire at Grays Point, New South Wales. All were members of the Heathcote Bushfire Brigade. The fire started in the Royal National Park south of Sydney adjacent to the suburbs of Gymea Bay and Grays Point. The fire started at 0915 hours in heathland and open woodland which had not been burnt for more than 15 years and was estimated to carry a fine fuel load of 16.5 t ha^{-1} (Shanahan 1984). The topography was a flat sandstone plateau deeply dissected by several small creeks.

The fire spread slowly in the first three hours and was held up by the lee slope into a creek line. Shortly after 1230 hours the fire crossed Temptation Creek, then between 1300 and 1315 hours burnt rapidly at around 2400 m h^{-1} after which it was held up again by the steep lee slope into the Hacking River (Figure 1).

The weather conditions recorded at Mascot airport, 10 km north, at 1300 hours were: temperature 38ºC, relative humidity 17%, wind speed 37 km h^{-1} from a direction of 320º. This gave a Forest Fire Danger Index (FFDI) of 57, an Extreme fire danger

Figure 1. Spread pattern of the Grays Point fire, 9 January 1983. Isochrones represent the perimeter of the fire at the indicated times.



Forest Fire Danger Index (FFDI) of 57, an Extreme fire danger rating (Colquhoun 1983).

At 1400 hours a helicopter reconnaissance revealed that the eastern flank of the fire was burning slowly against the wind (the wind direction at Mascot had veered to 350º) and a light shower of rain had partially extinguished the fire edge. In anticipation of a south-westerly change later in the day a decision was made to hold the fire on Greenhaven Road (also referred to as Angle Road). At 1549 hours four bush fire brigade tankers were dispatched onto the fire trail which rose in a series of steep grades onto Anana Hill (Wilson 1985). At 1610 hours the wind direction shifted to 300º. The fire danger was still Extreme (temperature 41ºC, relative humidity 13%, wind speed 35 km h^{-1}, FFDI 68). This wind shift was not the forecast frontal change and at 1618 hours the Sector Boss recognised the danger of the situation and ordered the evacuation of Anana Hill. By 1624 hours three tankers had cleared the area but the crew of the Heathcote tanker was slow to respond. At 1626 hours when the Heathcote tanker started to leave a tongue of fire had crossed the southern end of the fire trail, preventing their escape. The tanker reversed to a small clearing on Anana Hill and was over-run by fire about 12 minutes later (Wilson 1985).

We do not pursue the tactical decision to place crews on this trail in the first place but examine some of the factors that may have lead to the danger being perceived so late, thus limiting the time and space available for evacuation once the wind direction switched to 300º.

The shower of rain before 1400 hours that partially extinguished the fire edge certainly gave a window of opportunity for direct suppression of the eastern flank if crews had been equipped to run out a hose-lay and were in a position to act immediately. However, by 1600 hours the moisture from the rain shower had largely evaporated and the potential for rapid head fire spread had returned. Up until this time the flank of the fire immediately west of Anana Hill had been burning slowly down-slope towards a small creek and the rocky terrain on the lee slope probably broke the continuity of the flank fire. This reduced fire behaviour may have given the impression that the fire was still being affected by the rain. The distance from the creek line to Anana Hill is 180 m on a slope of 15 - 25º. At the rate of spread observed at 1300 hours the fire would have taken 4 $^1/_2$ minutes to travel from the creek line to Anana Hill but, when the rate of spread is corrected for slope of 20º, this time would reduce to a little over one minute. Because the fire crossed the creek line in a series of narrow tongues, the head fire probably did not reach its full potential rate of spread up the slope.

Given this potential rate of spread once the fire crossed the creek line there really was only time for the crews to abandon the hoses and leave. The height of the shrubs adjacent to the trail was 2-3 m and there was little indication that the ground sloped steeply to the west a few metres from the trail. The shift in wind direction was only 20º so it may not have been immediately obvious to the crews, particularly if they had started burning out. In this situation perhaps the only indication of the changed conditions would be the increase in smoke volume overhead.

