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Two Rural/Urban Interface fires in the Wellington suburb of Karori: assessment of associated burning conditions and fire control strategies

L.G. Fogarty

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Cover Photograph: Helicopter firebombing in gorse fuels at the McEwans Fire (Courtesy of the Dominion Newspaper, Wellington)

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Wildfire Case Study

Two Rural/Urban Interface fires in the Wellington suburb of Karori: assessment of associated burning conditions and fire control strategies*

Liam G. Fogarty (New Zealand Forest Research Institute)

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Private Bag 3020
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National Rural Fire Authority
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Abstract

The behaviour of two extreme wildfires burning in gorse (Ulex europaeus) fuels in the Wellington suburb of Karori is recorded for the future development and validation of fire behaviour prediction models. Burning on steep slopes and in High forest fire danger conditions, the McEwans Fire (6 February 1994) exhibited extreme fire behaviour with a head fire spread rate of 4440 m/h (± 360 m/h) and a fireline intensity of 60 000 kW/m. The Montgomery Crescent Fire (1 March 1994), which also burnt in High forest fire danger conditions had a rate of spread of 3400 m/h (±550 m/h) and the fireline intensity was greater than 25 000 kW/m.

The need to protect life and property during suppression of Rural/Urban Interface fires places firefighters under great stress. At both fires, firefighters responded to these pressures and adopted the high risk strategy of making a stand to halt the spread of the head fire. The McEwans Fire was controlled without incident when firefighters took advantage of favourable wind and slope conditions which had reduced fire intensity sufficiently to allow for the fire to be safely contained. In contrast, a crew of firefighters attempting to protect houses from the Montgomery Crescent Fire were burned-over by an extreme head fire. The safety aspects of making a stand in scrub fuels, and alternative methods of fire suppression are discussed.

At the Montgomery Crescent Fire, members of the public were evacuated before the fire reached their homes. This action is discussed through a comparison with research findings from the 1983 Ash Wednesday fires in Victoria, Australia, where it was found that unoccupied houses are more vulnerable to being destroyed by fire and that many civilian deaths resulted from people being caught outside the safety of their homes when the fire front arrived.

Making a stand and evacuating residents are both legitimate and useful techniques available to officers responsible for fire suppression in RUI areas. However, both have high levels of risk which need to be identified and accounted for in the development and implementation of fire suppression strategies and tactics. An understanding of fire behaviour and factors affecting firefighter and resident safety is imperative.

Keywords: Fire behaviour, Scrub fuels, Making a stand, Evacuation, Safety.

Introduction

During the 1993/94 fire season, the residents of the Wellington suburbs of Karori and Silverstream were subject to continued risk from fires caused by arson. Home owners living on the ridge-top roads of Montgomery Crescent and Appleton Street (Karori) were threatened by these fires on February 16 (McEwans Fire), and March 1 (Montgomery Crescent Fire). At the Montgomery Crescent Fire, 12 houses needed to be evacuated but, due to the efforts of professional and volunteer firefighters, no houses were lost or damaged.

Rural/Urban Interface (RUI) fires have greater potential to cause damage and loss than most other types of fire, so management and suppression can place high levels of stress on fire managers, firefighters, other emergency personnel and the public. At the Montgomery Crescent Fire, a team of volunteer firefighters who had deployed along the ridge top that defined the RUI boundary were nearly trapped and "burned over" by a fire that had a forward rate of spread of more than 3000 m/h, and a fireline intensity of greater than 25 000 kW/m. This fireline intensity exceeds 4000 kW/m, which is the threshold for "extreme" fire behaviour and is considered to be the highest intensity level at which head fire attack may be successful (Cheney 1981, Alexander 1992).

Gorse (*Ulex europaeus*) was the predominant fuel type at both fires, but the McEwans Fire also burnt a significant area with an overstorey of seven year old *Pinus radiata* that had been partially thinned and pruned. While no adequate Fire Behaviour Prediction (FBP) System (Forestry Canada Fire Danger Group 1992) exists for fires burning in gorse, it is apparent from numerous observations and some limited experimental burning (G. Pearce and L. Fogarty: unpublished data) that these fuels are exceptionally flammable and capable of sustaining extreme fire behaviour at Low to High forest fire danger conditions. Suppression of the Karori fires was difficult and hazardous, because they spread up slopes that average 30 to 35 degrees, and were at times fanned by moderate to strong winds. Given these conditions, extreme fire behaviour was inevitable.

The aim of this report is to investigate and record the fire behaviour observed to aid the future validation of fire behaviour models currently being developed by fire research scientists at the New Zealand Forest Research Institute. New fire management practices and procedures are often adopted as a result of fire *disasters* where accepted norms have failed, causing firefighters, people and their property to be threatened (Turner 1977, Mutch 1995). Suppression and evacuation strategies employed at the Karori fires are reviewed and benchmarked against practices and procedures used outside of New Zealand. By reviewing the applicability to New Zealand of lessons learnt from fire disasters such as the 1983 Ash Wednesday Fires in Australia, which burnt an approximate area of 350 000 ha, killed 75 people and destroyed 2463 houses (Alexander 1985), the likelihood of fire disasters in New Zealand can be reduced.

Fire behaviour and suppression strategy

Fast rates of spread were observed at both fires. Between 1043 hrs and 1048 hrs (daylight savings time) the spread of the McEwans Fire was recorded by NZ Fire Service Officer Dave Owens, as the fire moved up the slope along the <u>fire run 1</u> of Figure 1. The head fire travelled 370m (± 30 m) in a five minute period, corresponding to a spread rate of 4440 m/h (± 360 m/h). The fire was observed to be very responsive to wind fluctuations and did not appear to accelerate as it moved from the pine stand into the open area of gorse underneath the powerlines, possibly due to a decrease in wind at this time. The fireline intensity during this fire run was at least 60 000 kW/m, well outside the 4000 kW/m at which head fire attack may be successful (Cheney 1981, Alexander 1992).

The final fire area is shown by Figure 1 and also by Photograph 1, which is an aerial view looking over the fire from the west. The fire spread rapidly until it reached the top of a major spur, where it was controlled by firefighters dressed in urban attire, who *made a stand*[1] to prevent head fire spread. At this point the fire behaviour had decreased because the fire was backing into the wind and down a small drop into a minor gully. A major gully that contained native vegetation along the eastern edge restricted fire spread up the adjacent ridge. Ground and aerial attack were used to prevent the fire from spreading laterally along the ridge face.

[1] *Making a stand* is a NZ Fire Service equivalent to a direct attack on a head fire, but it usually involves pumper units spaced along the length of line where a fire will cross a track or reach houses.

