

A case study of grassland fire behaviour and suppression: the Tikokino Fire of 31 January 1991

J.H. Rasmussen and L.G. Fogarty



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Cover Photograph: Aerial view of the Tikokino Fire area (Courtesy of the Hawke's Bay Herald-Tribune, Hastings)

Wildfire Case Study

A case study of grassland fire behaviour and suppression: The Tikokino Fire of 31 January 1991*

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(New Zealand Forest Research Institute).

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Abstract

The behaviour of an extreme wildfire, burning in cured grassland near Tokokino in central Hawkes Bay, is recorded to assist validation and improvement of fire behaviour prediction models. During the major fire run, the rate of spread was estimated to be 13 950 m/h (± 3000 m/h) and the head fire intensity exceeded 13 500 kW/m. A fire appliance crew attempting suppression was overrun by the fire front and one person suffered burns.

Analysis of the fire showed that the predicted rate of spread was at the lower end of the range of values observed. This difference could have been due to the use of weather data recorded earlier in the day and at some distance from the fire. More attention to reporting fire behaviour and weather from fire sites would assist validation and improvement of fire behaviour models.

Assisted by barriers to fire spread, firefighters successfully contained slower and less intense back and flank fires, while the wind reduction effects of a shelterbelt may have slowed the rate of head fire spread and prevented it from crossing a road. The Tikokino Fire highlights the need for firefighters to have an understanding of fire behaviour and have access to predictive information to assist in the selection of suppression strategies and tactics. The strategy of making a stand against a head fire is compared with strategies that can increase firefighter safety.

Keywords: Grassland; fire behaviour; wildfire; making a stand; safety.

Introduction

Extreme fire danger days are common along the eastern side of both North and South Islands of New Zealand. The interaction of hot, dry, north westerly winds, low rainfall and cured light grass fuels on flat terrain, all contribute to severe burning conditions. The Tikokino Fire, which occurred on 31 January 1991 in the Central Hawkes Bay District (see Figure 1), spread under the influence of 'Extreme' fire danger conditions. Initial attack crews who observed the fire while it was still accelerating, underestimated the final level of fire behaviour and one appliance was overrun by fire during an attempt to *make a stand*¹. Another had to retreat into a paddock of green lucerne. Damage included the loss of a barn, shed, stockyards and fences, and two farm houses were threatened. The fire cost \$18 000 to suppress, and was attended by 100 firefighters and 14 fire engines. Fire control was achieved through direct attack by ground crews along the back and flanks which were burning at a lower intensity. A number of roads and water races assisted suppression by restricting lateral spread. The head fire run was halted by a green lucerne crop and a road where a *Pinus radiata* shelterbelt is thought to have slowed the wind speed and rate of head fire spread.

The reconstruction and analysis of fire situations can improve understanding of fire behaviour and the effectiveness of suppression resources (Alexander and Pearce 1992). The aims of this study were to analyse the actual fire behaviour, to compare it with that predicted by the New Zealand Fire Danger Rating System (NZFDRS), and to highlight potential dangers associated with the suppression of fast moving fires burning in relatively light grassland type fuels.

¹ *Making a stand* is the NZ Fire Service equivalent to a direct attack on a head fire, but it usually involves firefighters spaced along the length of line where a fire will cross a track or reach houses (Fogarty 1996).

Figure 1. The location of the Tikokino Fire, near Napier, Hawkes Bay.



Fire Chronology

At 9.15 pm on 31 January 1991, a motorist reported a grass fire burning on the eastern side of Highway 50 between the communities of Tikokino and Ongaonga. Volunteer brigades from these two communities responded quickly. At 9.24 pm, the time of initial attack, the fire was estimated to be 30 m wide and had spread approximately 250 m east from Highway 50. The approximate location of the fire when initial attack crews arrived is marked on Figure 2.

The initial strategy was for two fire appliance crews to contain the grass fire by extinguishing the head and nearby flank sections of the fire through direct attack. The crew of Appliance A moved up the north flank and found that the fire was moving more rapidly than they had anticipated. They decided to make a stand against the head fire near the first water race and positioned themselves near the intersection of the race and Makaroro Road, out of the smoke column north east of the head fire (Point 1 in Figure 2). Appliance B had similar problems and moved to the race ahead of the fire (Point 2 in Figure 2). As the firefighters from Appliance A were preparing to make a stand, the wind blew the head fire in a more north easterly direction toward them. The speed of advance of the head fire increased and Appliance A and its crew were overrun. At that time, the fire was burning in light fuels and the flame front depth was relatively narrow, allowing the firefighters to step through the flames without injury. One firefighter who remained with the appliance was caught by the fire and suffered minor burns.

In order to avoid a similar incident, the crew of Appliance B retreated to Makaroro Road with the crew still on the back and dragging a hose reel behind the vehicle. Due to heavy black smoke forced along by strong winds, the crew feared for their safety and turned east down Makaroro Road. The fire gained momentum and spread across the road behind them. They were able to escape into the green lucerne crop (Figure 2) which halted the advance of fire on the southern side of Makaroro Road.

The fire breached the 4 m wide tarsealed Makaroro Road and continued to spread in an easterly direction towards Butler Road. The fire did not cross Butler Road, but was contained near a large shelter belt of dense mature radiata pine trees. Estimates of time taken by the fire to travel 2910 m (± 25 m) during the fire run after initial attack range between 10 and 15 minutes. This is equivalent to a head fire rate of spread of 13 970 m/h (± 3035 m/h).

Ongoing suppression and mop up involved approximately 100 firefighters and 14 fire engines. Resources consisted of New Zealand Fire Services crews and appliances from throughout Hawkes Bay and firefighters from the District Council and Department of Conservation. Assisted by a number of barriers, such as roads, water races and green crops, firefighters were able to contain the slower-spreading back and flank sections of the fire. By 9.45 pm the fire was contained, but it had travelled approximately 3200 m and burnt an area of 130 ha.

Fire Environment

The fire environment is defined as “the surrounding conditions, influences, and modifying forces of topography, fuel and fire weather that determine fire behaviour” (Countryman, 1972). Assessment of the fire environment factors influencing the spread of the Tikokino Fire was assisted by the use of the New Zealand Fire Danger Rating System (NZFDRS)² which is based on the Canadian Forest Fire Danger Rating System (CFFDRS) (Stocks *et al.* 1989, Forestry Canada Fire Danger Group 1992). The NZFDRS is used by New Zealand fire authorities to assess the probability of a fire starting, spreading and doing damage.

Figure 3 shows the submodels of the NZFDRS. These include:

- The Fire Occurrence Prediction System: An incomplete module predicting the probability of fire ignition from natural or human causes.
- The Fire Weather Index (FWI) System: This module produces a set of codes and indices which estimate the relative flammability and availability of fuel, based on the current and preceding weather conditions, and the effect that this is likely to have on rate of head fire spread and intensity.
- The Accessory Fuel Moisture System: An incomplete system being developed to allow the estimation of fuel moisture content for a range of fuel components (e.g., elevated scrub twigs, grass, forest litter) and larger woody material, taking into account the effects of temperature, relative humidity, time, topography, latitude and season.
- The Fire Behaviour Prediction (FBP) System: This module combines the FWI spread indicators with data on fuel type and topography to make quantitative predictions of fire behaviour (e.g., head, flank and back fire rate of spread and fireline intensity).

As well as showing the broad structure of the NZFDRS, Figure 3 also lists the components of the Fire Weather Index (FWI) System. Values from the FWI System were used to describe the short and long term weather factors influencing the Tikokino Fire.

²New Zealand adopted the Canadian FWI System for fire danger rating in coniferous plantation forests in 1980 (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)). This was the precursor to the later adoption of the CFFDRS for use throughout New Zealand.