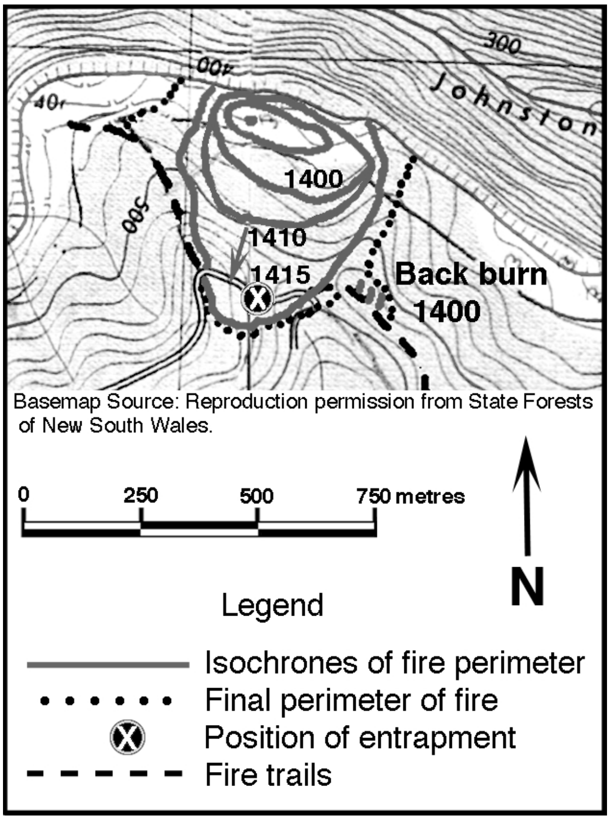
Johnstones Creek Fire, 1 January 1998

On 1 January 1998 one firefighter was killed and seven were injured in a fire at Wingello State forest near Bundanoon in southern NSW. All were members of the Wingello Bushfire Brigade. The fire was started by lightning and detected at around 1120 hours (Day and Strathdee 1998). At around 1300 hours, firefighters drove about 300 m down an old fire trail and walked in to inspect the fire. The fire was burning in low scribbly gum (*Eucalyptus manifera*) and *Hakea* scrub below some rock ledges. Equilibrium fine fuel load under these forests is typically 14 t ha^{-1} (Dowden 1986). The fire was burning under the influence of a light westerly wind and confined on its northern perimeter by the sheer cliffs above Johnstones Creek and on the southern perimeter by a low rock shelf running parallel to the cliffs (Figure 2).

The weather conditions at 1300 hours at Ellsmore tower, 13 km north of the fire, were: temperature 30ºC; relative humidity 27%; wind speed 5 - 10 km h^{-1} varying in direction from north-west to south-west. Using a drought factor of 10, the FFDI was 13 to 18. The fire weather forecast for Bowral (30 km north-east) issued at 0500 hours was: "Chance of afternoon and evening showers or thunderstorms, very warm to rather hot tempered on the coast by fresh to strong and gusty north-east winds; maximum temperature 29ºC, relative humidity 23%, north-west wind at 28 km h^{-1}, FFDI 29 (Very High)".

At the fire site the winds were light and generally considered on the location of the ridge to be from a west-south-westerly direction. There was a heavy cumulous cloud buildup above the area that may not have been obvious from the ground. Rather, the conditions were described as overcast.

Figure 2. Spread pattern of the Johnstones Creek fire, 1 January 1998.



At around 1400 hours back-burning was commenced from a ridge-top fire trail south of the fire. There were spots of rain. The origin of the back-burn was located at a position that was estimated to be 250 m east of the head fire. The wind direction on the ridge top trail appeared to be south-westerly when the back-burning was commenced and was blowing the smoke away from the trail (Robeson 1998). By this time the fire had probably crossed the rock ledge that was containing the southern perimeter. The area of the fire was approximately five hectares but with a flank 300 m long across the bottom of a steep slope. The average slope was 15° but increased to 18 - 20° towards the top of the ridge.