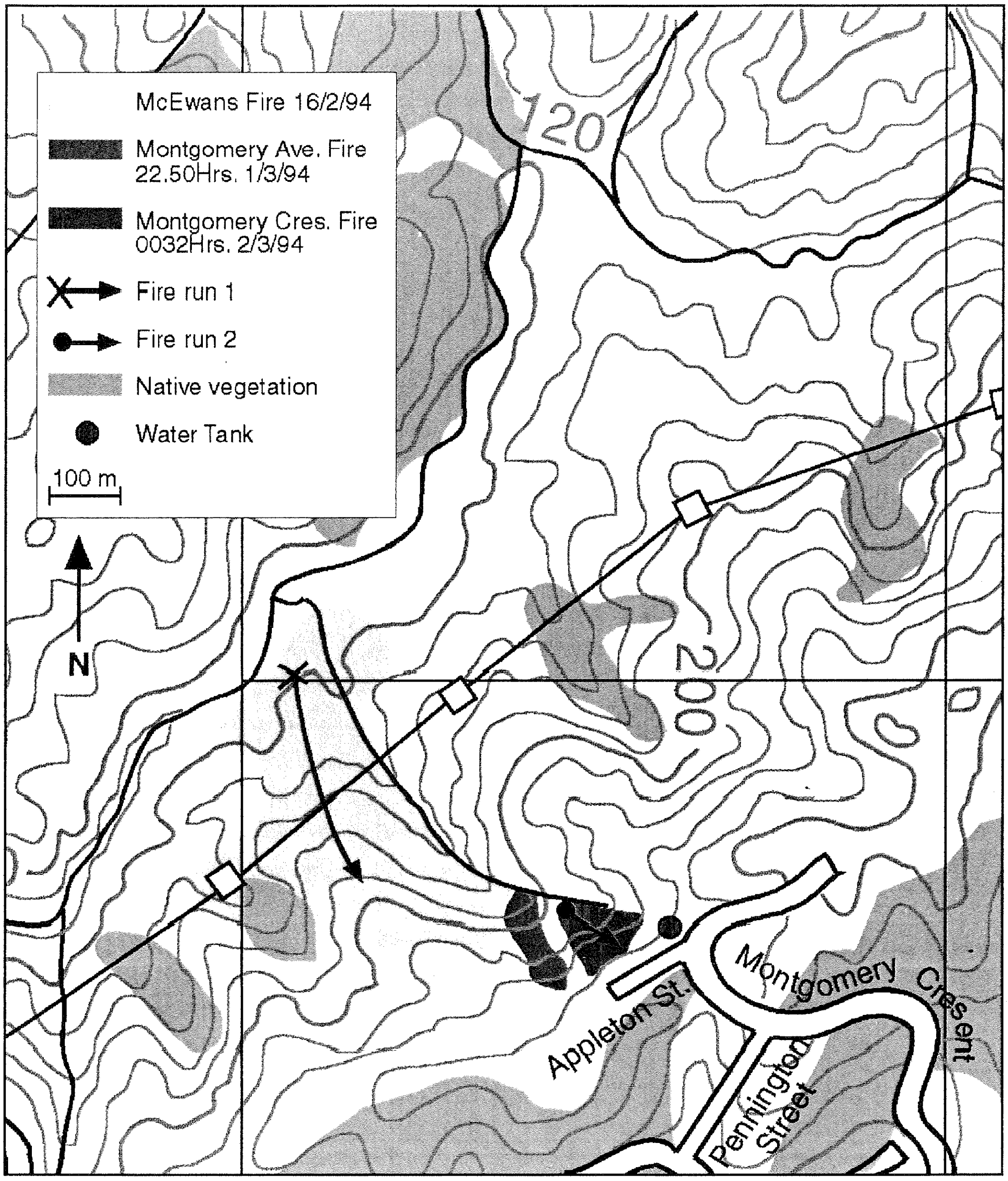
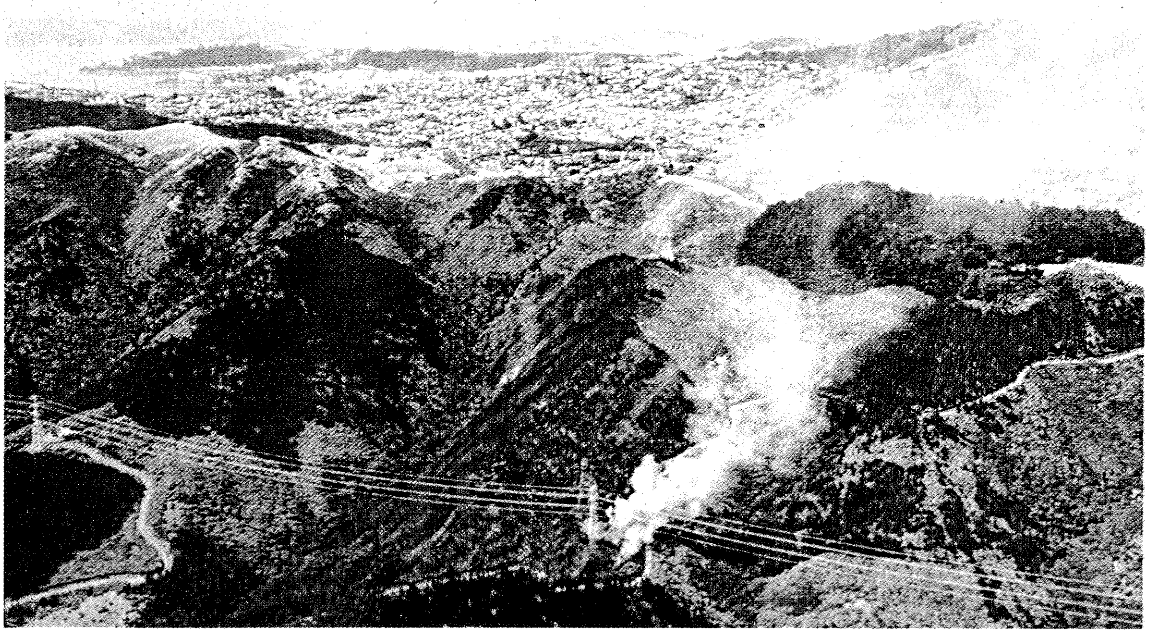


Figure 1. Map of McEwans Fire and the Montgomery Crescent Fire, Karori, Wellington.

The Montgomery Crescent Fire started at the top of the McEwans Fire, either from arson or a wildfire holdover. The fire was reported at 2134 hrs on 1 March 1994, and at 2208 hrs it was reported to be "burning slightly against the wind...no danger to any property". The fire was initially contained at approximately 2250 hrs on 2 March 1994 (i.e., the area marked as Montgomery Crescent fire at 2250 hrs in Figure 1). Firefighters were beginning to leave the area when, at 0021 hrs, smoke was seen to be coming from within the native vegetation in the gully near the north east corner of the fire contained 30 minutes previously.

