
Fire Protection Branch

FIRE BEHAVIOUR AND
FUEL REDUCTION BURNING

BEMM RIVER WILDFIRE,
OCTOBER 1988

RESEARCH REPORT NO. 28
ANDREW BUCKLEY
SEPTEMBER 1990

Department of Conservation & Environment

Fire Protection Branch
Department of Conservation & Environment
ISBN 0-7306-2081-6

**FIRE BEHAVIOUR AND
FUEL REDUCTION BURNING**

**BEMM RIVER WILDFIRE,
OCTOBER 1988**

**RESEARCH REPORT NO. 28
ANDREW BUCKLEY
SEPTEMBER 1990**

This is an unpublished report with a restricted distribution. It must not be cited as a reference or abstracted without the permission of the Chief Fire Officer, Fire Protection Branch.

SUMMARY

On 14 October 1988 a major wildfire occurred in the Bemm River area, 33 km east of Orbost in the East Gippsland region of Victoria. This report details the fire weather and the behaviour and development of the wildfire. The weather was dominated by wind speeds of gale force strength. The fire burnt under "very high" to "extreme" fire danger conditions with a maximum McArthur fire danger index of 82, an average maximum forward rate of spread between 3.5 and 4.0 km/h and an average maximum intensity in the range 31,200 to 35,500 kW/m. The final area of the wildfire was 5,670 ha and the perimeter was 80 km.

A highly significant influence on fire behaviour was the layer of aerated, highly flammable shrub fuel. This was combined in the coastal forests of the Bemm River area with high quantities of litter and the high spotting potential of the stringybark eucalypts. Total fine fuel loads averaged about 20 tonnes/ha.

The observed average rate of spread during the initial two hour period of the wildfire was between 2.0 and 2.6 km/h which compares favourably with the rate predicted by the McArthur Mk 5 Forest Fire Danger Meter. During the second two hour period, the observed rate of spread increased to between 3.5 and 4.0 km/h, despite a fall in the fire danger index. This result is discussed in relation to other severe wildfires.

The contribution of fuel reduction burns, of various ages and coverage, to fire protection within the coastal forest fuel type burnt by this wildfire is assessed. A minimum coverage of 50% is recommended to achieve effective protection. Evidence from this wildfire demonstrates dramatic protection under "very high" fire danger conditions in fuels burnt one-and-a half years previously. Similar protection was achieved under "high" fire danger conditions in fuels burnt six months and two-and-a half years previously and a measurable effect was apparent in fuels burnt seven years previously.

INTRODUCTION

The understorey of the coastal forests of East Gippsland, Victoria, is a dense, aerated layer of highly flammable fine fuels which facilitate the spread of fire, even under mild conditions, and which under more severe conditions give rise to dramatic and uncontrollable fire behaviour. This understorey, in combination with high levels of litter fuels and the presence of stringybark eucalypts with high potential for generating spot fires, presents one of the highest fire hazards found in Australian forests.

Reducing the fire hazard can be difficult. Fuel reduction burning or prescribed burning, which is the primary management tool for reducing fuel quantities, and hence the impact of wildfires in a range of Victorian and Australian forests (McArthur 1962; Luke and McArthur 1978), is routinely practised in the dry sclerophyll forests of East Gippsland. However, these operations can be difficult to implement, particularly in coastal forest fuel types, because the fuels tend not to burn at all or to burn at intensities which are difficult to control.

Extensive areas of even aged eucalypt regrowth have resulted from past timber harvesting and wildfire events in the coastal and foothill forests of East Gippsland. Current harvesting and regeneration operations result in significant annual additions to this area. The protection from wildfire of this resource, dispersed amongst old growth and mixed aged forests, presents similar problems to those faced in the management of regrowth forests in south eastern New South Wales, south west Western Australia and Tasmania (Sneeuwjagt 1981). Protection within these stands, both to provide internal protection and to provide fuel reduced strategic breaks within the broader forest area, is urgently needed. Current research by the Fire Protection Branch of the Department of Conservation and Environment (DCE) and other agencies aims to establish fire behaviour data and prescriptions for the conduct of regrowth fuel reduction burning in this forest type.