At 1407 hours firefighters on the top of the knoll noticed that the wind had switched to the north and that the fire behaviour was intensifying. The Fire Boss decided to evacuate the crew conducting the back-burn up the hill as they had established less than 50 m of fire line. The elapsed time between deciding to evacuate and entrapment on the fire trail is unclear, but may have been less than five minutes. At the time they left the back-burn, a firefighter estimated that there was still about 200 m of unburned country between the road and the fire (Robeson 1998). He also observed flames were now starting to climb into the canopy of the trees. Because the firefighters only had 200 m to travel to the top of the hill this observation may have influenced the decision to evacuate uphill ahead of the approaching head fire.

After inspecting the area we consider that it would be difficult to see the flames of a surface fire 200 m from the trail and we suggest it was probably less than 100 m away when the firefighters started to leave the back-burn. The strength of the wind is unknown. It was probably associated with outflow winds from a shower or thunderstorm in the vicinity, which may have been strengthened by a coastal sea breeze arriving at the site. The wind speed could have exceeded of 25 km h^{-1}. Using the 1300 hours temperature and relative humidity (30ºC, 27%), we estimate the potential rate of spread of a wide headfire up a 15° slope to be 3870 m h^{-1}. Thus a line of fire 100 m away moving at this rate would reach the trail in less than two minutes.

The crews had established a burnt-out area about 30 m deep by supplementary lighting down slope of the fire trail that would have provided a refuge if they had returned to their starting point. A planned refuge was also at a helipad at the end of the trail some 1300 m away to the south-east but this route had not been scouted and presumably the condition of the track was not known. Ironically, rain soon after the entrapment extinguished the fire before it met their back-burn.

Linton Fire, 2 December 1998

On 2 December 1998, five firefighters were trapped and killed while undertaking parallel attack on the Linton fire near Geelong, Victoria. All were members of the Geelong West volunteer fire brigade. The fire started in private property at around 1300 hours, then burnt for a little over five kilometres through State Forest (Anon 1999). The forest contained messmate stringybark (*E. obliqua*) and narrow-leaf peppermint (*E. radiata*) up to 25 m high in the gullies with brown stringybark (*E. baxteri*) up to 20 m high on the upper slopes and ridges. The forest was long unburned and carried an equilibrium fuel load of around 15 t ha^{-1}.

The weather conditions during the main run of the fire were: temperature 28ºC, relative humidity 24%, wind north-north-west at 44 km h^{-1}. Grasses in the surrounding pastures were only partially cured and held up sections of the fire when it came out of the forest. At a drought factor of six these conditions give a FFDI of 22, and rates of spread of the head fire between 1000 and 1600 m h^{-1} (Anon 1999).