At the time that the fire crossed the gully, an aerial observer reached the fire and saw it accelerate rapidly through the gorse just above the gully and reach the ridge in 3 to 4 minutes, at 0032 hrs. This distance can be accurately measured as being 200 m along fire run 2 on Figure 1. The rate of spread was approximately 3400 m/h (±550 m/h). The fireline intensity during this fire run was at least 25 000 kW/m, which is also well outside the 4000 kW/m at which head fire attack may be successful. The width of this fire was only 100 to 150 m when it reached the top of the ridge, so it would have had to undergo a phase of acceleration and the rate of spread cannot be considered to have been at equilibrium.



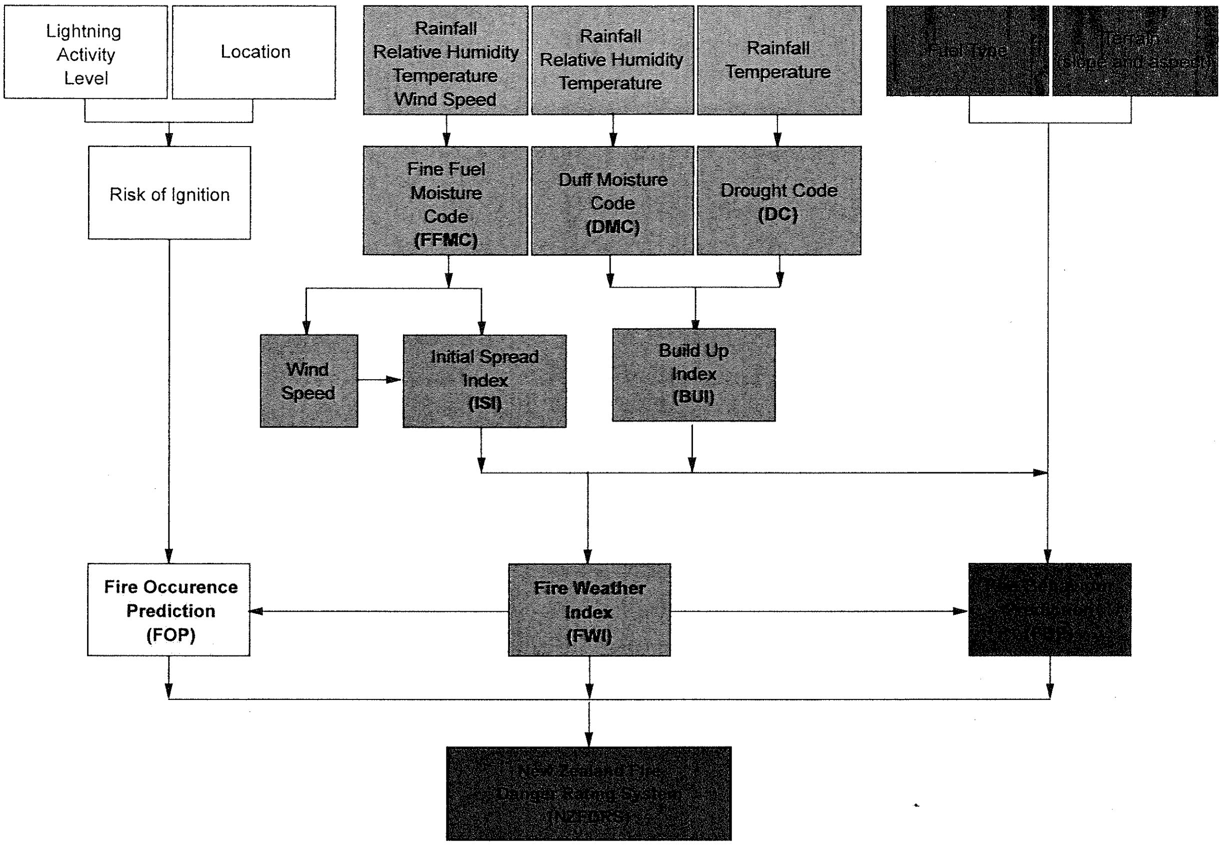
Photograph 1. Aerial view of the McEwans Fire (Courtesy of the Dominion Newspaper, Wellington).

When the Montgomery Crescent Fire reached the top of the ridge it was driven by strong wind gusts, and the flame front rolled over, reaching the roofs and walls of houses 30 to 40 m away. A team of firefighters that had deployed along the ridge top had to retreat to the flank of the head fire to a 5 to 10 m wide strip of green grass. A pall of embers and smoke covered the firefighters who stayed low to the ground and sent up a mist spray for protection. Another team of firefighters, who were initially deployed along the road between the fire and the houses, had to retreat until the fire intensity had subsided. In the face of an accelerating fire that had an average rate of spread of greater than 3 km/h and an intensity of greater than 25 000 kW/m, it was fortunate that no firefighters were injured.

The Fire Environment

The fire environment concept (Countryman 1972) is useful for defining "the surrounding conditions, influences, and modifying forces of topography, fuel and fire weather that determine fire behaviour" (Merrill and Alexander 1987) at these and other fires. The fire environment influencing the Karori fires is detailed in the following sections on fuels, weather and topography. This description incorporates outputs from the New Zealand Fire Danger Rating System (NZFDRS), which is used to quantify the effect of the fire environment factors on fire behaviour and is shown in Figure 2. The NZFDRS adopted the structure and underlying principles of the Canadian Forest Fire Danger Rating System (Stocks et al 1989, Forestry Canada Fire Danger Group 1992) in 1980, because it was based on sound scientific principles, had outstanding interpretative backup and was developed in a maritime climate similar to that of New Zealand (Valentine, 1978[2]).

[2] Valentine, J.M., 1978. Fire Danger Rating in New Zealand - review and evaluation. New Zealand Forest Service, Forest Research Institute, Forest Establishment Report No. 123 (unpublished).



FFMC	A numerical rating of the moisture content of litter and other cured fine fuels. This code is an indicator of the relative ease of ignition and flammability of fine fuel.
DMC	A numerical rating of the average moisture content of loosely compacted organic layers of moderate depth. This code gives an indication of fuel consumption in moderate duff layers and medium-sized woody material.
DC	A numerical rating of the average moisture content of deep, compact organic layers. This code is a useful indicator of seasonal effects on forest fuels, and amount of smouldering in deep duff layers and large logs.
ISI	A numerical rating of the expected rate of fire spread. It combines the effects of wind and FFMC on rate of spread without the influence of variable quantities of fuel.
BUI	A numerical rating of the total amount of fuel available for combustion that combines DMC and DC.
FWI	A numerical rating of fire intensity that combines ISI and BUI. It is suitable as a general index of fire danger.

Figure 2. Structure of the New Zealand Fire Danger Rating System (adapted from Hirsch 1993).

Fuels

The predominant fuel type at both fires was gorse. The gorse at both fires was very dense and restricted firefighter access. Native species occurred in the major and minor gullies. Gorse was interspersed at the margins of these, and sometimes penetrated into the minor gullies. Small areas of open grass were scattered throughout the burnt area with the largest being a continuous strip along the ridge top. The degree of curing of these grassy patches was approximately 70%.

