Fire Technology Transfer Note

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A field guide for predicting grassland fire potential: derivation and use
by L.G. Fogarty and M.E. Alexander

Introduction

Most rural fire managers have a fairly good idea of when grasslands will burn vigorously or not at all. At one end of the fire behaviour spectrum are conditions where grasslands are green or affected by recent rain, and fires will not start nor spread. At the opposite end, fire spread is in dry, fully cured grassland under the influence of severe fire weather (e.g., Noble 1991)[1], and the occurrence of erratic and vigorous fire behaviour is easily predicted. However, the fire environment factors (fuel, weather and topography) interact in a complex way to influence a fire's behaviour (Countryman 1972), so predicting fire behaviour between the two ends of the spectrum is somewhat more difficult. The 1991 Tikokino Fire[2], where firefighters used an initial observation of fire behaviour to set their initial attack strategy and were overrun by fire, provides an example of this.

A working knowledge of the effects of wind and other weather elements on fire behaviour, supported by accurate fire intelligence, is vital for good suppression planning. Without good fire behaviour information firefighters are unable to (from McArthur 1966):

- determine the number of firefighters and level of equipment necessary;
- identify the location of suitable areas for backburning; and
- ensure that the general public is informed of the fire situation.

The burn-over incident at the 1991 Tikokino Fire (Rasmussen and Fogarty 1997) shows that the ability to anticipate worst case fire behaviour is also vital for safe and effective initial attack.

To assist fire suppression planning, the Fire Behaviour Prediction (FBP) System component of the New Zealand Fire Danger Rating System combines outputs from the FWI System with topographical and fuel information to produce quantitative estimates of fire behaviour (Forestry Canada Fire Danger Group 1992). Applications of the FBP System can range from computer systems which combine map-based information (fuels and topography) with fire behaviour outputs to produce relatively accurate predictions of fire spread (e.g., Wallace 1993), through to simple tables that can be used in the field (e.g., Taylor *et al.* 1997). As a part of the Tikokino Fire case study, a *Field Guide* was developed for the prediction of grassland fire behaviour in periods of Very High or Extreme fire danger (Rasmussen and Fogarty 1997). The aim of this *Fire Technology Transfer Note* (FTTN) is to present information on the derivation and use of this simple *Field Guide* (Figure 1).

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[1] The 1987 Boonoke Fire burnt an area of 120 000 ha in the western Riverina region of New South Wales, Australia (Noble 1991). Midday weather and selected Fire Weather Index (FWI) System (Van Wagner 1987) values were: temperature 40.6 °C, relative humidity 7%, 10 m wind speed 44.5 km/h, Fine Fuel Moisture Code (FFMC) 99.3 and Initial Spread Index (ISI) 144.6 (M.E. Alexander and H.G. Pearce, unpublished data). The average rate of spread was 23 km/h.

[2] The 1991 Tikokino Fire burnt an area of 130 ha of the coastal plains in the Hawkes Bay region of New Zealand. Midday weather and selected FWI System values were: 24.5 °C, relative humidity 31%, 10 m wind speed 56 km/h, FFMC 91.9 and ISI 95. The average rate of spread was approximately 14 km/h (Rasmussen and Fogarty 1997).

Figure 1. - Guidelines for judging potential fire behaviour in grasslands under severe burning conditions. The *Field Guide* was developed by the authors of this Fire Technology Transfer Note for the Tikokino Fire case study report (Rasmussen and Fogarty 1997). Both sides of the pocket card are shown.

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 metres. 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[a]	Forward spread distance/perimeter length/maximum breadth versus elapsed time since ignition --------------------------kilometres--------------------------				Head fire intensity --kW/m--	Head fire flame length -metres-	Minimum firebreak width required to stop head fire[b] -------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+
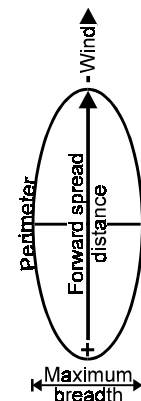
[a] See reverse side for details on the Beaufort Wind Scale.

[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.

forest research

FIRE

Derivation

Figure 1 shows the two sides of the pocket 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", which provides estimates of head fire rate of spread (ROS), fire perimeter, maximum breadth, flame length, fire intensity and the minimum width of firebreak needed to stop the head of a spreading grass fire solely as a function of wind speed.