On Friday, 14 October 1988 a major wildfire occurred in the Bemm River area, 33 km east of Orbost, Victoria. The general location of the fire area is shown in Figure 1. The fire was fanned by gale force winds, burnt through typically hazardous fuels of old growth and regrowth coastal forest, travelled 11.5 km in the first four hours and threatened the Bemm River settlement. The fire also encountered several areas of forest which had been previously fuel reduced.

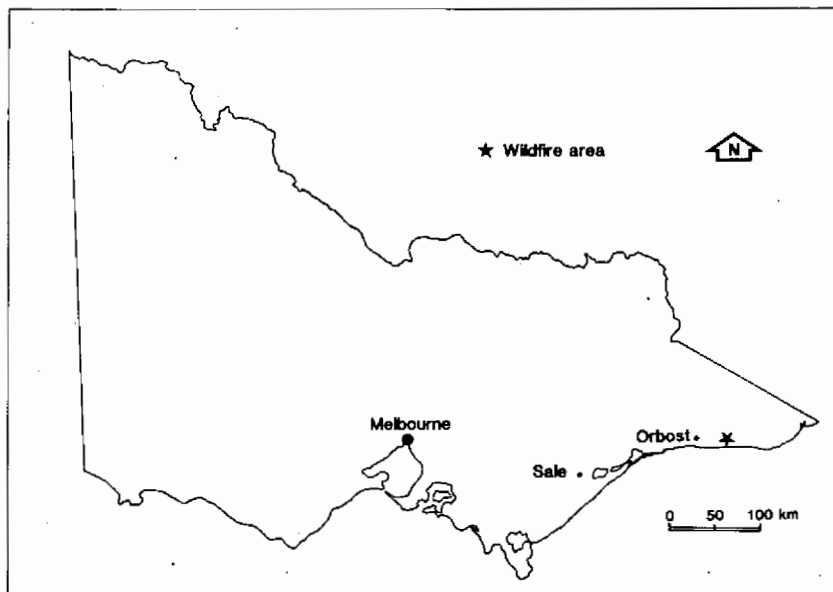


Figure 1. Location of the Bemm River wildfire.

The aims of this report are to document the observed behaviour of the Bemm River wildfire; to examine the applicability of the McArthur Mk 5 Forest Fire Danger Meter (Luke and McArthur 1978) in this hazardous fuel type and under the gale force wind conditions experienced; and to assess the contribution of fuel reduction burning to fire protection within the fuel type burnt by this wildfire.

FOREST TYPE AND FUEL CHARACTERISTICS

The forest type which covers most of the area burnt by the fire is classified as Silvertop Stringybark Open Forest III (28-40 m) (Land Conservation Council 1974) and occurs as even aged regrowth stands, mixed age stands with a mixture of regrowth and old growth, or as old growth forests. The age of regrowth stands within the fire area ranges from 13 to 30 years. Dominant tree species are *Eucalyptus sieberi* (Silvertop), *Eucalyptus globoidea* (White Stringybark), *Eucalyptus baxteri* (Brown Stringybark) and *Eucalyptus muelleriana* (Yellow Stringybark). Dominant shrub species include *Tetrarrhena juncea* (Wiregrass), *Pteridium esculentum* (Bracken), *Platylobium formosum* (Handsome Flat-pea), *Gahnia* spp. (Saw Sedge), *Hakea sericea* (Silky Needlewood) and *Acacia terminalis* (Sunshine Wattle). The topography is flat to undulating with slopes less than 15° except near the main creeks and rivers.

The fuel arrangement in this forest type is illustrated in Photos 1 and 2. Prior to the wildfire, shrub and litter fuels had been assessed as part of the fire research program at the two sites shown on Figure 5. The fuel definitions used in this sampling program are indicated below*. The results of this sampling, which seem representative of fuel quantities over much of the fire area, are summarised in Table 1 and Table 2 and indicate a high average fine fuel load of 19-22 tonnes/ha, with a maximum value recorded of 31 tonnes/ha. Of this quantity, living shrub fuel (less than 6 mm thickness) contributes an average of about 5 tonnes/ha. The average shrub height of the destructively sampled plots was 1.2 m. However, the average height of the shrub complex was commonly greater than this figure indicates.

* Fuel definitions.