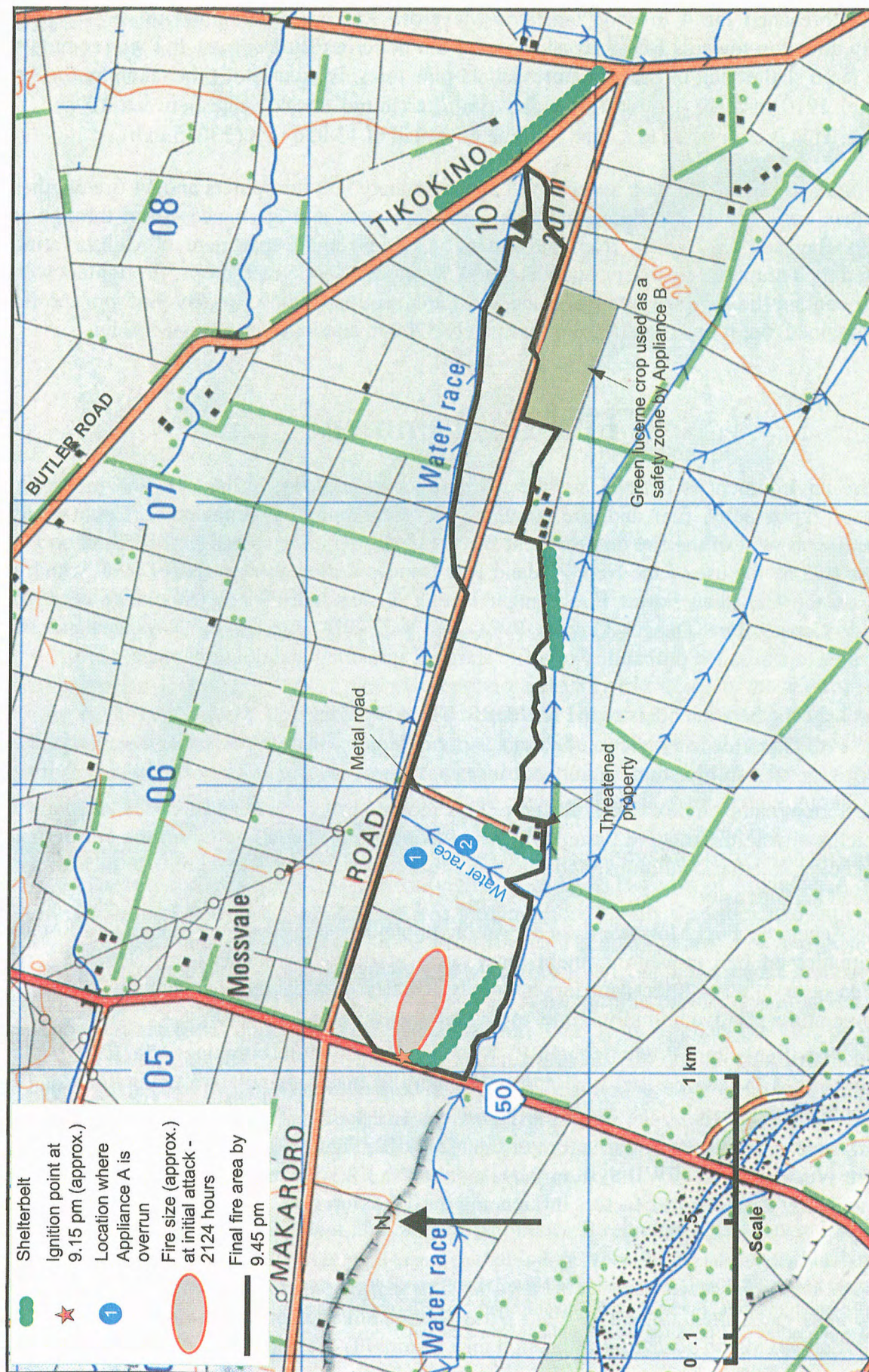


Figure 2. Map of the final fire area.

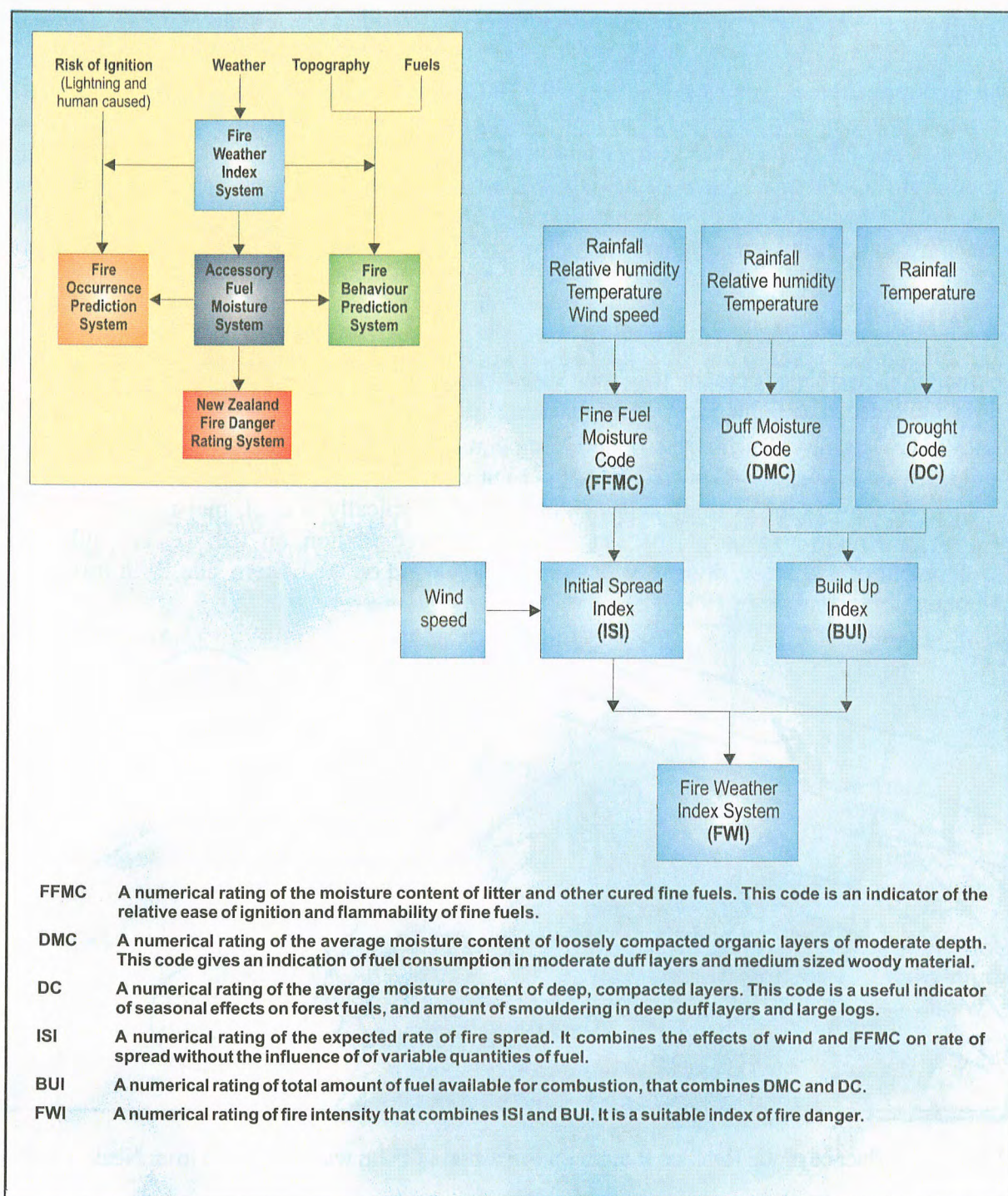


Figure 3. Structure of the New Zealand Fire Danger Rating System and the Fire Weather Index System (adapted from Canadian Forest Service 1984 and Stocks *et al.* 1989).