To provide timely estimates of fire behaviour, field guides have to reduce the number of factors or inputs considered, and the complexity of the computations involved in gaining a prediction. The *Field Guide* presented here is based on several assumptions that could cause fire behaviour estimates to be greater or less than the actual observed fire behaviour. The assumptions and their potential consequences are as follows:

1. As with the New Zealand grassland fire danger class criteria (Alexander 1994), fire spread is in continuous, natural standing grasslands (i.e., FBP System Fuel Type O-1b) with an average fuel load of 3.5 t/ha. If grass fuels are cut, matted or heavily grazed, then the ROS may be reduced.

2. Grasslands are 100% cured. If the grass is less than fully cured, the ROS and other fire behaviour characteristics will be reduced accordingly. Curing also alters fuel continuity, and fires are unlikely to spread continuously over the landscape when curing falls below 90% (Cheney 1991). Thus the *Field Guide* is best suited to grasslands that are 90% to 100% cured.

3. Fire spread is over level to gently undulating terrain. In areas with long and steep slopes, fire spread will be faster upslope, and slower when backing downslope.

4. Fires are assumed to have been burning for sufficient time such that the head fire is wide enough for the fire to be spreading at its maximum potential ROS for the prevailing burning conditions. Fires that are still growing may spread more slowly and thus burn less intensely than would be predicted

(Cheney and Gould 1995). None of the fire spread and growth estimates consider acceleration of a fire to steady-state conditions after ignition. Fire behaviour estimates are based on the "worst case" ROS (15 000 m/h) predicted from the FBP System grassland O-1b fuel type fire behaviour model. However, the previously mentioned 1987 Boonoke Fire (Noble 1991) had a forward ROS of 23 000 m/h, some 7000 m/h faster than would be predicted by the *Field Guide*.

5. ROS predictions use an "average worst" FFMC of 93.2. The "average worst" FFMC is the average of the maximum FFMC values recorded at 20 weather stations throughout New Zealand (Pearce 1996). By estimating the range of FFMC values that would encompass one third (33%) of the variation either side of the average worst value, we can calculate the standard deviation. Figure 2, which shows ROS predicted using FFMC values two standard deviations (i.e., two thirds or 66%) above (97.3) and below (89.1) the "average worst" FFMC, demonstrates that if the FFMC is more or less than the "average worst", then the ROS and in turn the other estimated fire behaviour characteristics, will vary widely.
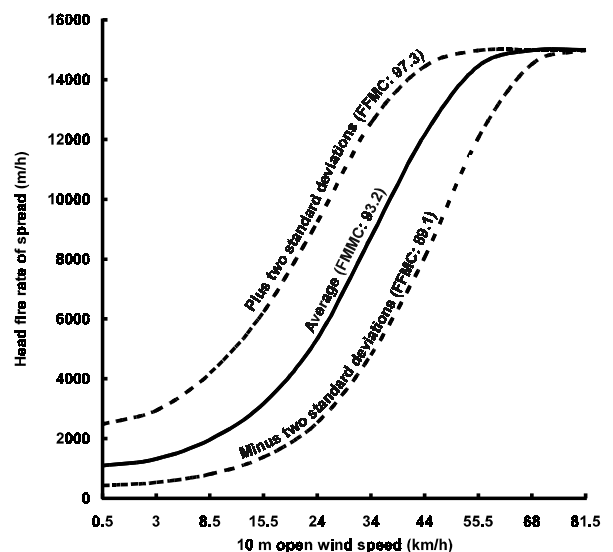

Figure 2. Variation in head fire rate of spread in fully cured grasslands on flat ground as a function of wind speed (from the mid-point values of the Beaufort Wind Force class) at three different Fine Fuel Moisture Code (FFMC) levels.

The FFMC of 93.2 embodied in the *Field Guide* applies to the time of day when dead fine fuel moisture content is at or near its daily minimum which usually occurs in late afternoon (Van Wagner 1987). For fully cured or completely dead grass, an FFMC of 93.2 equates to a dead fine fuel moisture content of less than 6% (L.G. Fogarty, unpublished), a critically dry level from the standpoint of extreme fire behaviour (Burrows 1984).

6. The ROS predictions incorporated into the *Field Guide* are based on the mid-point value for the range in wind speeds associated with each Beaufort Wind Force class. As a result, all the fire behaviour characteristics and suppression interpretations given in the *Field Guide* will be greater or less than predicted depending on whether the actual observed wind speed is at the upper or lower portion of the range (Figure 3).
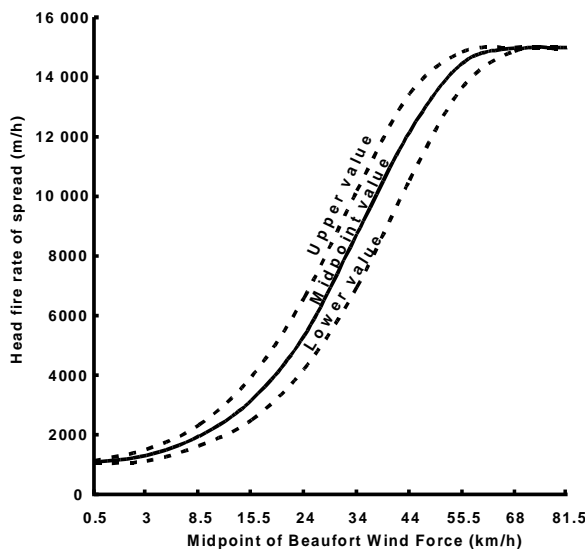