The McEwans Fire burnt in 2 - 2.5 m gorse under 7 year old pine that had been partially thinned and pruned to waste. No fuel sampling was conducted in this area, but samples from gorse of similar height and cover suggest that available fuel loads were at least 30 t/ha (G. Pearce and L. Fogarty: unpublished data). The pine trees ranged in height from 9.5 - 12.5 m, and had been pruned to an average height of 2 m. Shorter (0.8 - 1.2 m) gorse shown by Photograph 2 was burnt at the Montgomery Crescent Fire. The pre- and post-burn fuel measurements indicate that approximately 17 t/ha was consumed by the fire.

Photograph 2. Short (0.8 - 1.2 m) gorse fuels burnt by the Montgomery Crescent Fire.

Topography

Both fires burnt up steep slopes (30 to 35°) that had a north or north-east aspect. The McEwans Fire ran up two north/north-east spurs before reaching the top of a divide in the slope, where the fire was contained. The Montgomery Crescent Fire started near the end of the previous fire, and burnt to the top of the next spur where it was temporarily halted. This fire then reignited at the intersection of the gully and the north eastern corner of the fire (see Figure 1). After reignition, the fire spread rapidly up a north facing slope to the top of the ridge line that ran parallel to Appleton Street.

Weather and Fire Weather Index System Codes and Indices

An automatic weather station at Wellington Airport, located 10 km east of the fires, supplied all weather data except for rainfall which came from Kelburn, 4 km east of the fire site. The data were used to determine Fire Weather Index (FWI) System codes and indices (Van Wagner 1987) which are presented in Table 1. Time since significant rain (> 0.6 mm) before the McEwans Fire was 21 days and 0.7 mm of rain fell on the day of the Montgomery Crescent Fire. The wind on the days of both fires was northerly, and was blowing approximately up slope during both of the recorded fire runs. Firefighters at the Montgomery Crescent Fire estimated that surface wind gusts at the top of the ridge were up to 50-60 km/h just before and during the fire run. The forecast maximum (i.e., based on midday values) Forest Fire Danger Class (Alexander 1994) on the day of both fires was Very High, but neither of these fire occurred during the mid-afternoon, and the actual fire danger conditions during the "fire runs" was High. The Grassland Fire Danger Class (Alexander 1994) at the time of both fires was also High.

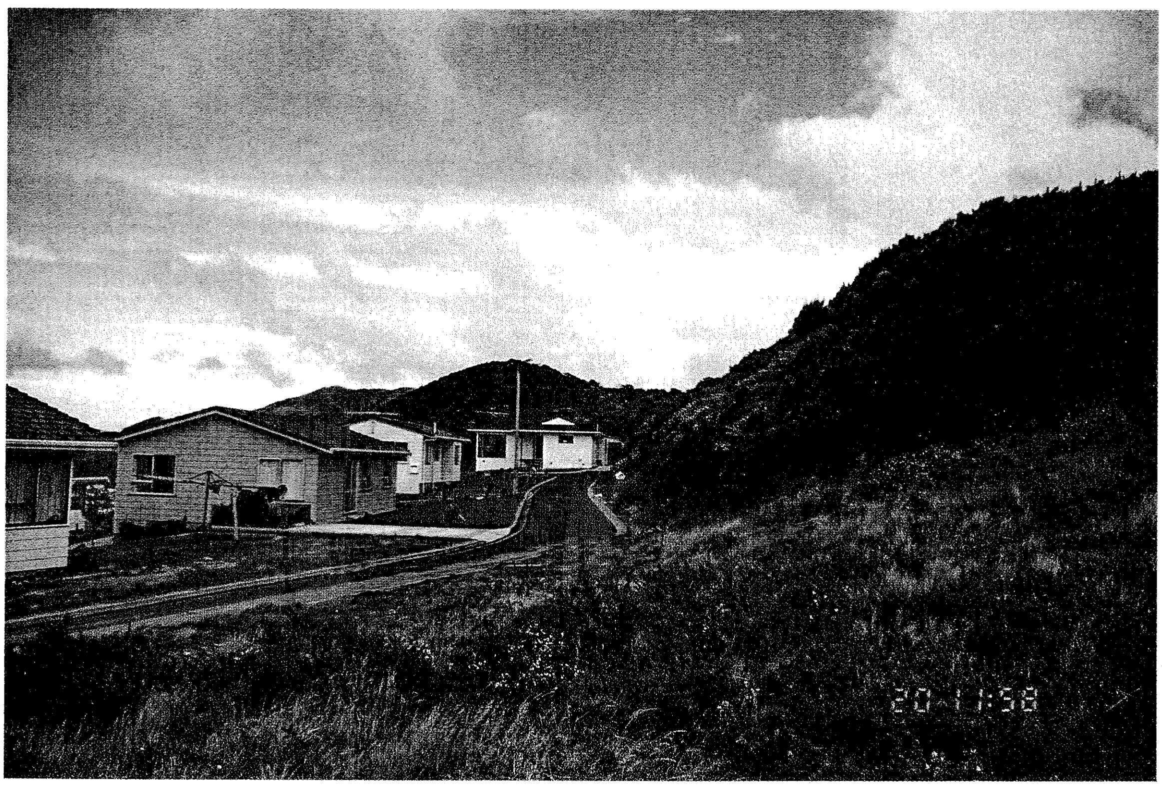
Table 1 Weather values and Fire Weather Index System Codes and Indices at Midday and during the fire run, for the McEwans and Montgomery Crescent Rural/Urban Interface Fires.

FWI and Weather component	McEwans Fire - 16/2/94 Daily Maximum (1200 NZST)	Value during fire run (1000 hrs)	Montgomery Crescent Fire - 2/3/94 Daily Maximum (1200 NZST)	Value during fire run (2400 hrs)
Temp (oC)	26.0	23.0	12	17.5
RH (%)	39.0	50	77	83
Wind (km/h)	20.4	20.4	37	25.0
Fine Fuel Moisture Code	89.8	87.5	82.8	82.9
Duff Moisture Code	39	39	40	40
Drought Code	339	339	414	414
Initial Spread Index	11.7	8.4	10.1	5.6
Build Up Index	61.8	61.8	64.9	64.9
Fire Weather Index	27.6	15	26.3	16.8
Forest Fire Danger Class	Very High	High	Very High	High
Grassland Fire Danger Class	High	High	High	High

Fire Danger Class ratings follow Alexander (1994)

Evacuations

The residents of 12 houses, some of which are shown by Photograph 3, were considered to be at risk during the Montgomery Crescent Fire. An *in situ* evacuation commenced at approximately 0021 hrs, and was completed at 0025 hrs.



Photograph 3. Some of the 12 houses evacuated during the Montgomery Crescent Fire.