Topography

The Tikokino Fire burnt across flat plains that lie in the lee of the Ruahine Ranges to the west. After prolonged dry periods, few natural firebreaks (e.g., moist forest) exist, but the plains are dissected by roads and water races that provide potential barriers to fire spread, depending on burning conditions.

Fuels

The predominant fuel type was dry grass, 90 - 100 % cured. Estimated fuel loadings were 1 - 3 tonnes dry weight per hectare (expressed as t/ha for the remainder of this report) in most paddocks, and 3 - 5 t/ha in road verges and in the paddock where the fire started. Grass height varied from a few centimetres in heavily grazed paddocks to over 40 centimetres on road verges and areas not subject to recent grazing. The fuel was continuous apart from breaks created by water races, tracks and roads.

Weather

Lenticular (lens shaped) clouds had been observed in the sky during the previous three days. These indicated that Föhn winds were blowing on to the foothills and coastal plains of the Central Hawkes Bay. During this period, temperatures in the high twenties (°C) and relative humidities as low as 21 % were recorded. Figure 4 schematically shows the effect of the Ruahine Ranges on the development of Föhn winds. Typically, a cool, moist, south west to westerly airstream rises over the ranges, causing precipitation on the western side and development of a warmer, drier west or nor-westerly wind on the eastern side, with formation of lenticular clouds (Neale 1993).

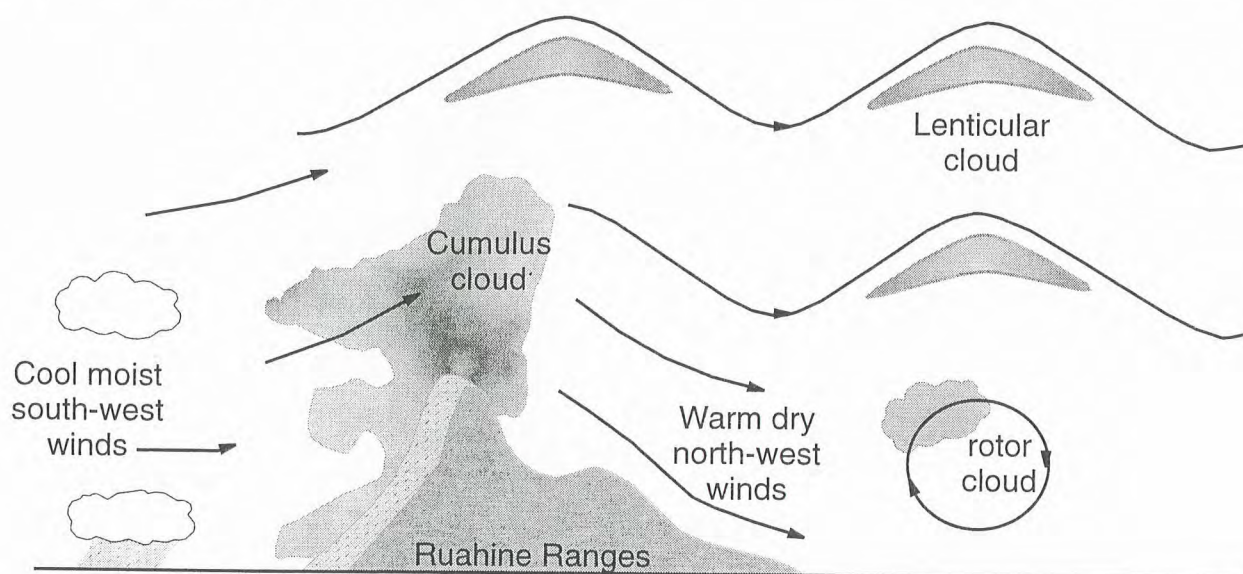


Figure 4. Influence of the Ruahine Ranges on formation of Föhn winds (adapted from Neale 1993).

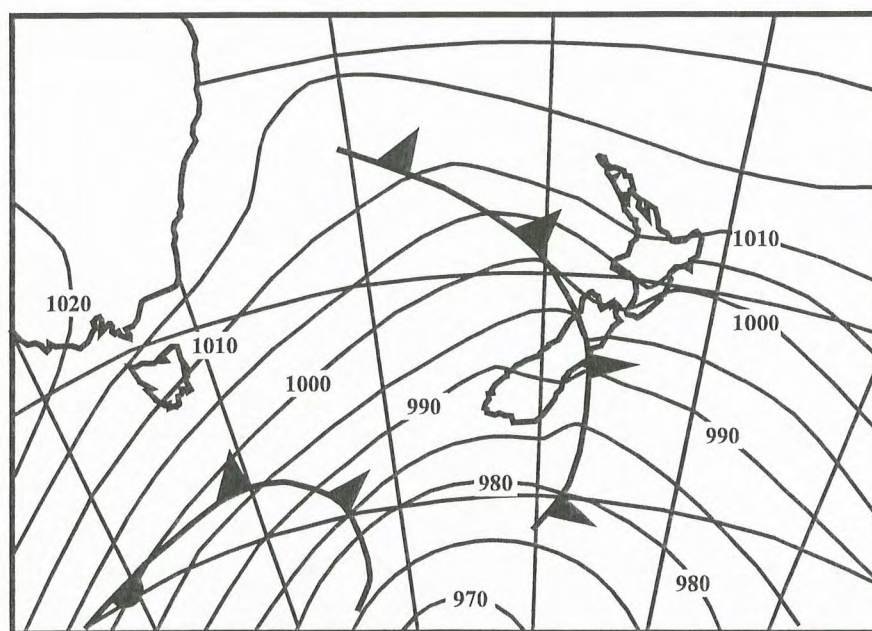
Table 1 shows the weather records made at Napier Airport and at Gwavas on 31 January 1991. The day of the fire was characterised by warm temperature (24.5 °C), low relative humidity (31 %) and near gale force winds (56 km/h). At the time that daily fire danger conditions were calculated (1300 hours during daylight saving), dry fuels (as indicated by an FFMC of 91.9) and near gale force winds combined to produce an Initial Spread Index (ISI) of 95. Drought conditions existed on the day of the fire, as indicated by a Drought Code value of 459. In the evening a cold front passed over the country (see weather map, Figure 5), bringing stronger and more erratic westerly winds in advance of its arrival. No readings were taken on-site but firefighters had difficulty standing up and wind gusts at the fire were estimated to have increased from around 30 km/h to 80 km/h between 9.00 pm and 10.00 pm. Near gale or gale force winds in excess of 50 km/h drove the forward spread of this fire.

Table 1. Weather and Fire Weather Index System readings for Napier Airport and Gwavas* at 1300 hrs (daylight saving time) on 31 January 1991.

Weather values and FWI System codes and indices	Value
Temperature (°C)	24.5
Relative humidity (%)	31
Wind direction (degrees)	270
Wind speed (km/h)	56
24-hour rainfall total (mm)	0
Fine Fuel Moisture Code (FFMC)	91.9
Duff Moisture Code (DMC)	60
Drought Code (DC)	459
Initial Spread Index (ISI)	95
Buildup Index (BUI)	90
Fire Weather Index (FWI)	119

*All values, except for rainfall, are from Napier Airport (54 km northeast of the fire site). Rainfall data was recorded at Gwavas Forest Headquarters (6 km northwest of the fire). Reports from the fire site described similar conditions.

Figure 5. Surface weather chart showing progression of a cold front and the westerly direction of surface winds over eastern parts of the North Island on 31 January 1991.