Figure 3. Variation in head fire rate of spread in relation to upper and lower wind speeds associated with each Beaufort Wind Force compared with mid-point values at an FFMC level of 93.2.

7. The perimeter length and maximum breadth estimates are based on the simple elliptical fire growth model (Alexander 1985) embodied in the FBP System (Forestry Canada Fire Danger Group 1992). Both perimeter length and maximum breadth will be underpredicted if there are wide fluctuations in wind direction (Richards 1994).

8. Fire intensity refers to the rate of heat energy released from the flaming portion of the fire front (Byram 1959) and is expressed in kilowatts per metre (kW/m). The fire intensity

calculations presented in the *Field Guide* are based on a nominal net low heat of combustion of 18 000 kJ/kg (Forestry Canada Fire Danger Group 1992), the assumed fuel load, and the ROS predicted by the FBP System as determined by the FFMC, wind speed and the degree of curing as discussed previously. Fire intensity will be over- or under- predicted in heavier and more sparse fuels, respectively. Similarly, increases or decreases in ROS will cause an associated change in fire intensity.

9. Flame size is the main visual manifestation of fire intensity. Flame lengths increase as fire intensity rises. The flame length values presented in the *Field Guide* are based on Byram's (1959) flame length-fire intensity relation. Flame length will be over- or under-predicted if any of the assumptions used to estimate ROS, fuel load and subsequently fire intensity, differ appreciably. Putnam's (1965) relation for flame angle versus flame length and wind speed coupled with flame geometry (Alexander 1982) was used to determine flame heights which in all cases were greater than 2.5 metres, assuming the ground level wind speed was approximately two-thirds of the 10-m open wind speed (Turner and Lawson 1978).

10. The minimum firebreak widths required to stop a head fire in grass fuels were derived using the relationships of Wilson (1988). The chance of a firebreak failing to stop a fire (i.e., the probability of firebreak breaching) increases as fire intensity increases and when trees or shrubs, which provide a ready source of embers or firebrands, are present within 20 m of the firebreak (Davidson 1988, Wilson 1988). The minimum widths shown on the *Field Guide* have a high (i.e., greater than 90%) probability of holding a fire. In the absence of trees or shrubs, the minimum widths agree reasonably well with Byram's (1959) rule of thumb where he suggested that a firebreak or fireguard should, in the absence of spotting, be one and a half times wider than the expected flame length in order to stop a fire's advance (*see* Fogarty 1996).

In addition to the schematic diagram illustrating the forward spread distance, perimeter and maximum breadth of an elliptically shaped fire, a 100 mm ruler has been added to the *Field Guide* to assist with mapping projected fire spread and growth.

Use: an example

An example scenario provides a means of illustrating how the grassland fire behaviour *Field Guide* can be used. In this scenario, conditions are similar to those experienced on the day of the 1991 Tikokino Fire (Rasmussen and Fogarty 1997). The scenario starts with a small fire (referred to here as the Waipawa Fire) occurring/breaking out on the Waipawa River terrace at the western edge of the map (Figure 4). On arrival, the Initial Attack (IA) boss experiences some difficulty walking into the wind and notices that whole trees are swaying, but only twigs break off from the few trees in the area during occasional strong gusts. Using the *Field Guide*, the IA boss decides that a moderate gale persists and that the Beaufort Wind Force is 7.

During the initial size-up, the Waipawa Fire is backing down into a gully, outside the influence of the wind. Flame heights are less than 2 m, and the fire appears to be controllable. However, the *Field Guide* indicates that under these conditions the ROS of the head fire will be around 14.5 km/h, with flame lengths up to about 8 metres and fire intensities in excess of 25 000 kW/m.

Even though the present behaviour of the Waipawa Fire is relatively mild, the *Field Guide* provides a timely warning that once exposed to the full force of the wind, the potential worst case fire behaviour would threaten the safety of firefighters if they place themselves ahead of the fire after it crosses the gully. The IA boss is aware that a grassland fire burning in similar conditions accelerated rapidly and overran an IA crew near Tikokino in 1991 (Rasmussen and Fogarty 1997). The important lessons from this fire were:

- Fires spreading in fine, dead grass fuels are fully exposed to the force of the prevailing weather conditions, particularly wind (McArthur 1966, Cheney and Sullivan 1997).