- | | | |
|-------------------|---|--|
| Fine fuel | : | fuels less than 6 mm thickness excluding fuels such as eucalypt capsules and charcoal which do not ignite and burn readily. |
| Litter bed | : | dead fuels less than 6 mm thickness, including both surface and profile litter fuels. |
| Elevated litter | : | dead fuels less than 6 mm thickness, suspended in the shrub layer and generally greater than 10 cm above ground level. |
| Living shrub fuel | : | living understorey shrub fuels less than 6 mm thickness and less than 2 m in height; emergent species up to 6 m in height such as <i>Acacia</i> and <i>Hakea</i> are excluded. |
| Shrub height | : | height of the living shrub complex on the sample plot of area 0.37 m ² . |

The elevated litter was concentrated at lower levels of the shrub complex. Consequently, the boundary between the litter bed and elevated litter was often unclear, but was usually assessed at about 10 cm above ground level.

Photo 1. Shrub and litter fuels,
Hippo Track. (Plot data below).



FUEL TYPE		DRY WEIGHT (t/ha)
LITTER BED	0-6 mm	12.9
ELEVATED LITTER	0-6 mm	3.2
TOTAL LITTER	0-6 mm	16.1
LIVING SCRUB	0-6 mm	3.0
<hr/>		
TOTAL FINE FUELS	0-6 mm	19.1
<hr/>		
DEBRIS, DEAD	6-25 mm	1.4
<hr/>		
(1.2 m HEIGHT POLE, 0.3 m INTERVALS)		



Photo 2. Shrub and litter fuels,
Hippo Track.(Plot data below).

FUEL TYPE		DRY WEIGHT (t/ha)
LITTER BED	0-6 mm	15.3
ELEVATED LITTER	0-6 mm	3.2
TOTAL LITTER	0-6 mm	18.5
LIVING SCRUB	0-6 mm	5.6
<hr/>		
TOTAL FINE FUELS	0-6 mm	24.1
<hr/>		
DEBRIS, DEAD	6-25 mm	4.3
<hr/>		
(1.2 m HEIGHT POLE, 0.3 m INTERVALS)		

Table 1(a). Average shrub height as measured at twelve sampling points near Hippo Track.

	MEAN (m)	VARIANCE	RANGE (ON TRANSECTS BETWEEN PLOTS) (m)
Average shrub height	1.2	0.1	0.6 - 2.4

Table 1(b). Fuel load as measured at twelve sampling points near Hippo Track.

FUEL TYPE	MEAN (t/ha)	VARIANCE	RANGE OF PLOT MEANS (t/ha)
Litter bed 0-6 mm	15.5	10.1	11.0 - 21.6
Elevated litter 0-6 mm	2.2	0.8	0.9 - 3.2
Total litter 0-6 mm	17.7	11.9	15.0 - 23.4
Living shrub fuel 0-6 mm	4.7	3.7	2.3 - 9.0
Total fine fuels 0-6 mm	22.4	17.3	16.0 - 29.3
Debris (dead) 6-25 mm	3.7	6.7	0.3 - 8.8

Table 2(a). Average shrub height as measured at six sampling points near the junction of Patrol and Tolly Tracks.

	MEAN (m)	VARIANCE	RANGE (ON TRANSECTS BETWEEN PLOTS) (m)
Average shrub height	1.2	0.1	0.9 - 2.1

Table 2(b). Fuel load as measured at six sampling points near the junction of Patrol and Tolly Tracks.

FUEL TYPE	MEAN (t/ha)	VARIANCE	RANGE OF PLOT MEANS (t/ha)	
Litter bed 0-6 mm	10.9	12.3	6.9	- 15.0
Elevated litter 0-6 mm	3.1	8.9	0.8	- 8.5
Total litter 0-6 mm	14.0	37.7	7.8	- 23.1
Living shrub fuel 0-6 mm	5.2	8.6	2.4	- 9.9
Total fine fuels 0-6 mm	19.2	53.9	11.1	- 30.9
Debris (dead) 6-25 mm	2.1	3.4	0.0	- 4.9