Fire Behaviour Prediction and Fire Danger Rating

The Tikokino Fire burnt through continuous grass cover, and the presence of occasional trees or shrubs did not appreciably affect fire behaviour. The observed fire behaviour was compared with that predicted by the FBP System using the natural/standing grass (O-1b) fuel type model. In grasslands, the degree of curing, (i.e., proportion of cured or dead material) has a pronounced effect on fire behaviour. The model takes into account the effects of curing along with weather conditions (as represented by the ISI) to predict the rate of fire spread. The actual rate of spread of the head fire was estimated to be 13 970 m/h (± 3035 m/h). Using the standard midday ISI value (95) and an average degree of curing of 95%, the FBP System predicted a rate of spread of 12 700 m/h. For comparison, the rate of spread predicted from

recently developed Australian grassland fire behaviour model for a fully developed head fire in natural/standing grass (Cheney *et al.* in press) would be 10 480 m/h.

Fire intensity is the rate of heat energy released from each meter of fireline. Frontal fire intensity has a major influence on difficulty of control and is expressed in kilowatts per metre (kW/m). Fireline intensity can be expressed by the following formula (Byram 1959):

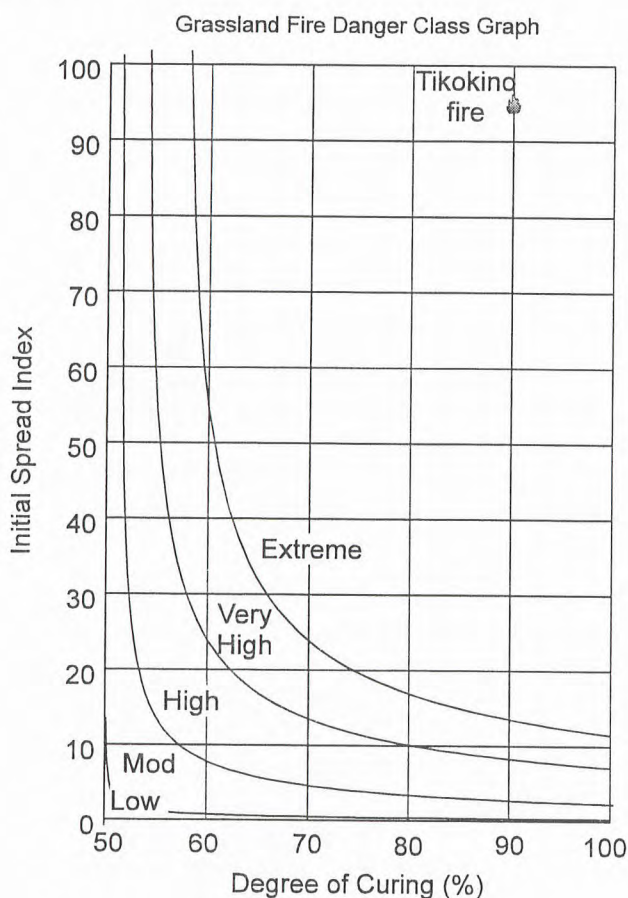
$$I = H w r$$

where : I = fireline intensity (kW/m);
 H = heat of combustion (standard value of 18000 kJ/kg of fuel);
 w = oven-dry weight of fuel consumed (kg/m²); and
 r = rate of frontal fire spread expressed in m/s.

At this fire: $w = 0.1 - 0.5 \text{ kg/m}^2$, which is equivalent to 1 - 5 t/ha; and
 $r = 3.88 \text{ m/s } (\pm 0.84 \text{ m/s})$, which is equivalent to 13 970 m/h ($\pm 3035 \text{ m/h}$).

The estimated frontal fire intensity of the major fire run was 13 970 kW/m ($\pm 3035 \text{ kW/m}$) in most of the paddocks, and 34 900 kW/m ($\pm 7600 \text{ kW/m}$) along road edges. Figure 6 is a Grassland Fire Danger Class Graph derived using ISI, degree of curing and a fuel loading of 3.5 t/ha as inputs to natural/standing grass (O-1b) fuel type model (Alexander 1994). The fire danger classes shown indicate the expected difficulty of control for a range of fireline intensity classes. Extreme and uncontrollable fire behaviour occurs when the intensity exceeds 4000 kW/m (Alexander 1992, Alexander 1994). The position of the Tikokino Fire on this graph indicates that this fire was well into the Extreme class.

Figure 6. The Grassland Fire Danger level on the day of the Tikokino Fire.



The perimeter of a free-burning fire on flat ground is often highly irregular, but the overall pattern can usually be represented by an ellipse when wind speed and direction are reasonably constant (Alexander 1985). The relative dimensions of an elliptical fire vary with fuel type (see Figure 7) and wind speed. Figure 7 shows that based on a 50 km/h wind speed, a length-to-breadth ratio of 7:1 would occur. Comparing the actual fire perimeter with this elliptical model (Figure 8) the fit seems to be good. However, roads, water races, a paddock of green lucerne and suppression operations restricted perimeter growth in some sectors of the fire. Because of this, the Tikokino Fire is not a good example to use for validation of the model.

Figure 7. Relationship between wind speed and shape of free-burning fires in grasslands and forest. Curves derived using the Canadian FBP System (Forestry Canada Fire Danger Group 1992).

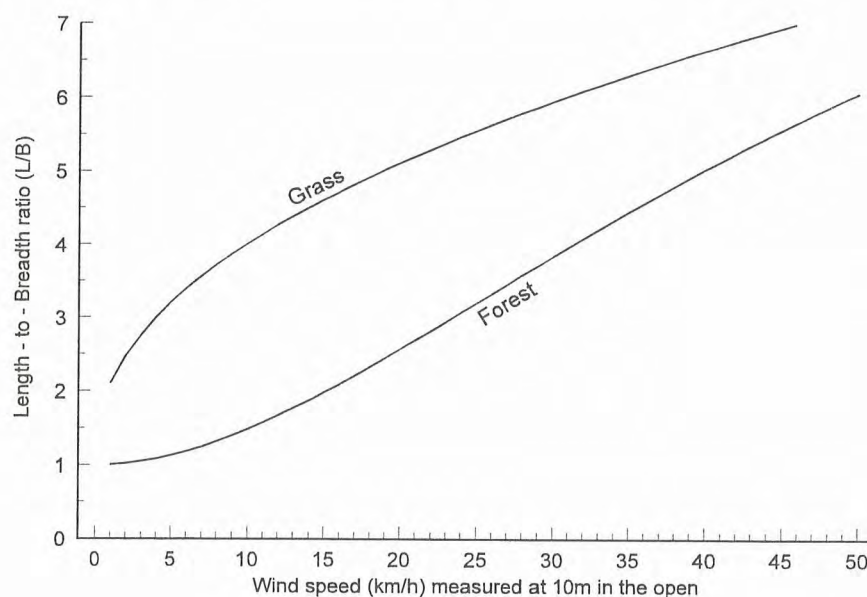
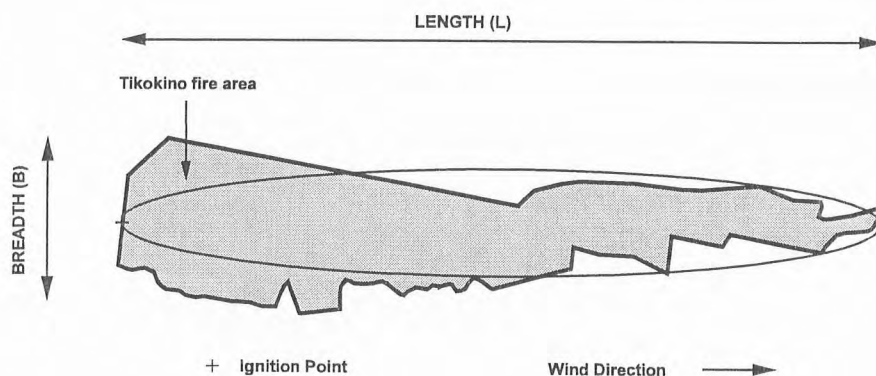


Figure 8. Shape of the Tikokino Fire compared with an ellipse having a length-to-breadth ratio of 7:1.