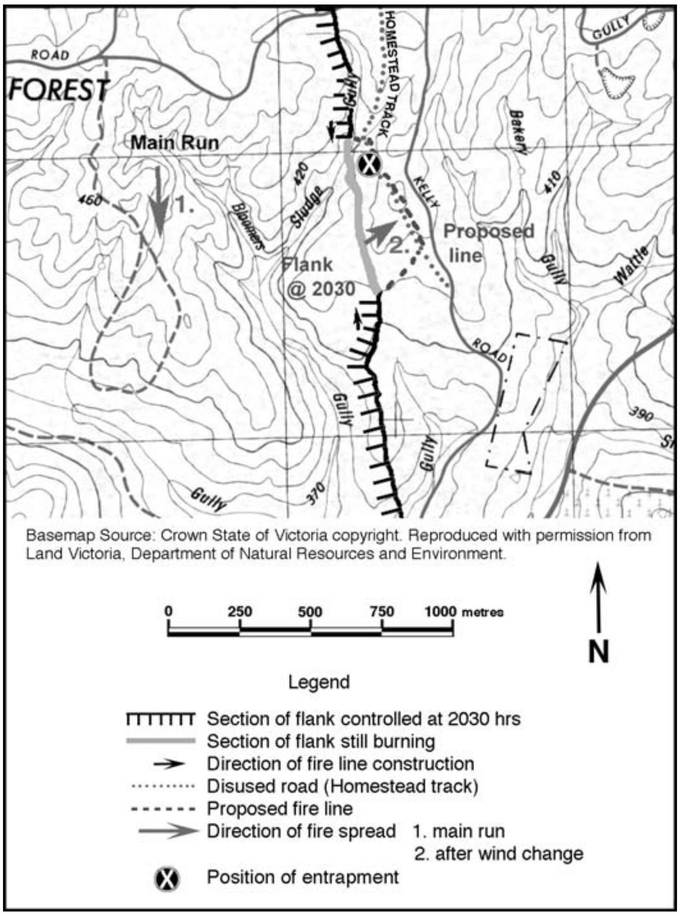
By 1800 hours the forward spread of the fire was stopped short of the township of Linton. Control of the eastern flank west of Kelly Road commenced using bulldozers building line close to the fire edge, supported by tanker crews who were burning out and mopping up. Although the temperature and relative humidity had remained at 28ºC and 24% respectively, and the wind direction remained north-north-westerly the wind speed had dropped to 10 km h^{-1}. Flame heights on the flank fire were generally less than one metre. A south-westerly wind change was forecast to cross the area at 2300 hours.

At 1810 hours a large bulldozer began constructing the control line from the Pittong-Snake Valley Road heading south. Fire line construction was slow because the area was pitted with old mine shafts and water flumes from gold mining before the turn of the century. By 2030 hours the bulldozer working from the north had reached a point where it was approximately 600 m from a second bulldozer constructing fire line from the south (Figure 3). The large bulldozer moved away from the fire edge to construct a fire line along part of a disused road (the extension of Homestead Track) that was roughly parallel to and 30 - 90 m east of the fire edge (Anon 1999). Constructing fire line along the old road formation would have been quicker and easier than constructing line through the bush adjacent to the fire edge. Two fire tankers followed the bulldozer onto the extension of

Homestead Track, then passed the bulldozer heading south to replenish water supplies.

Shortly after the tankers passed the bulldozer, the wind change arrived and the fire spread very rapidly towards the east. The tankers were located approximately 25 m beyond the end of the bulldozer trail and approximately 70 m from the fire edge before the wind change arrived. As the wind changed the bulldozer operator immediately returned to the burnt out section of fireline. The tankers remained stationary and were over run by a moderate intensity fire that entered the tree crowns as it neared the location of the tankers.

Figure 3. Map of the entrapment site, Linton Fire, 2 december 1998.



Wind speeds associated with the frontal change were estimated to be 30-35 km h^{-1} with gusts to 68 km h-1. Immediately prior to the wind change the air temperature and relative humidity were the same as during the period of the main fire run earlier in the afternoon, and it is probable that fine fuels had not increased in moisture content. If the rate of spread of the fire after the wind change was similar to that observed during the peak of the north-north-westerly run, then the fire would have taken 2.6 minutes to travel the 70 m to the tankers. However, if the initial gust associated with the front averaged 60 km h^{-1} for several minutes then the fire could have been spreading at 2400 m h^{-1} and taken only 1 minute 45 seconds to reach the tankers.

These three examples highlight the risks to firefighters undertaking parallel attack on bushfires in heathland and eucalypt forests. Other examples of entrapments could be used to illustrate this point. The common theme in these examples is that firefighters were caught by a sudden and dramatic escalation in fire behaviour that resulted from changes in wind direction and/or strength influencing an established line of fire. The rapid response by the fires to changing conditions and the distance between the fire edge and the fireline left the firefighters with only a very short time to assess the situation, communicate the decision amongst the crew, and take evasive action.