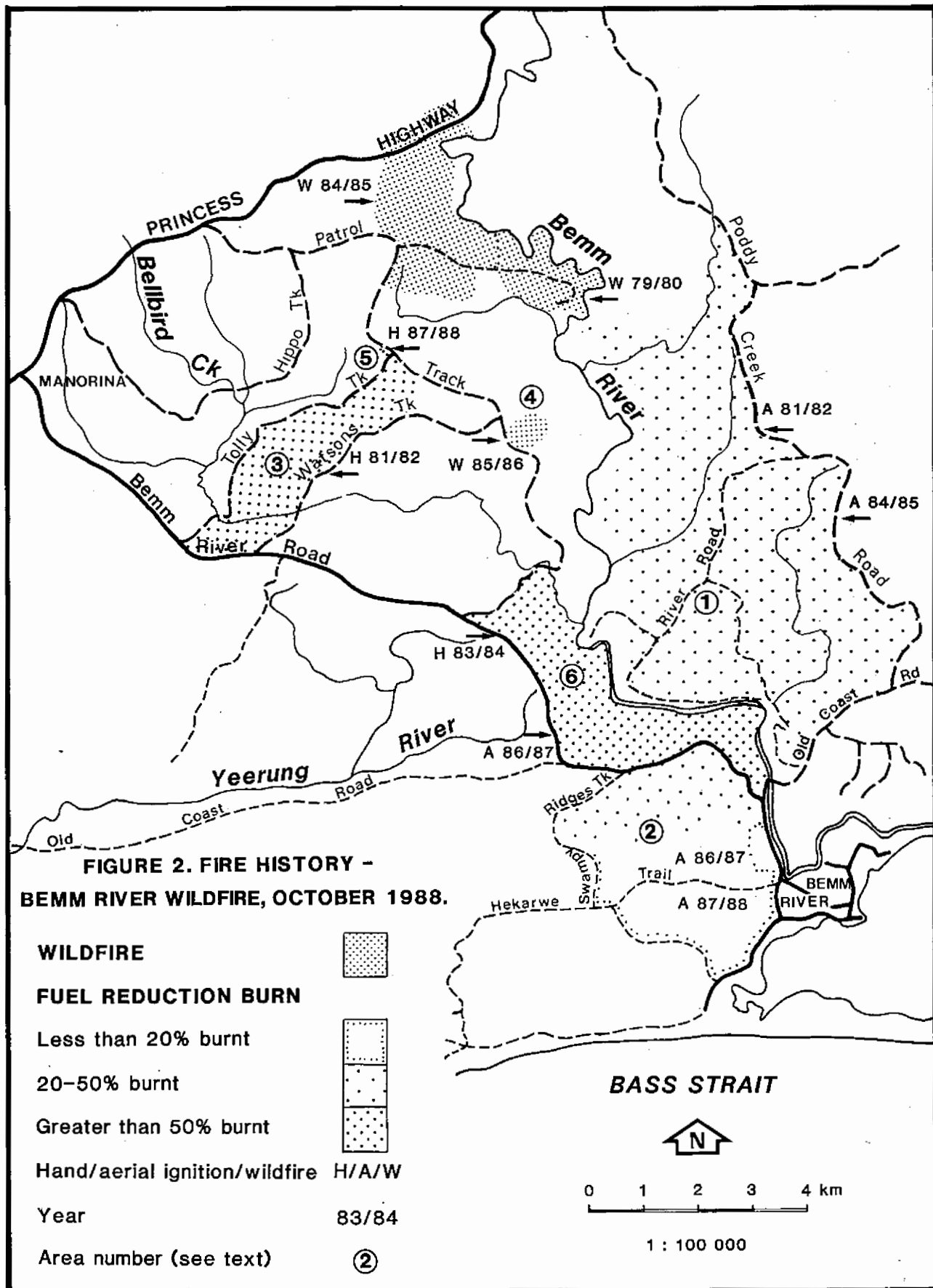
The forest type on lower quality sites and on sand dune soils in the south of the wildfire area is classed as Woodland I-II (less than 28 m). Dominant tree species are *Eucalyptus consideriana* (Yertchuk), *Eucalyptus botryoides* (Southern Mahogany), *Eucalyptus glôboidea* (White Stringybark) and *Banksia serrata* (Saw Banksia), generally with a heath understorey. Measurements of fuel load had not been made in this forest type but are probably about 25 tonnes/ha, based on the measurements of fuel load in the Open Forest class and having regard to the increased contribution to dry weight of the heath component of the understorey.