The 4 m wide Makaroro Road was an ineffective firebreak and was easily breached. Effectiveness of a firebreak is influenced by fire intensity, firebreak width and the proximity of woody fuel (Wilson 1988). Figure 9 shows how fire intensity affects the probability of a firebreak being breached. From this figure, there is a high probability (90%) that a 4 m wide break in a grassland without trees or shrubs will be breached by a fire with an intensity of 14 000 kW/m (the most conservative estimate of head fire intensity). Makaroro Road was unlikely to be an adequate firebreak.

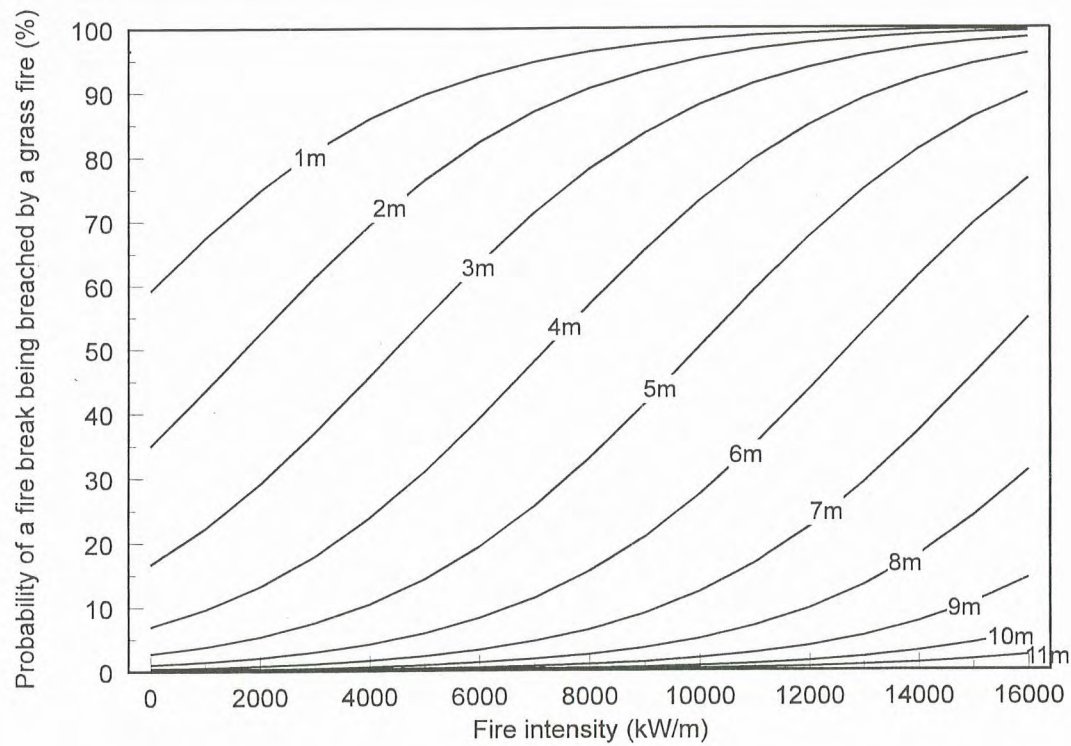


Figure 9. Relationship between fireline intensity and the probability of a firebreak being breached in the absence of trees. Curves derived using the relationship of Wilson (1988) and a format outlined by Alexander (1994).

Discussion

The Tikokino Fire exhibited extreme fire behaviour. Firefighters, assisted by a number of barriers to fire spread, successfully contained the fire to 130 ha within 45 minutes of its ignition. This was achieved by concentrating suppression efforts on the slower burning and less intense back and flank sections of the fire. However, when initial attack firefighters made a stand against the head fire, they underestimated the magnitude of the potential fire situation and unknowingly placed themselves at risk. This incident is similar to many others in New Zealand where firefighters have been overrun by fire or had to take evasive action after adopting high risk suppression strategies. Recent examples include³:

- The 1994 Purakanui Fire where a crew of firefighters had to abandon attempts to make a stand against a fire front that was spreading uphill through dense gorse and immature *Pinus radiata* (White⁴ pers. comm.).
- The 1994 Montgomery Crescent Fire where one crew of firefighters had to retreat from making a stand in order to protect houses and another had to take evasive action after a gorse fire re-ignited and spread rapidly uphill towards them (Fogarty 1996).
- The 1994 Mt Noble Fire where a crew of firefighters became confused after attempting to backburn in a mixture of scrub and tussock fuels in heavy smoke. They were overrun by a fire which was blown up a steep gully and over the saddle where they sheltered in their vehicle. A single firefighter panicked at seeing a fast moving fire from another backburn. After initially fleeing from the safe area where he was stationed, he had to hastily return to escape the approaching fire (Unpublished report 1994⁵).
- The 1994 McDonald Downs Fire where a crew of untrained firefighters ignored instructions and entered an unburnt area in a gully between a backburn and the wildfire. They were overrun by flames (Unpublished report 1994⁶).
- The 1995 Okuku Hills Fire where two firefighters were overrun by fire after being caught in unburnt fuels on a steep slope and had to be doused with aerially applied suppressant for protection (Thompson⁷ pers. comm.).

No serious injuries occurred at the Tikokino Fire or at the other incidents mentioned. However, as Cheney (1994) points out, "there is a hairline difference between a situation that leads to a fatality and many other situations where movement from the fireline to a safe area means that the same fire behaviour passes without incident or comment". Successful results involving unnecessary risks or survival from occasional near-miss events can lead to the adoption of unsafe practices as a standard procedure (Cheney 1994). It is therefore important that all near-miss incidents are reported and analysed in a process of on-going education and as a basis for remedial action.

³ The incidents cited above are not a complete summary for the last four years because like some of the incidents recorded here they have gone unmentioned at the fire debriefs and no single authority takes responsibility for recording and analysing such events so that remedial action can be taken.

⁴ D. B. White, Senior Conservation Officer (Fire), Department of Conservation, Otago Conservancy.

⁵ Minutes of a debrief relating to 27-28-29 Mt Noble Fire. Hurunui District Council Chambers, Amberly. 30 September, 1994.

⁶ Minutes of a debrief meeting held to discuss various aspects of a recent hill country fire on McDonald Down. Hurunui District Council Chambers, Amberly. 16 September, 1994.

⁷ M Thompson, Conservation Officer, Department of Conservation, Mt Thomas Field Centre, Canterbury Conservancy.

The Tikokino Fire provided the initial attack crews with what one firefighter described as a “never to be repeated learning experience”. This and the other incidents listed above, all indicate a lack of knowledge and appreciation of potential wildfire behaviour by the firefighters and managers involved. The incidents are characterised by common factors described by Wilson (1977) and Millman (1993) who found that injury or threat occur more often when:

- fires are relatively small, or firefighters are positioned on a relatively quiet sector of a larger fire;
- fuels are relatively light (e.g., grass, scrub);
- there is an unexpected increase in wind speed or change in direction; and/or
- the fire responds to topographic conditions (e.g., chimney effects) or runs up slope.

The continued failure of firefighters and managers to recognise suppression strategies and tactics that involve unacceptable risks suggests that, despite the greater emphasis on fire behaviour training since 1992, many New Zealand fire authorities require further substantial investment in training to ensure that firefighters are able to work safely.