Discussion

At both of the Karori fires, the rates of spread and fireline intensities were in excess of 3000 m/h and 25 000 kW/m. The extreme fire behaviour reported in both cases has also been observed by the author at three experimental burns conducted in gorse in New Zealand. Under Low to High forest fire danger conditions and on flat ground, the rate of spread of these fires ranged from 900 and 3600 m/h and intensity from 21 000 to 90 000 kW/m. The wildfires and experimental burns described provide examples of the uncontrollable fire behaviour that can occur in Low to High fire danger conditions, when steep slopes, strong winds and flammable scrub fuels are involved. All of these fires reinforce the findings of Wilson (1977) and Millman (1993) that wildfires do not have to be particularly large to be threatening and dangerous.

The Karori fires were fought under difficult conditions, with steep slopes and heavy scrub fuels making suppression arduous, especially at night. Despite these difficulties, firefighters made great efforts to suppress the fires and minimise damage to homes and other assets. The McEwans Fire burnt a significant area of 7 year old pine and if the fire had sustained the initial reported spread rates, then the houses along Montgomery Crescent and Appleton Street would have been threatened. Firefighters were placed under greatest stress when the Montgomery Crescent fire directly threatened 12 houses along Appleton Street, and police support for the fire evacuation was required. At the same time the fire boss was also responsible for the suppression of another fire in Karori.

The evacuation and suppression strategies adopted might have been different at the Montgomery Crescent fire if the fire controllers had a greater knowledge of the factors that affect house and occupant survival. The predicted probability of house survival in Appleton Street was approximately 50 - 60%[3] if *able bodied* residents were on site to suppress structural fires after the fire front had passed, but only 10 - 20% if they were evacuated. The actual survival rate for both attended and unattended houses was probably much greater, because firefighters with good water supplies and structural fire suppression skills were on site.

An informed decision to evacuate houses during RUI fires requires a working knowledge of fire behaviour and the factors that affect house and resident safety. In instances such as the Karori fires, where little time is available because of fast rates of spread over short distances, fire behaviour must be assessed to ensure that there is adequate time to complete the evacuation before the fire front arrives. When directly threatened by a high intensity fire front, *able bodied* people are much safer sheltering inside their homes (provided there is good access and egress), because houses are a better shield from radiant heat than a car, log or a hole in the ground (Wilson and Ferguson 1984). At a larger fire than the Montgomery Crescent Fire, evacuation when the fire is close will increase the risk of damage to the houses and, if the fire front arrives during evacuation, then the residents will be at greater risk than if they stayed inside. New Zealand fire managers responsible for the protection of RUI areas need to be made aware of the lessons learnt from RUI fires in New Zealand and overseas. Specifically, they need guidelines to assist the determination of the advisability, timing and safety of evacuation procedures. This type of information is currently available, but has not been readily taken up by RUI fire managers.

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[3] This value is estimated using the "House survival meter", which was developed after a survey of 450 houses threatened or burnt by the Ash Wednesday fires in Victoria, Australia (Wilson 1984, 1988). In this instance, the probability of survival is underestimated because these homes were below the ridgeline and were not directly exposed to the bulk of the heat (convective and conductive) and embers from the flame front. Furthermore, the meter was developed in a eucalypt fuel type that "throws" more embers than gorse.

During the Montgomery Crescent Fire run, professional and volunteer firefighters placed themselves in dangerous situations when they *made a stand* to protect life and property. This approach may succeed in the suppression of fires burning at lower intensities. On the other hand, Figure 3 shows clearly that rate of spread of fires burning in scrub fuels is more sensitive to increased wind speed than fires in forest fuels. An increase in wind speed from 0 km/h to 10 km/h would increase the rate of spread by approximately 30 in scrub and 3 times in forest. A further increase in wind speed from 10 to 20 km/h would result in two- to three-fold increase in the rate of spread for both fuels. This would correspond to a rate of spread 72 times faster than the rate observed with no wind in scrub and 9 times as great as under still conditions in forest. Therefore the risk of scrub fires exhibiting low or moderate fire behaviour accelerating rapidly to become extreme is great in unstable conditions, especially when a flank fire becomes the head fire. This may explain why, in a survey of firefighter fatalities, injuries and near misses in New Zealand (Millman 1993), at least 20 out the 34 cases reported involved firefighters being trapped in dangerous situations because of a "fire run" or "wind change", and why open scrub fuels were involved in all except one of these events (over 50% were in gorse).

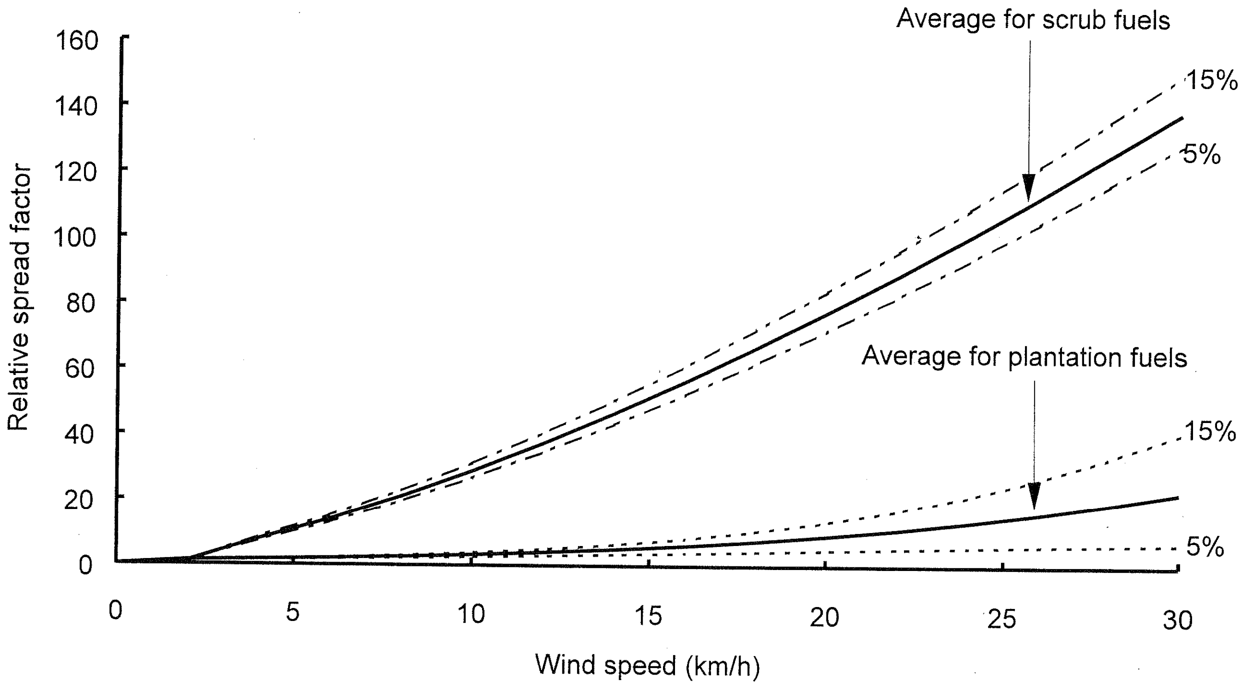

Figure 3. The effect of wind speed on increasing or decreasing the head fire rate of spread relative to fires burning in no wind conditions for open scrub and forest fuels[4]. For each fuel type, an average relative spread factor and the range for fuel moisture contents of 5% to 15% are shown.