Regardless of the specific tactics in each case, and subsequent actions taken after the wind change, it appears that the fires spread much faster than the firefighters anticipated and they did not allow sufficient time for safe egress. An analysis of recent forest fire behaviour data might help to appreciate some of the factors contributing to these entrapments.

Development of a fire from a line

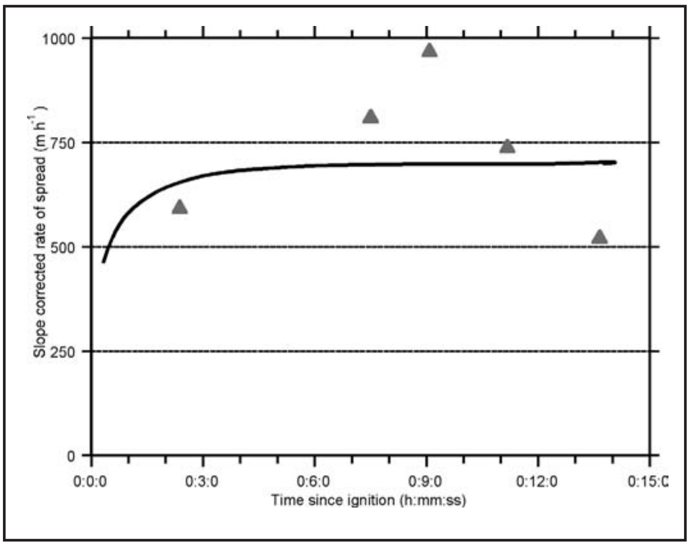
A preliminary analysis of the initial spread data of fires during Project Vesta (Cheney *et al*. 1998) was undertaken to estimate the time for a fire to reach its potential rate of spread when it develops from a line (for example from a rapidly ignited line at right angles to the wind direction or when a flank fire turns into a head fire after a 90º shift in wind direction). Fires were lit during the summer months in the jarrah (*E. marginata*) forest in Western Australia carrying fine fuel loads of 10 - 12 t ha^{-1}. Fire danger conditions during the experiments were Moderate, but fuels were dry (< 8% moisture content) and completely available for combustion.

The experiments were designed anticipating a period of fire growth before the fire reached its potential rate of spread and the first measurement of spread was made 25 m downwind of the ignition line. Two igniters started at the centre of a 120 m line and completed the ignition in exactly two minutes. Figure 4 shows the rate of spread for a fire burning in 16-year-old fuel across a block 200 m long. The terrain was gently undulating and the spread has been corrected for slope changes but not for variation in wind speed. This fire reached a spread rate of 600 m h^{-1} in the first three minutes and had an average rate of spread across the block of 750 m h^{-1}.

Figure 5 presents the data from 20 fires burning in 8, 11 and 16-year-old fuels. The rates of spread are taken for selected distances from the ignition line and have been corrected for variation in slope. The initial rates of spread across the first 25 m are a little slower than spread measured elsewhere in the blocks. There is no consistent pattern of spread beyond 25 m and variation in individual spread rates is probably attributable to variation in wind speed over the duration of the fires.

Examination of individual fires shows that the initial spread rate was lower when the wind speeds were lower. At the highest wind speeds (18 km h^{-1}) there was little difference between the spread rate over the first 25m and the spread rates further from the ignition line. The fire crossed the 25 m line before ignition had been completed (1.5 min). We consider that reduced spread in the first 25 m was due to the fact that two minutes were taken to complete the 120 m ignition line. Under low wind speeds large logs or occasional bare patches near the ignition line tended to delay fire spread to a greater extent than under high wind speeds. For all practical purposes we consider that a fire moving away from an established line of fire will immediately reach its potential rate of spread.

Figure 4. Periodic headfire rate of spread of a fire ignited from a 120 m line in a 16-year-old eucalypt forest fuel.