At the time of initial size-up, the Tikokino Fire was approximately 30 m wide and was advancing relatively slowly. The rate of spread of a grassland fire depends on a combination of factors, including wind speed, fuel moisture content, degree of curing, the level of grazing or trampling, slope and head fire width (Cheney *et al.* in press). The maximum rate of spread only occurs when the head fire is sufficiently large to interact with the prevailing fire environment conditions (Cheney and Gould 1995). Relationships developed by Cheney and Gould (1995)⁸ suggest that in conditions such as those experienced at the Tikokino Fire, a head fire width of over 250 m is required for a fire of this intensity to spread at a rate that is in equilibrium with the surrounding burning conditions. Given the small size of the head fire at the time of initial attack, it is probable that the rate of fire spread was less than half the rate that could be expected if the fire was fully developed.

The initial growth phase of a fire can provide an opportunity for the suppression of fires that would be impossible to control once they reach a rate of spread and intensity that is in equilibrium with the surrounding burning conditions (Alexander 1992). However, analysis of the Tikokino Fire shows that potential fire behaviour can be easily underestimated at this phase. As a fire develops, its behaviour can change between the time of initial assessment and the time of implementing a suppression strategy. It is known that fires spread faster up slope than on flat ground (Luke and McArthur 1978), and that fires burning in grass accelerate rapidly if the wind speed increases (McArthur 1966). The findings of Cheney and Gould (1995) help to explain further why injury and threat are commonly associated with small fires and variable winds. At wildfires such as the Tikokino Fire where unstable wind conditions are experienced, short duration wind gusts may fan the fire in a number of directions and cause it to spread in fits and starts, making suppression difficult and dangerous (McArthur 1966). This action also reduces the time taken for the fire to reach the size needed for reaction with the prevailing burning conditions and may cause a quantum leap in head fire behaviour when the wind returns to the prevailing direction. Similarly, wind gusts can temporally turn a flank (which are usually wider than the head in windy conditions) into a head fire. If firefighters are located in unburnt fuels as they were at the Tikokino Fire, the blow-out along the affected flank can endanger them.

¹ The relationship used to assess the effect of head fire width on rate of spread is (from Cheney *et al.* in press): $\Phi W = \exp[(-0.859 - 2.036 U_2)/W]$, where ΦW is the head fire width coefficient, U_2 is 2m-wind speed (m/s) and W is head fire width (m).

Suppression strategies should not be rushed into but should be selected on the basis of current and expected weather and fire behaviour, whether the fire is still accelerating, fuel types involved, access to safety zones and the knowledge and skills of firefighters (Cheney 1994). The Moonbulla grass fire (Douglas 1966) which burnt 1456 ha under somewhat similar conditions to the Tikokino Fire, provides an example of how aggressive attack by an adequate number of fire units along the less intensely burning flanks of a fast moving grass fire can lead to containment. This strategy confined the fire and did not endanger the firefighters (see Figure 10).

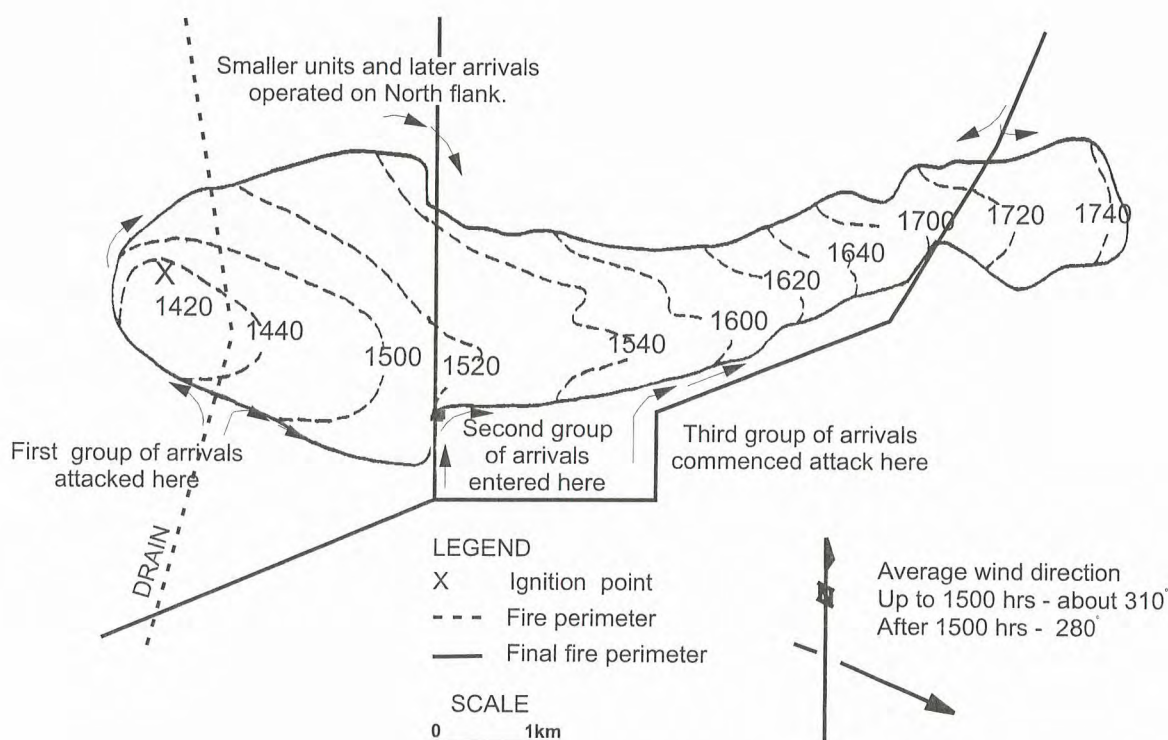


Figure 10. The effect of suppression strategy on the fire growth pattern of the Moonbulla Fire (from Douglas 1966).

While direct attack on the head fire may be an appropriate option in some instances, the strategy of attacking the fire flanks should also be considered for the following reasons:

- If the fire is moving slowly and burning at a low intensity, it can usually be quickly and safely suppressed by flank fire attack, particularly if firebreaks are linked to burnt out areas so that safe areas are easily accessible should burning conditions change.
- If the head fire is exhibiting extreme, or potentially extreme behaviour, there is danger in making a stand.
- When the fire behaviour is extreme, there is a high risk that a direct attack at the front will be ineffective and effort and time will have to be diverted to escape and rescue operations.
- Flanks consume a greater area than the head fire and thus require high priority attention.
- If the wind changes direction, a flank may become the head fire and increase the area burnt.

Only after failure of initial attempts to attack the head of the Tikokino Fire directly was the flank fire attack strategy employed. What happened at the Tikokino Fire illustrates the danger of making a stand and shows that effective alternatives were available.

Fire behaviour models, which were not in use in New Zealand at the time of the Tikokino Fire, are increasingly being used to evaluate fire potential and to assist decision making even before a fire starts. For the Tikokino Fire, the rate of spread predicted by the Fire Behaviour Prediction (FBP) System (12 700 m/h) was within the range of the estimated actual rates (10 935 - 17 005 m/hr), but below the mean value (13 970 m/h). In comparison, the predicted rate of spread for a fully developed fire from the Australian grassland fire behaviour model is 10 480 m/h which is outside the range of estimated actual rates.

Most fire behaviour models incorporate uncertainty, but the possible under-prediction of spread rate at the Tikokino Fire cannot be attributed to modelling errors alone. The difference between the predicted (from the Australian and FBP System models) and actual estimated rate of spread is most likely due to the lack of good data for the model calculations. In particular, no on-site weather data was available for use in the model comparisons. Greater emphasis on observing and recording fire behaviour and weather during all stages of a fire suppression operation (i.e., detection, initial attack, on going suppression and mop-up) using the procedures outlined by Alexander and Pearce (1992) will increase the value of case studies.