Making a stand along a fireline (or even worse, standing in scrub with no suitable escape routes) to suppress wildfires is dangerous, especially when any or all of the common denominators at most firefighter incidents (i.e., small fires, light fuels that are often in an open area, changes in wind direction or speed, fires burning up steep slopes) are present (Wilson 1977). Making a stand should be done only when the operations boss has taken full account of the quality of the firebreak, escape

[4] The relative spread factors are based on the average factor for fires burning when fine fuel moisture contents are approximately 15%, 10% and 5%. The scrub fuel relationship was derived from the button grass moorlands fire behaviour model (Marsden-Smedley 1993) using an age class of 30, which is similar to tussock grasslands reverting to scrub with a fuel load of 30 t/ha. The forest relationship is derived from plantation conifer forest models (Forestry Canada Fire Danger Group 1992), which are similar to mature plantation forest in New Zealand (Alexander 1994). The relative spread factors for wind *should not* be used for operational decision making, its purpose here is to illustrate the difference between the effect of wind on fires burning in forest and open scrub fuels only. Furthermore, the relative spread factor for forests is based on surface fires only.

routes and the expected weather and fire behaviour. If a fire is so intense that the only suppression strategy available is to make a stand, then it is probably too intense for this to be safely carried out as well.

When *making a stand* at severe wildfires, natural or man-made firebreaks need to be wide enough to ensure that the heat transferred from flames and radiant energy is dissipated to a level that it will not place firefighters at risk (Green and Schimke 1971, Green 1977, Anon. 1991a). Some approximate levels of exposure of firefighters to radiation intensity (kW/m^2) for a range of fireline intensities and distances from the fire front are shown in Figure 4. At the Montgomery Crescent Fire, where the fireline intensity was at least 25 000 kW/m, any firefighters closer than 27 m to the flame front would have been exposed to radiation intensity levels greater than 16 kW/m^2, causing burns that require medical treatment to skin exposed for more than 5 seconds (exposure levels from Drysdale 1985). These exposure levels do not incorporate the effects of flame roll-over at firebreaks, which have been observed to be between 10 - 20 m in New Zealand scrub fuels at fire intensities of 10 000 - 20 000 kW/m, and were 30 - 40 m at the Montgomery Crescent Fire. Therefore, it is anticipated that at this fire, a break of greater than 65 - 70 m would have been necessary for firefighters in rural attire to safely *make a stand*.

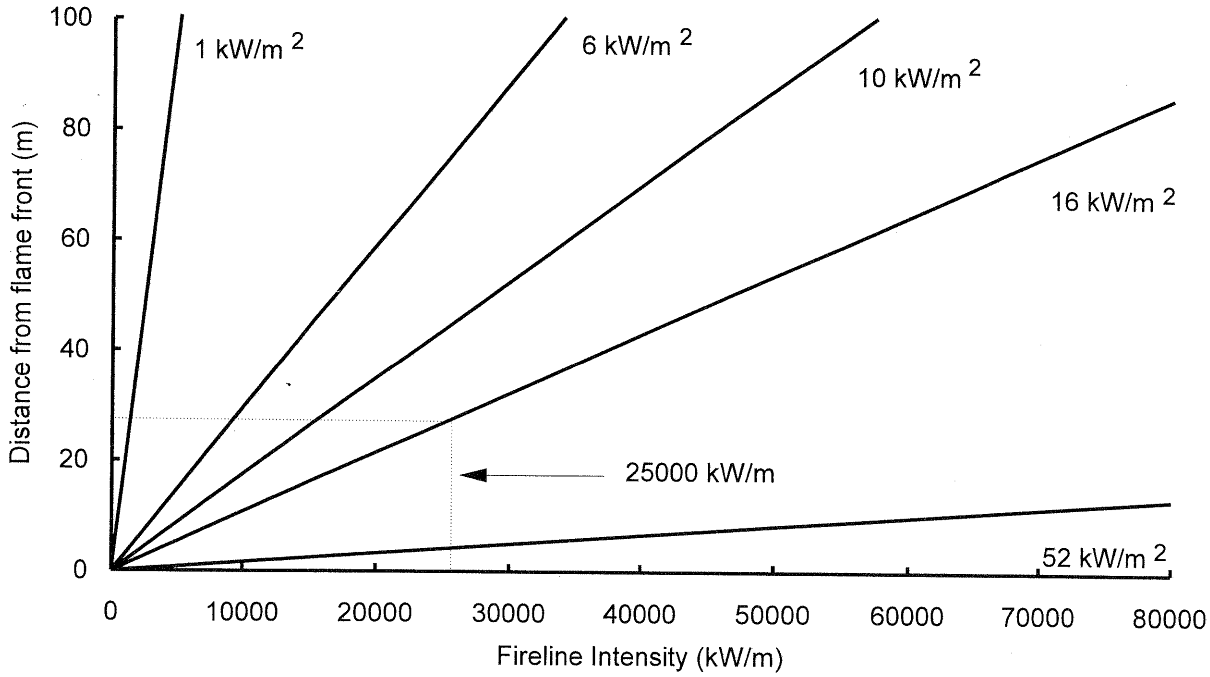

Figure 4. Approximate radiation intensity levels (kW/m^2) at different fireline intensities (kW/m), and distances (m) from the flame front[5], where each of the levels are as follows (from Drysdale 1985):.

1 kW/m^2:	the level where firefighters can withstand indefinite skin exposure;
6.4 kW/m^2:	the level where pain will be experienced after 8 seconds on exposed skin;
10.4 kW/m^2:	the level where pain will be experienced if the skin is exposed for 3 seconds;
16 kW/m^2:	the level where exposed skin will blister after 5 seconds of exposure, and medical treatment will be required, and
52 kW/m^2:	the level at which fibreboard will spontaneously ignite.

[5] The relationship used is from Leicester (1985); it is: $Q = 60\ (1\text{-}\exp[-I/3000\ D])$, where Q is radiation intensity (kW/m^2), I is fire intensity (kW/m) and D is distance from flame front (m).

It is more difficult to prescribe a safe working distance for firefighters dressed in the more protective urban attire. However, one of the lessons learnt from the 1988 Akatarawa Road Fire where two firefighters were burned over and one seriously injured, was that "no practical level of protective clothing could be expected to provide total protection from exposure to such intense temperatures as those to which" the firefighter[6] "was subjected" (Smith, R.H.; Bishop, R.H. and Wood, J.R.: unpublished[7]). A large proportion of the injuries received were attributed to a gap in the firefighters clothing which allowed the skin to be exposed to convective and radiant energy. Therefore, in the absence of accurate information on the performance of urban firefighter attire at rural incidents, a 65 - 70 m firebreak is also recommended for the direct attack of fires of similar magnitude to the Montgomery Crescent Fire.