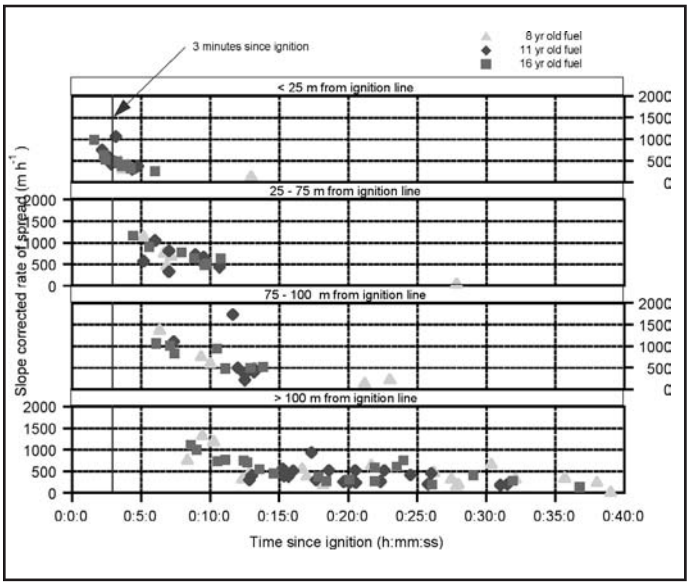


We consider the concept that all fires go through a growth period, as observed on a fire developing from a point, has been thoroughly ingrained into all firefighters. We allowed for a delay in reaching potential rate of spread in Vesta experiments and previously considered that line fires would take a few minutes to reach their potential rate of spread (Cheney and Gould 1997). Thus it is understandable that firefighters may not seek immediate egress following a wind change and wait to see how the fire develops.

Recognising changes in fire behaviour.

If firefighters working more than a few metres from an extended line of fire do not appreciate the speed that a fire can travel then they will get little warning if the fire moves away on a broad front when there is a change of wind direction. If they wait until they see the flames their escape time may be very short indeed. Although there is virtually instantaneous response in the rate of spread there is a delay before the flames reach their full potential and this may be up to one minute or more before all the fuel bed is contributing to the flame dimension. Immediately after the wind change, flames will spread across the top of the fuel bed and may travel 50 m before the convection has built up to the point where the flames are lifted into the elevated fuel layers and are visible through the forest. This effect may be accentuated on a steep slope and under strong winds.

Figure 5. Headfire spread rates of 20 experimental fires recorded over four distance intervals from the ignition line. Data from fires in 8, 11 and 16-year-old eucalypt forest fuels.



We believe there is a common tendency to overestimate the distance to a fire when observing through the forest[1]. On Project Vesta fires it was nearly impossible to see the flames in a forest containing a 2 m shrub layer and an intermediate tree layer when the fires were 100 m distant, even when there was intermittent crowning in the overstorey. When flames were clearly visible, even experienced observers consistently overestimated the distance between the flames and some reference point such as the plot boundary, at times by more than 100%. This illusion may lull firefighters into thinking there is more time for egress to a safe location than is actually the case.

Firefighters who do not remain fully aware of their situation may be lulled into a false sense of security if they base their actions only on the appearance of the fire and do not take account of likely future changes of wind and particularly its direction in relation to the slope and the resulting headfire width. Although the Bureau of Meteorology monitors the passage of a cold front firefighters should not expect a highly accurate forecast of the time of arrival of the frontal wind change. Fronts can speed up or slow down as they travel across the land. Estimates of the speed of the frontal passage depend on the orientation of the front relative to the observing points. A pre-frontal trough may develop ahead of the main front producing a change of wind direction to the west which later changes back to the north. In some locations, particularly in the south west of Western Australia, the pre-frontal trough can form, move east, move back to the west or dissipate completely making precise forecasts of wind changes extremely difficult, if not impossible.