A third vegetation type found in low lying areas within the wildfire area is Heathland. These sites are generally covered in dense heath between 2 to 4 m in height, and of a number of different associations including *Leptospermum juniperinum* (Prickly Tea-tree).

Some of the fuels in the fire area had been modified during the previous ten years by fuel reduction burning or wildfire. The method of ignition, boundary, year and estimated effectiveness of each burn are shown on Figure 2. Individual burn units are identified as Area 1 to Area 6.

The south eastern half of Area 1 had been aerially ignited in Autumn 1985. Field officers had estimated at the time that the result was "satisfactory" with 20-50% of the area burnt. A similar "satisfactory" result had been achieved in Autumn 1982 when fuel reduction burning had been attempted on the north western half of the block.

Numerous attempts had been made to fuel reduce Area 2 over the preceding ten years using the preferred techniques of edge lighting by hand and aerial ignition of the block interior in the Autumn. The two most recent burns, conducted in August 1987 and Autumn 1988, had been assessed by field officers to be "satisfactory" only in the northern half of the block, with 20-50% of that area burnt.



Ground ignition of Area 3 in the Spring of 1981 resulted in extensive crown scorch but had successfully reduced fuel loads on 80-90% of the area (R. Willersdorf pers. comm.*). Fuel loads had increased to significant levels over the seven years since the burn.

A wildfire in February 1986 almost completely removed shrub and litter fuels over the entire 41 ha of Area 4. Area 5 had been fuel reduced in Autumn 1988 as part of the fire research program. Fuel reduction of most shrub fuels and about 80% of litter fuels was achieved over the three hectares treated.

Considerable effort had been devoted to the fuel reduction of Area 6 over the six years prior to the wildfire. Recent burning history includes a successful roadside "edge burn" in 1984, an unsuccessful attempt at aerial ignition in Autumn 1985 and a successful aerial ignition in Autumn 1987. DCE regional records indicate that the 1987 operation had reduced fuel loads on most ridges, spurs and upper slopes but that the lower slopes and gullies had remained unburnt. The reduction of fuels on greater than 50% of this block was considered a "good" result.

The moisture content of the fine fuels was determined on the day of and the day prior to the wildfire by collecting samples of litter for subsequent oven drying. The results, which are shown in Table 3, indicate that the moisture content of the profile litter** on the day prior to the wildfire ranged from 35% to 156%, and that at 1500 hours on the day of the wildfire, the minimum moisture content of surface** and elevated eucalypt litter*** was 10%.

Table 3. Fine fuel moisture content data for surface, elevated and profile litter.

LITTER LOCATION	COLLECTION DETAILS		FINE FUEL MOISTURE CONTENT (% ODW)
	DATE	TIME (hours)	
Surface litter	14 October	1500	10.3
Elevated litter	14 October	1500	10.2
Profile litter	13 October	1200	156
Profile litter	13 October	1440	35

* Rob Willersdorf, Science Officer, Bairnsdale Region, DCE.

** Definition of surface litter and profile litter are derived from Dexter (1975):

- Surface litter : dead fuels less than 6 mm thickness found in the top 1.5 cm of the litter bed.
- Profile litter : dead litter bed fuels less than 6 mm thickness situated below the surface litter.

*** Elevated eucalypt litter : dead eucalypt leaves suspended in the shrub layer.

The samples of surface and elevated fuel collected on the day of the wildfire reflected maximum exposure to the drying elements of air movement and sunshine.

FIRE WEATHER

The synoptic situation at noon on the day before the fire is shown in Figure 3(a). A high pressure centre was centred over south eastern New South Wales and a weakening cold front was approaching Tasmania with a stronger front located south west of the Bight. On the day of the fire, the front located south west of the Bight moved rapidly eastward, extending to eastern Victoria during the afternoon as shown in Figure 3(b). It was preceded by warm, gale force, north to north west winds which shifted to gale force, west to south westerly following the passage of the front.

Two forecasts issued by the Bureau of Meteorology which are relevant to the wildfire are shown below:

- (a) Forecast for East Gippsland issued at 1900 hours on 13 October 1988 for 14 October 1988

Mainly fine and warm with a freshening north to north west wind. Showers and local thunderstorms developing later in the day as the wind turns cooler south westerly and strengthens.