Where fuels are continuous, very extreme fires will breach firebreaks with relative ease. There is no detailed knowledge of the width of a firebreak needed to stop scrub fires at different intensities. However, Byram (1959) suggests as a "rule of thumb" that in the absence of spotting, a break that is 1.5 times as wide as the flame length has a high probability of containing a wildfire. Figure 5 shows the effect of fire intensity on the expected flame length and the minimum width of fire break needed to contain a fire in scrub. A scrub fire that has an intensity of 25 000 kW/m will have a flame length[8] of approximately 20 m and it is estimated that a firebreak width of 30 m is needed to prevent breaching. A road or track usually provides a 6 - 10 m firebreak which is likely to be insufficient to prevent breaching when tested by an extreme fire. In these situations *making a stand* is not only dangerous, but futile.

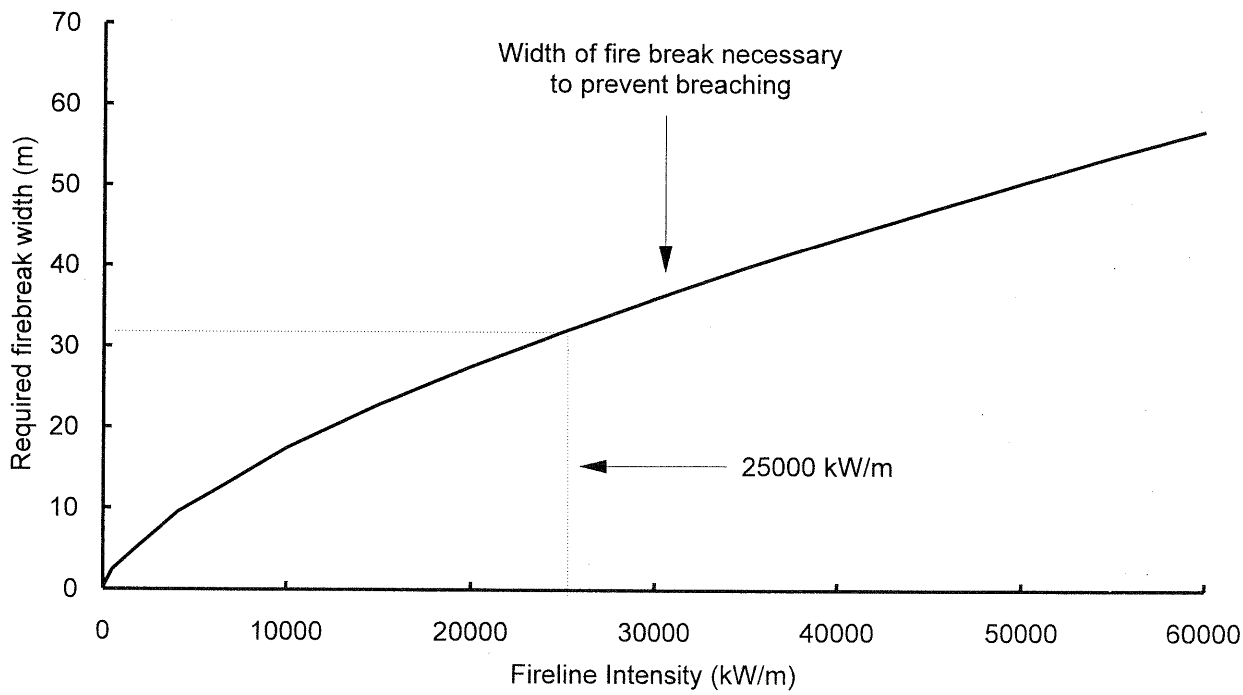

Figure 5. The estimated width of firebreak needed to contain fires in scrub fuels at different fire intensities in the absence of spotting. The relationship is derived from Byram's (1959) rule of thumb that firebreak widths must be 1.5 times greater than the flame length to prevent breaching.

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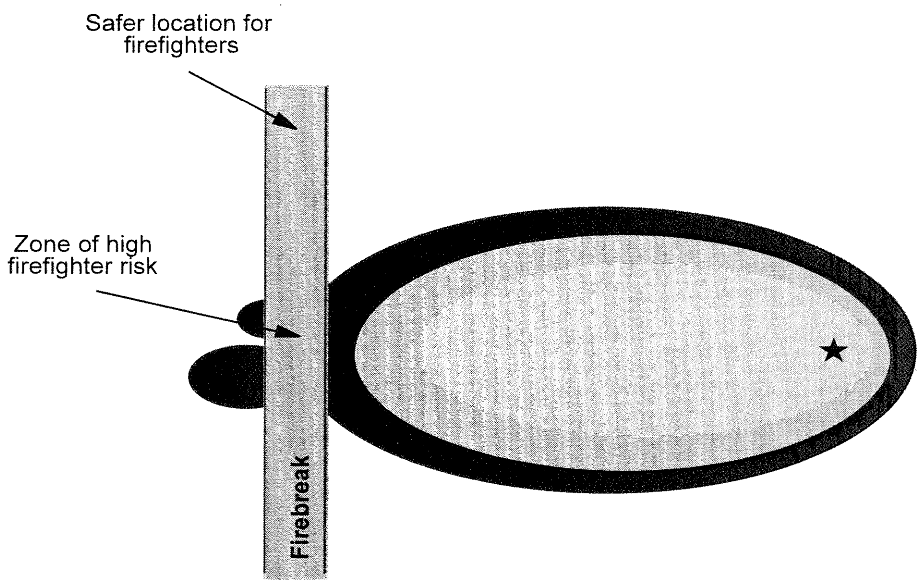
6 "The firefighter" replaces the name of the fire officer injured at the Akatarawa Road Fire.

7 Internal New Zealand Fire Service "Report to the New Zealand Fire Service Commission on incident at Akatarawa Road, Upper Hutt on 9 April 1988 and the injuries sustained by senior firefighter (name deleted) Trentham Station". Undated.

8 The equation used to estimate flame length (m) in scrub fuels is from Thomas (1963); it is as follows: $L = 0.0266\ (I^{0.66})$, where L is the flame length (m) and, I is the fire intensity (kW/m).