- A fire needs to reach a certain size before it will spread at its maximum potential ROS and intensity for the prevailing burning conditions; in cases such as those experienced at the Tikokino Fire, it is anticipated that a head fire width of over 250 m would have been required to reach this point (Cheney and Gould 1995, Cheney *et al.* 1998).

- In unstable atmospheric conditions, gusty and variable winds can cause the head fire to expand rapidly, or suddenly turn a flank into a head fire, resulting in a dramatic escalation in fire behaviour (Cheney and Gould 1995, Cheney *et al.* 1998).

This information helps the IA boss to understand why fatalities, injury or near miss incidents usually occur in situations such as during the initial attack of this fire (i.e., fires that are small or part of a relatively quiet section of a larger fire are spreading in light, open fuels) where changes in slope, wind speed and/or wind direction can cause the fire to escalate unexpectedly and trap or overrun firefighters before they can reach a safety zone (Wilson 1977, Anon. 1996).

Containing the Waipawa Fire before it crosses the gully and becomes fully exposed to the force of the wind is essential for successful containment. However, the IA boss realises that relying on observations of the fire during its early growth stages can lead to an underestimate of potential fire behaviour. With this knowledge, and an estimate of "worst case" fire behaviour from the *Field Guide*, the IA boss proceeds with caution. Before the IA crew can reach the Waipawa Fire and begin attack at the rear, it crosses the gully and spreads up to the terrace. Fire behaviour escalates dramatically, and initial attack subsequently fails.
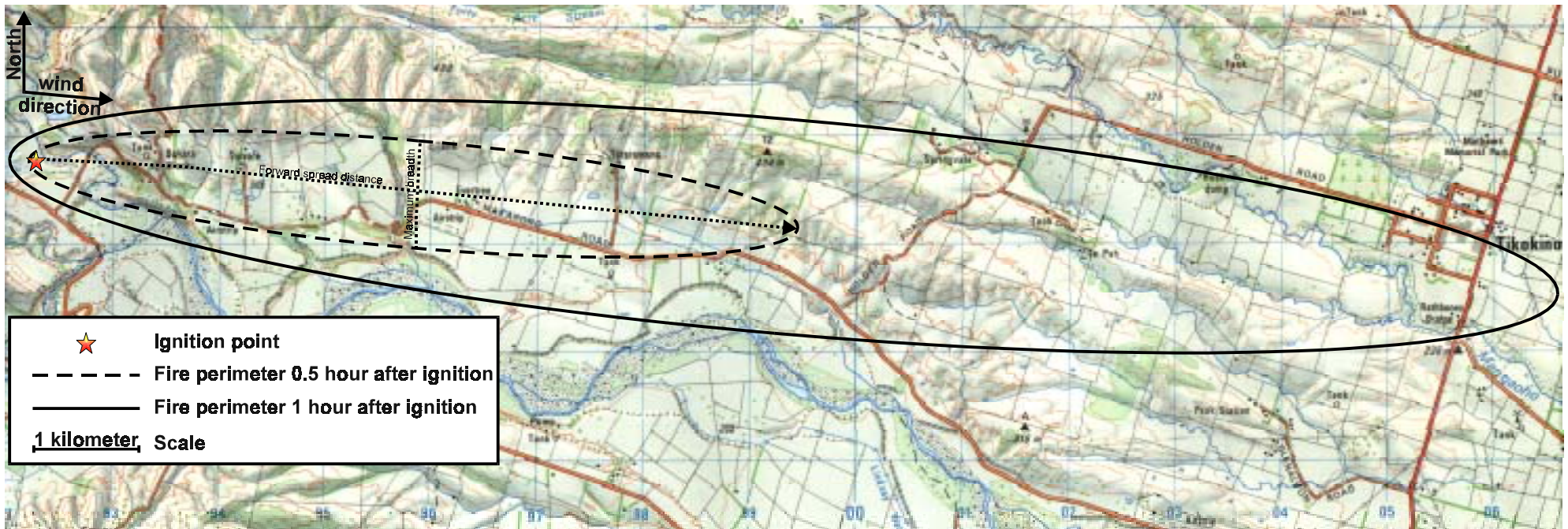
Figure 4. Free-burning fire growth projected for conditions similar to those experienced during the 1991 Tikokino Fire using the *Field Guide*.