- (b) Forecast for East Gippsland issued at 0630 hours on 14 October 1988 for 14 October 1988

Showers and isolated thunderstorms developing. Northerly wind reaching strong to gale force near the coast and shifting cooler south westerly this afternoon. A land gale warning is current. Maximum temperature for Orbost 29°C.

These forecasts indicate that the gale force winds preceding the wind change had not been forecast until the morning of Friday, 14 October. The weather predicted by these forecasts illustrates an extreme example of a rapid change in both wind speed and direction which is characteristic of Spring weather systems in Gippsland.

A continuous record of the wind speed and direction on the day of the wildfire is shown in Figure 4. This trace was produced by a Dynes anemometer, located at the RAAF East Sale Base, 160 km west south west of the fire area. These data are summarised in Table 4, and indicate a sudden increase to gale force winds at 1000 hours, a maximum average wind speed at Sale of 70 km/h between 1000 and 1200 hours and a maximum gust of 122 km/h at 1125 hours.

Table 4. Data from Dynes anemometer trace, RAAF, East Sale, 14 October 1988.

(Note that wind speed measurements in this table are in units of km/h rather than knots).

TIME (hours)	WIND SPEED (km/h)		WIND DIRECTION
	MAXIMUM	AVERAGE	
0900-1000	30-45	20	260°-340° (W-NNW)
1000-1200	90-115	70	280°-360° (W-N)
1200-1400	50-70	35	280°-350° (W-N)
1400-1800	85-100	55	220°-290° (SW-WNW)
1800-2400	65-85	30-35	220°-300° (SW-WNW)