Some visual indicators may precede local wind changes but these may not be easily observed from within the forest. The start of a sea breeze may be heralded by the formation of cumulous clouds towards the coast. Firefighters should always be wary of the chance of downdraft winds whenever there is a large build up of thunderclouds in the area. Winds are usually preceded by the appearance of virga beneath the cloud or spots of rain reaching the ground. However, there are shifts of 20º to 40º in the direction of the prevailing wind that can dramatically change a flank fire to a head fire as occurred at Grays Point. In Southern Australia these shifts will commonly be towards the west but their timing is impossible to predict.

A further complication is that a large fire will influence the local winds in the forest so that a change of wind direction will not be reflected in the direction of the wind beneath the canopy. Often the first reliable indication that a firefighter has of a change in wind direction is given by the direction that smoke is moving above the canopy.

[1] When an object is viewed through space filled with other objects there is an illusion that viewed the object is further away (Jim McLennan, Senior Research Fellow, Swinburne Computer-Human Interaction Laboratory, pers. comm.)

Other factors to watch for are the ephemeral effects of light showers of rain; the difference in moisture content and consequent fire behaviour when a fire moves from a sheltered southern aspect to a drier northern aspect; and the drop in temperature at night and the rise in humidity which may not be associated with a rise in fuel moisture due to the delay in the uptake of fuel moisture. These factors may appear to reduce the potential fire behaviour of the flank fire that disappears when a wind change turns the flank into a head fire.

Safe distance for indirect attack

Although our analysis of spread data from Project Vesta is incomplete we believe that there is strong evidence that the table of fire spread given on the Forest Fire Danger Meter (McArthur 1967) seriously under estimates the rate of spread at all fire danger indices and fuel loads. To indicate the time and distance required to egress safely from parallel attack we have assumed that the rate of spread in a 15 t ha^{-1} fuel will be three times that given on the Forest Fire Danger Meter. The distance a fire will burn in five minutes under different fire danger conditions and on different slopes is given in Table 1. Egress in five minutes is considered possible if firefighters are working close to a burnt out section of line and they react quickly. The actual time required will depend on such factors as the delay in recognising that conditions have changed, the mobility of the crew, the time to communicate decisions to crew members, ground conditions and the distance to a safe area. If a safety factor of three is incorporated, as is commonly used in risk engineering, then the distances shown in Table 1 should be trebled. Indirect attack at a FFDI > 40 is a very risky proposition indeed.

Table 1. The Deadman Zone - the distance (m) a line fire can travel in five minutes.

Forest Fire Danger Index	Slope		
	Level ground	10^o	20^o
20	87	174	348
40	170	340	680
60	258	510	1020
80	338	676	1352

Unless parallel attack is within one or two metres of the fire edge it must be considered as an indirect method of attack and associated with close burning out. The fire crew must adjust the rate of line construction to ensure that burning out is of sufficient depth to provide a refuge so that they can fall back to burnt-out area rather than seek egress through unburned fuels, even though this may appear to be a more comfortable option. Although it is rare in Australia for fires to reburn across burnt area, this can happen in certain heathland fuel types. When flames are backing down steep slopes in litter beneath the elevated fuel there may be sufficient elevated fuel remaining to carry a fire if a strong wind drives a wide head fire up-slope as occurred during the South Canyon fire incident in Colorado (Butler *et al*.1998).

The safest method for firefighters inexperienced in forest fire fighting is direct attack. When direct attack is not possible using dry fire suppression techniques they should withdraw or use direct suppression with water with hose lays and work from the burnt area inside the fireline. In southern Australia, the strategy of controlling the eastern flank as rapidly as possible before the westerly wind change occurs is essential to reduce the area burnt and the damage done. Firefighters must be competent in fire behaviour assessment and entrapment risk avoidance being ever vigilant on the fireline. Wind changes will occur without warning despite the best efforts to forecast them. When the change occurs firefighters downwind engaged in indirect attack, must abandon their task in "The Dead-Man Zone" and go immediately to a safe area without waiting to see what the fire is going to do.

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