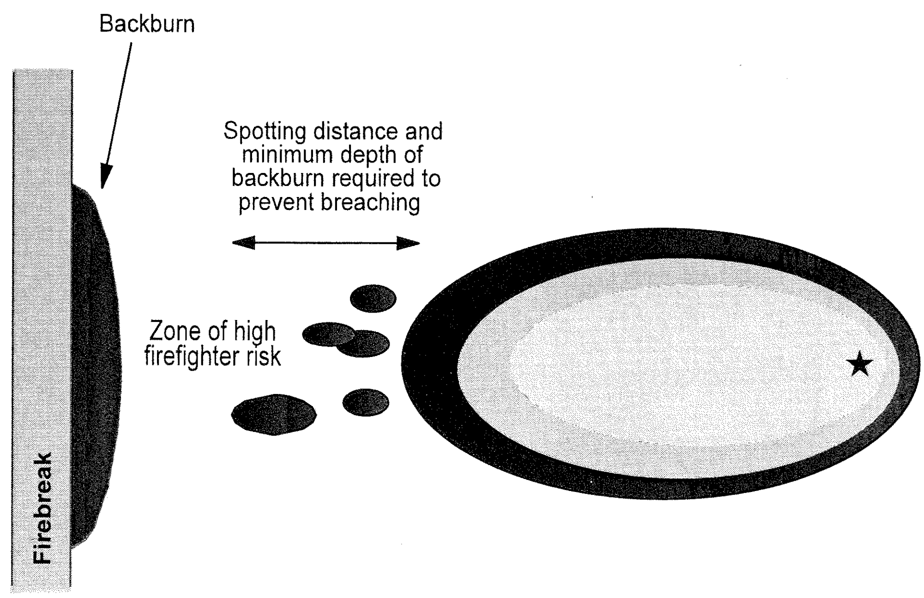
When firefighters are likely to be exposed to radiation intensity levels that will place them at risk, a much safer approach to *making a stand* is shown in Figure 6. In this example, firefighters *stand off* the length of break threatened by the fire, and then move in rapidly after it has reached the break and has burnt most of the available fine fuels. Using observed or predicted fire behaviour information, the operations or sector boss is able to estimate the time available to dowse the vegetation on the opposite side of the firebreak using class-A foam or long-term retardant. The laying of suppressant or retardants will reduce the probability of ignition. If spot overs do occur, the dowsed area will slow the acceleration of the developing fire and provide an area that can be quickly secured and used as an anchor point for fire suppression.

Figure 6. *Standing off* - an alternative strategy to *making a stand* for the suppression of wildfires.



Backburning or indirect attack from a firebreak is another option for preventing the spread of a head fire burning at intensities of greater than 4000 kW/m, and possibly up to 10 000 kW/m (Alexander 1992). Figure 7 shows that to be successful when backburning, firefighters need to use fire behaviour information (e.g., rates of spread and spotting distance), and the effectiveness of fire suppression resources to ensure that control lines are established well before the firebreak and firefighters are threatened by the fire (Burrows 1986). In severe burning conditions, an escaped backburn can add to control problems. It is important to overcome the inadequate levels fire behaviour knowledge and backburning expertise which currently preclude the use of this useful fire suppression tactic in New Zealand.

Figure 7. *Backburning* - an alternative strategy to *making a stand* for the suppression of wildfires.



When fighting RUI fires, the same principles apply. Extreme fires in grass and other light fuels emit lethal quantities of heat for a few minutes only (Wilson and Ferguson 1984), and in forest conditions heat is thought to remain unbearable for no longer than 15 to 20 minutes (Cheney 1983, from Wilson and Ferguson 1984). Gorse has a high fine fuel loading that is elevated and aerated, so it is likely to burn out more slowly than a grass fire, but quicker than a forest fire which has greater quantities of coarse material to sustain residual burning after the fire front has passed. Therefore, in most instances, firefighters should be able to move in rapidly after the fire front has reached the RUI boundary to secure the houses. At the Montgomery Crescent Fire, urban firefighters dressed in full protective clothing and shielded behind a mist of water had to retreat from the intense heat emitted from the head fire, but this fire took 2 to 3 minutes only for the available fuel to burnout and the heat to reduce to bearable levels.

Figure 4 illustrates that when *making a stand*, firefighters are likely to experience hazardous levels of exposure (i.e., radiation intensities of greater than 16.4 kW/m^2) that is lower than the level of radiation intensity required for an average fibreboard house to spontaneously ignite (i.e., greater than 52 kW/m^2). It is evident that if a vegetation fire is too intense to enable houses to be saved, then it is definitely too intense for firefighters to safely *make a stand* to protect them.

Firefighters cannot attend every threatened structure during all RUI fires, because in many instances there are not enough resources and, even at small fires like Montgomery Crescent, severe burning conditions can restrict firefighter access. Therefore, in areas where steep slopes, scrub fuels and strong winds are the predominant features of the fire environment, residents need to initiate some local prevention, presuppression and preparedness measures. Detailed guides which should be reviewed when determining the levels of fire protection required are available (NFPA, 1991; CFA, 1991). An aim of the guidelines is to reduce potential for high intensity fires in the area adjacent to houses, because it has a significant influence on the probability of house survival (Wilson 1984, 1988).

Fire intensity is determined by a fire's rate of spread and the available fuel load (Byram 1959), and in a survey of 450 homes following the 1983 Ash Wednesday fires in Victoria, Australia, reducing fuel loads within 50 to 100 m from houses was found to significantly increase the chances of house survival (Wilson 1984, 1988). The absence of heavy accumulations of flammable materials (e.g., wood heaps) or buildings and, of continuous trees and scrub within 40 m of a threatened structure was found to further increase the probability of survival by reducing fire intensity and allowing safe access for residents and firefighters to the structures soon after the fire front had passed (Wilson 1984, 1988). In many RUI areas of New Zealand where the probability of severe fires burning up gorse covered slopes is high, planning guides (NFPA, 1991; CFA, 1991) recommend a clean[9] defensible space of 40 m for structure protection. Flame rollover from the Karori fire was 30 to 40 m, so this distance should be regarded as a minimum for these locations.

[9] This does not preclude the planting of some low flammability trees and shrubs provided they are not too dense, and dead foliage and litter is removed.

Conclusion

The Karori fires are an example of the possibility of extreme fire behaviour in the fire environment of many New Zealand RUI areas. The suppression of these fires in difficult situations often places great pressure on fire managers and firefighters, especially when *making a stand* between the fire and the houses at risk is seen as the only possible suppression strategy. Fire managers need to improve their level of understanding of fire behaviour and the management of fires in the RUI to ensure that firefighters, and the public and their property, are not placed at unnecessary risk. An accurate fire behaviour prediction system is needed for the planning and implementation of wildfire suppression strategies. These models do not exist for gorse or other scrub fuels and their development must remain a high priority for fire research. Firefighters need to be more aware of the surprisingly rapid rates of spread and high intensities that fires in scrub fuels can reach with only minor changes in wind speed or direction. When *making a stand*, firefighters are most at risk of injury from a "wind change" or a "fire run".

During many RUI fires, firefighters will not be able to protect all houses because of limited resources or severe fire behaviour. Homes on sites characterised by steep slopes and gorse are at great threat from severe fires. In these situations fire mangers need to make the public aware of the threat of wildfire and residents need to undertake local fire protection action. The clearing of fuels to create *at least* 40m of defensible space in the most likely direction of fire spread is one option that will increase the probability of house survival by minimising exposure to sources of ignition and by reducing the period before safe access and egress can be allowed after the fire front has passed.

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