In the meantime, the IA boss has been able to draw the potential worst case situation on a map (Figure 4). Even though it is a simplification, the fire shape can be reasonably represented by an ellipse that is 7.2 km long and 1 km wide (at the widest point) after 30 minutes, and 14.5 km long and 2 km wide after an hour. The IA boss has an appreciation of the "art and science" of fire behaviour prediction, and reasons that because the FFMC (91.9) is lower than the "average worst" FFMC (93.2) and the pasture has been heavily grazed, the head fire ROS and intensity are likely to be less than that estimated by the *Field Guide*. The IA boss considers the relative refinement of tabulated values in the *Field Guide*, but continues to use them as the best information available to support decision making. An overestimate of fire behaviour can be easily dealt with during fire suppression, but underestimates can be disastrous (Cheney 1981), so the IA boss decides that the potential overestimate will provide a useful margin for safety when implementing suppression strategies (e.g., backburning, public notifications and possible evacuations).

The fire growth projections indicate that the Waipawa Fire will reach Tikokino within one hour, and that a number of other farms and settlements will be threatened by the head and flank fires before then. The IA boss warns central fire control of the current and expected situation. By the time that the fire reaches Tikokino, the perimeter length will be approximately 29.5 km, and it is clearly evident that many more resources are necessary. However, the IA boss considers that wind funnelling along the river terrace may increase the wind speed and drive the fire down the terrace until it bends to the south near the intersection of Makaroro and Holden Roads. There is also a chance that the Fohn winds may swing more to a northwest direction, pushing the fire towards Peak Station. Therefore, the possibility that the fire will reach Peak Station within the hour also needs to be incorporated into the fire suppression plan.

Looking at possible options for control, it is clear that most of the roads in the area will not be wide enough to halt the forward spread of the fire, as breaks wider than 13 m would be needed provided no trees were on the windward side.

However, most of the roads are lined with shelterbelts, so only breaks wider than 30 m have a reasonable chance of halting fire spread. Holden Road provides a possible location from which to backburn, but less than 40 minutes is available to reach the road and establish a burn that is wide enough to contain the fire without jeopardising crew safety. Furthermore, the fire will cut off access along Makaroro Road from the west.

Knowing that in Australia, many public fatalities have occurred in similar instances, particularly involving landowners carrying out last minute protection works or moving stock (McArthur *et. al.* 1982, Krusel and Petris 1992), the IA boss decides to warn and assist nearby landowners before moving onto the suppression of the northern flank.

The northern flank of the Waipawa Fire will be more than 14 km long after an hour, and is likely to be fanned by a strong southerly change expected later in the afternoon. Once the change arrives, there is potential for the northern flank to result in a large head fire, which could advance at a ROS and intensity equal to or greater than previously experienced, threatening firefighters, the public and their property in its path. Considering this pending danger, the IA boss ensures that crews begin knockdown of the north flank from secured anchor points, and that they are working near the burnt out edge as they proceed.

Concluding remarks
This FTTN has documented the derivation and shown the use of a simple *Field Guide* for predicting grassland fire behaviour. The guide will assist fire control personnel to estimate fire potential in cured grasslands under critical fire weather conditions and, in turn, to assess the implications for initial attack suppression operations and the protection of life and property. The *Field Guide* is based on a number of underlying assumptions that could result in under- or over-predictions, although serious differences should be minimal. However, rural fire managers and IA bosses who recognise these situations and have a

knowledge of the "art and science" of predicting fire behaviour, will find that it is a useful tool during initial size-up and fire suppression plan development.

Copies of the *Field Guide* are available upon request from: The Forest and Rural Fire Research Programme, *Forest Research*, P.O. Box 29237, Christchurch, New Zealand.

Acknowledgments

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Dedication

Bernie Swan 1943 - 1993

This *Fire Technology Transfer Note* and the associated *Field Guide* are hereby dedicated to the memory of Mr Bernie Swan, a rural volunteer firefighter, who eventually died as a result of the burns he sustained while suppressing a grass fire near Anerley, Saskatchewan, Canada on October 2, 1993.

The inspiration for the *Field Guide* came about as a result of one of the authors (M.E. Alexander) undertaking an investigation of this burn-over incident in cooperation with Duncan Campbell, Forest Protection Branch, Department of Environment and Resource Management, Prince Albert, Saskatchewan.

About the Authors

At the time that this Fire Technology Transfer Note was initially prepared, Liam Fogarty was a Forest and Rural Fire Research Scientist at *Forest Research* in Rotorua. He held this postion from July 1993 to March 1998, and currently works for Forestry Tasmania as a plantations coordinator for the Derwent District, in Hobart, Tasmania.

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