Despite the use of similar weather inputs, predicted head fire rates of spread from the FBP System and Australian natural standing grass models differed by 2220 m/hr. Although the models were derived from same basic data-set⁹, some additional wildfire data was used in the Australian grassland fire behaviour and more detailed data analysis was done during its development. This showed that differences in head fire width explained some of the observed variation in rate of fire spread (Cheney and Gould 1995). Further development of the grassland model of the FBP System to incorporate the additional data and the influence of head fire width may be warranted (Catchpole¹⁰ *pers. comm.*).

Analysis of the behaviour of the Tikokino Fire does not provide specific conclusions necessary for the validation of the natural standing grass (O-1b) fuel type model from the FBP System for New Zealand conditions. However, the model did predict a high probability of extreme fire behaviour and provided sufficient information for the magnitude of the fire situation to be estimated. In the absence of other information, it is recommended that the model should be used for fire management in grassland areas.

Fire managers who can predict where a fire will be at certain times, can better estimate the firefighting resources required to safely and effectively contain the fire, identify possible locations for backburning ahead of the front, and provide advanced warning to threatened landowners (McArthur 1966). To assist fire managers to use information from the FBP System during the initial suppression of wind-driven grass fires spreading under Very High or Extreme fire danger conditions, a field guide which predicts the rate of head fire spread, flame length, fire intensity and the minimum width of firebreak needed to stop a head fire has been included in Appendix 1a¹¹.

⁹ The experimental and wildfire data for both models was collected by the National Bushfire Research Unit at the Australian CSIRO Division of Forestry and Forest Products.

¹⁰ W.R Catchpole, Lecturer, Department of Mathematics and Statistics, University College, Australian Defence Force Academy, University of New South Wales.

¹¹ The field guide assumes that fire spread is in fully cured, natural standing grasslands (FPB System Fuel Type O1b). The predictions are based on the mid-range value of the observed Beaufort Wind Force, an "average worst" FFMC of 93.2 and a fuel load of 3.5 t/ha. The "average worst" FFMC of 93.2 is the average of the maximum FFMC values recorded at 20 weather stations throughout New Zealand. The FFMC values were obtained from Pearce (1996). The minimum fire break widths are derived using the relationships of Wilson (1988) and have a high probability (greater than 90%) of holding a fire.

The field guide will generally over-predict fire behaviour, but users need to be aware of situations where the fuel is drier (i.e., the FPMC is higher) and fuel loads are heavier, because fire behaviour will be under-predicted. For example, when applied to the Tikokino Fire, the guides predict a head fire spread rate of 14 500 m/hr with an intensity of 25 300 kW/m, compared with the actual estimated values of 13 970 m/h (± 3035 m/h) and 13 750 kW/m (± 3035 kW/m) respectively. Despite the possible errors from simplifying the FBP System, the guide will assist fire suppression decision making.

The shape of the Tikokino Fire (Figure 8) was close to the expected elliptical shape, but was also influenced by the presence of water races, Makaroro Road, green lucerne paddocks and fire suppression efforts. The firebreak breach model (Wilson 1988) successfully predicted that Makaroro Road would not halt the forward spread of the wildfire. This case study supports continued use of these two models in fire prevention, preparedness and suppression planning.

Even though the Tikokino Fire surmounted Makaroro Road, it did not cross the 4 m wide Butler Road. A possible reason is that the fire slowed, as the water races caused the head fire to narrow and as the fire spread to an area where wind speed slackened because of a shelterbelt orientated at right angles to the prevailing wind and fire spread direction. The survival of the house marked “Threatened property” in Figure 2, which was down-wind of another shelterbelt may have been assisted by a similar reduction in wind speed and subsequent fire behaviour. As shown in Figure 11, shelterbelts reduce wind speeds on the upwind and leeward side as the approaching wind flow is dammed and then directed over the shelterbelt. Densely planted belts can reduce wind speed by up to 70% and more open belts can cause a 50% reduction (Simpfendorfer 1989). Using these reduction factors to recalculate the ISI for the Tikokino Fire, values of 13 and 23 are obtained for the dense and open belts respectively. The natural/standing grass model (O1-b) predicts that head fire rates of spread would have been reduced from 11 200 m/h to 2000 and 4400 m/h respectively. The behaviour of the Tikokino Fire indicates that the effect of shelterbelts on wind speed could be an important factor in reducing the rate of fire spread and intensity. More comprehensive fire behaviour information and additional case study analysis are required before the effect of shelterbelts can be predicted with confidence.

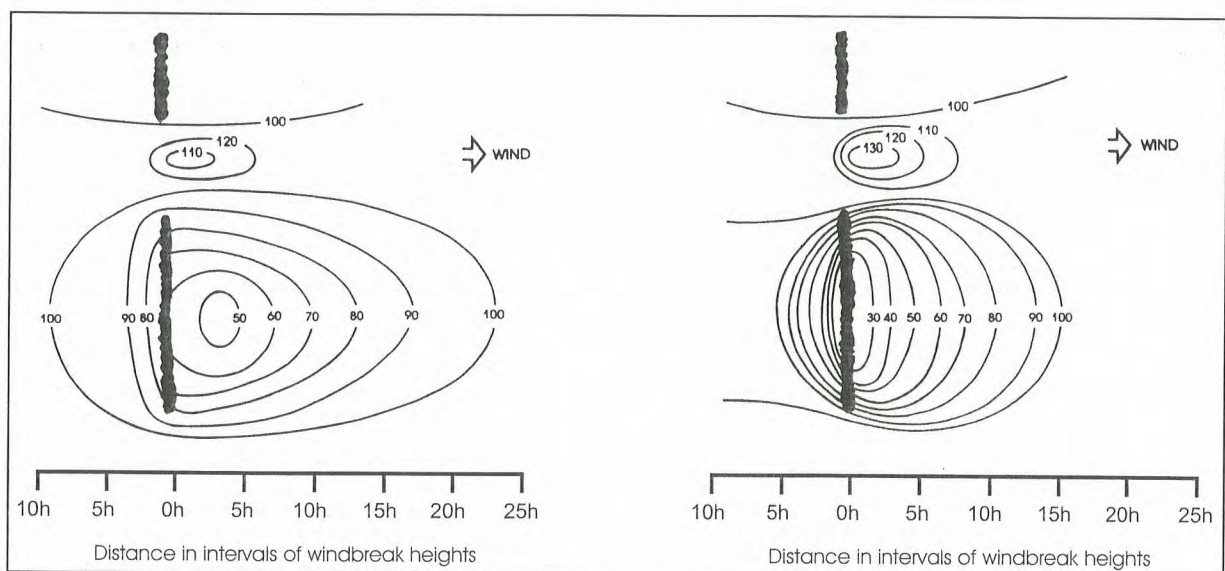


Figure 11. Percentage decrease in surface wind speed caused by (left) an open and (right) a dense shelterbelt of trees (from Simpfendorfer 1989).

Conclusion

Severe fire weather is common in eastern areas of New Zealand. The Tikokino Fire demonstrated the very real threat and impact of grassland fires to human life and property in times of drought and critical fire weather conditions. Analysis of this fire and its implications for fire management has drawn attention to the following points:

- Firefighters and fire managers need a greater knowledge of the usefulness of fire decision support models in fire management (e.g., the NZFDRS and the firebreak breaching model of Wilson 1988).
- Firefighters attending vegetation fires need more training in fire behaviour and safety related considerations. The following points should be covered:
 1. The behaviour of fires in light and open fuel types is highly responsive to changes in wind speed and direction.
 2. Fire growth and acceleration is influenced by time since ignition, as well as other factors that affect the development of the fire front (e.g., wind speed and direction, head fire width, slope and fuel type).
 3. Gusty variable wind conditions that fan the fire in a number of directions can change fire behaviour dramatically. In particular they can cause the size of the head fire to increase rapidly or turn a flank into a head fire.
 4. Fire intensity, which varies around the fire perimeter and is generally greatest at the head, dictates the limits of effective fire control and should be considered in the development of fire suppression strategies.
 5. Making a stand involves a high risk, particularly when one or more of the common factors associated with fatality and near miss events are present.
- Near miss events should be documented and analysed to ensure that additional common factors are identified and existing ones confirmed. This will reduce the existing potential for inadvertent use of unsafe fire suppression strategies.
- Wildfire documentation provides valuable information for improving our knowledge and understanding of fire behaviour and, reviewing the effectiveness of fire suppression operations.

Acknowledgments

Appreciation is extended to Vaughan Gera (New Zealand Forest Research Institute) for assistance in the preparation of the figures in this report, and to Ruth Gadgil, Grant Pearce and Leslie Whitehouse (New Zealand Forest Research Institute) for many useful comments on the report contents and layout. Thanks to Marty Alexander (Canadian Forest Service) for his effort and advice of during the preparation of this case study, in particular, it should be noted that Appendix 1 was developed using his ideas. The contributions of Wendy Catchpole (University of New South Wales) and Phil Cheney (CSIRO, Australia) for providing the Australian Grassland Fire Behaviour Model and assisting with its use are also acknowledged and appreciated. The field data describing weather and fire behaviour information were derived from a number of sources and the assistance of R Bradley, P Harris, G Mackie and W Kent is gratefully acknowledged. We would also like to thank Richard Rawson (Department of Natural Resources and Environment, Victoria) for permission to reproduce Figure 11.

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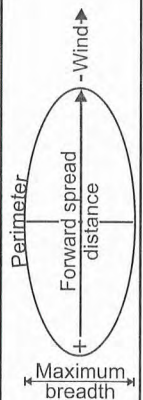
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Appendix 1a - Guidelines for judging potential fire behaviour in grasslands under severe burning conditions¹²

A SIMPLE FIELD GUIDE FOR ESTIMATING THE BEHAVIOUR AND SUPPRESSION REQUIREMENTS OF FIRES DRIVEN BY WIND COMING FROM A CONSTANT DIRECTION, IN OPEN, FULLY CURED GRASSLANDS AT LOW FUEL MOISTURE.

Caution: Flame heights at the fire's head will be greater than 2.5 meters. Under NO circumstances should direct attack be mounted on the head fire. Any containment action must begin from a secured anchor point and progress along the flanks toward the head as the fire edge or perimeter is "knocked down".

Beaufort Wind Force	Forward spread distance/perimeter length/maximum breadth versus elapsed time since ignition				Head fire intensity --kW/m--	Head fire flame length -metres-	Minimum firebreak width required to stop head fire	
	-----kilometres-----						-----metres-----	
	0.5 hour	1 hour	1.5 hours	2 hours			Trees absent	Trees present
0-1	0.7/2.4/0.4	1.3/4.9/0.7	2.0/7.3/1.1	2.6/9.8/1.4	2300	2.7	5	12
2	1.0/2.7/0.4	2.0/5.5/0.7	2.9/8.2/1.1	3.9/10.9/1.5	3450	3.3	6	13
3	1.6/3.7/0.4	3.2/7.4/0.8	4.8/11.1/1.2	6.3/14.8/1.6	5550	4.1	7	15
4	2.7/5.7/0.6	5.3/11.5/1.1	8.0/17.2/1.7	10.7/22.9/2.2	9350	5.2	8	30+
5	4.4/9.1/0.8	8.7/18.2/1.5	13.1/27.3/2.3	17.5/36.4/3.1	15 300	6.5	10	30+
6	6.1/12.5/1.0	12.2/25.0/1.9	18.2/37.5/2.9	24.3/50.0/3.8	21 300	7.6	12	30+
7	7.2/14.8/1.0	14.5/29.5/2.0	21.7/44.3/3.1	28.9/59.1/4.1	25 300	8.2	13	30+
8 & higher	7.5/15.2/1.0	15.0/30.5/2.1	22.5/45.7/3.1	30.0/60.9/4.1	26 200+	8.4+	14+	30+



^a See reverse side for details on the Beaufort Wind Scale.

^b The "Trees absent" and "Trees present" classes refer to the absence or presence of trees/scrub within 20 metres of the windward side of the firebreak. The presence of trees or scrub has a significant influence on firebreak effectiveness because they supply woody material for firebrands which can spot across the break.

Beaufort Wind Scale for estimating 10 - m open wind speed over land

Beaufort Wind Force	Descriptive Term	10 - m wind speed ---km/h---	Observed wind effects
0	Calm	< 1	Smoke rises vertically.
1	Light air	1 to 5	Direction of wind shown by smoke drift but not by wind vanes.
2	Light breeze	6 to 11	Wind felt on face; leaves rustle; ordinary vanes moved by wind.
3	Gentle breeze	12 to 19	Leaves and small twigs in constant motion; wind extends light flags.
4	Moderate breeze	20 to 28	Wind raises dust and loose paper; small branches are moved.
5	Fresh breeze	29 to 38	Small trees in leaf begin to sway; crested wavelets form on inland waters.
6	Strong breeze	39 to 49	Large branches in motion; whistling heard in telephone wires; umbrellas used with difficulty.
7	Moderate gale	50 to 61	Whole trees in motion; inconvenience felt when walking against wind.
8	Fresh gale	62 to 74	Breaks twigs off trees; generally impedes progress.
9	Strong gale	75 to 88	Slight structural damage occurs (e.g., TV antennas and tiles blown off).
10	Whole gale	89 to 102	Seldom experienced inland; trees uprooted; considerable structural damage.

Note: Fire behaviour predictions in this guide are based on head fire rate of spread in fully cured standing grasslands (Fire Behaviour Prediction System Fuel Type O-1b) on flat to undulating terrain, assuming a fuel load of 3.5 t/ha, a Fine Fuel Moisture Code of 93.2, and the midpoint of the wind speed range associated with each Beaufort Wind Force. Use of the guide is at the reader's sole risk.

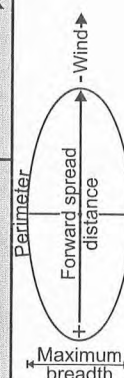


¹² This field guide can freely be reproduced for training and operational purposes. It is intended that the two parts comprising the guide will form the front and back sides of a single card.

A SIMPLE FIELD GUIDE FOR ESTIMATING THE BEHAVIOUR AND SUPPRESSION REQUIREMENTS OF FIRES DRIVEN BY WIND COMING FROM A CONSTANT DIRECTION, IN OPEN, FULLY CURED GRASSLANDS AT LOW FUEL MOISTURE.

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	-----kilometres-----						-----metres-----	
	0.5 hour	1 hour	1.5 hours	2 hours			Trees absent	Trees present
0-1	0.7/2.4/0.4	1.3/4.9/0.7	2.0/7.3/1.1	2.6/9.8/1.4	2300	2.7	5	12
2	1.0/2.7/0.4	2.0/5.5/0.7	2.9/8.2/1.1	3.9/10.9/1.5	3450	3.3	6	13
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5	4.4/9.1/0.8	8.7/18.2/1.5	13.1/27.3/2.3	17.5/36.4/3.1	15 300	6.5	10	30+
6	6.1/12.5/1.0	12.2/25.0/1.9	18.2/37.5/2.9	24.3/50.0/3.8	21 300	7.6	12	30+
7	7.2/14.8/1.0	14.5/29.5/2.0	21.7/44.3/3.1	28.9/59.1/4.1	25 300	8.2	13	30+
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