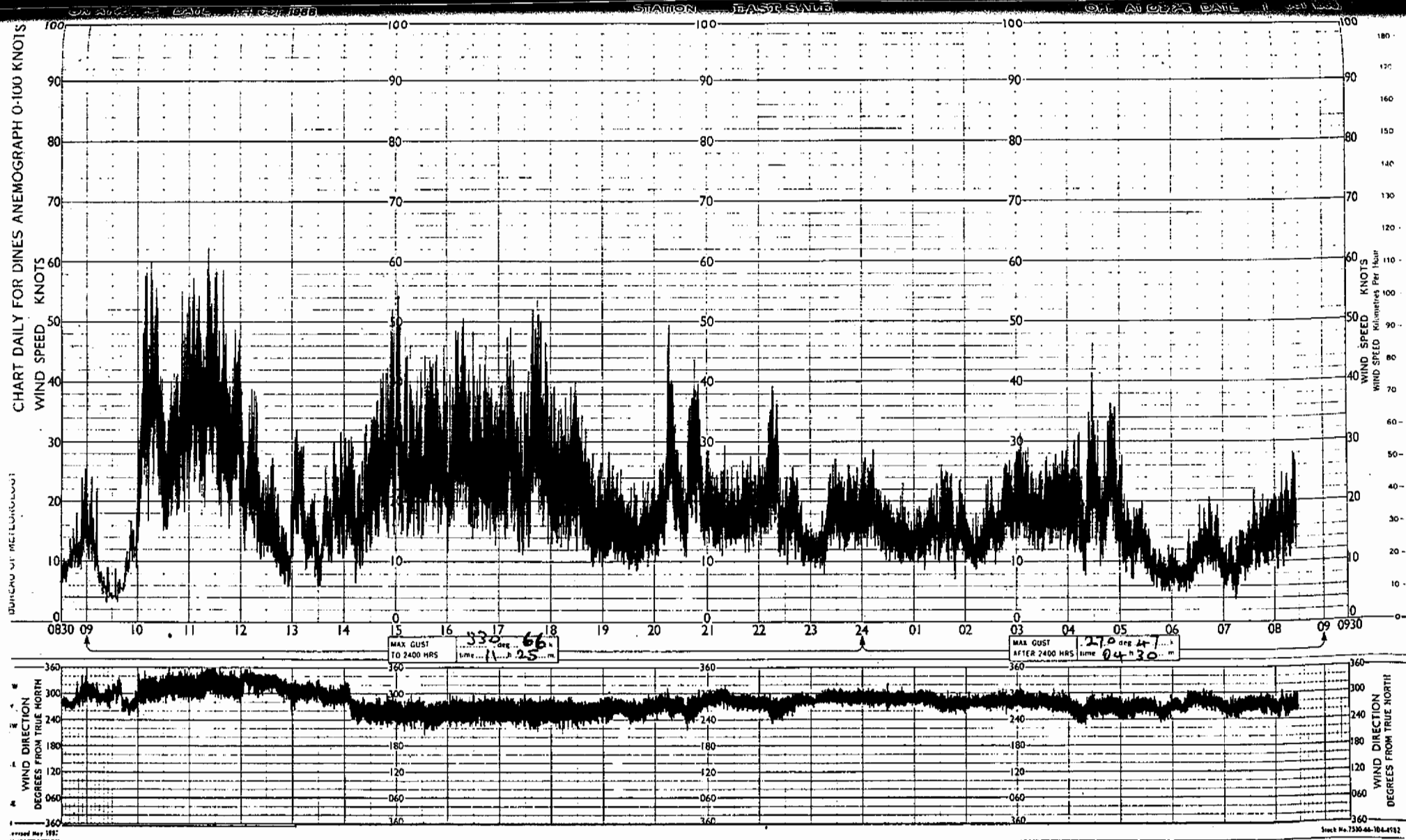


Figure 4. Dynes anemometer trace of wind speed and direction for RAAF East Sale base for 14 October 1988.

(Note : LHS wind speed scale in knots, RHS wind speed scale in km/h. 1 knot = 1.85 km/h).

The sudden increase to gale force wind speeds occurred in the fire area at 1125 hours, approximately one hour 30 minutes later than at East Sale. The west to south west wind change reached a location two kilometres north of the Bemm River township at 1530 hours, again approximately one hour 30 minutes later than at East Sale, although a further hour passed before the change reached the inland location of Manorina (see Figure 2). In this report, a time adjustment of one hour 30 minutes is therefore applied to wind data between East Sale and the fire area.

Wind speed at the fire area was assessed using the Beaufort Scale (Bureau of Meteorology 1984). A "Force 10 storm or whole gale", which corresponds to an average wind speed of 89 to 102 km/h, characterised the initial two hours of the wildfire. Observations of maximum gust wind speed made on a Dwyer anemometer at the Orbost DCE office during this time ranged between 120 and 130 km/h. Higher wind damage levels in the Orbost area compared to the Sale area support the higher average wind speed assessed at the wildfire area. The wind uprooted trees, snapped off branches and tree trunks and caused structural damage to buildings and utilities; winds of such strength are rarely experienced inland.

Wind speed at the fire area during the two hour period prior to the wind change decreased to a Force 8 to 9 on the Beaufort Scale, which corresponds to an average wind speed of between 62 to 88 km/h (gale to strong gale). The extent of the decrease in wind speed recorded at East Sale did not occur in the wildfire area. Wind speed following the wind change continued at gale force strength for at least one-and-a-half hours before moderating late on the Friday afternoon.

Temperature and relative humidity data derived from a thermo-hydrograph trace at Orbost are shown in Table 5. Temperature and relative humidity data collected at Hippo Track, near the point of fire ignition, are shown in Table 6. The data in Tables 5 and 6 correspond closely; although a lag of between half and one hour in the increase in relative humidity at Hippo Track is apparent. A maximum temperature of 30°C and an estimated minimum relative humidity of 26% occurred in the wildfire area between 1115 and 1145 hours, which illustrates that extremes of temperature or relative humidity are not features of this wildfire.

Table 5. Temperature and relative humidity data, Orbost, 14 October 1988.

TIME (hours)	TEMPERATURE (°C)	RELATIVE HUMIDITY (%)
0900	24	33
1000	27	32
1100	29.5	26
1200	28	27
1300	25	30
1400	24	37
1500	24	45
1600	24	45
1700	17	84
1800	15	62
1900	14.5	65
2000	14	70

Table 6. Temperature and relative humidity data, Hippo Track, 14 October 1988.

TIME (hours)	TEMPERATURE (°C)	RELATIVE HUMIDITY (%)
1100	28.5	-
1115-1145 (approx)	30	-
1500	25	37
1530	23	45

The metric Byram Keetch Drought Index (Keetch and Byram 1968) at Orbost for Friday, 14 October 1988 was a relatively low 29. The following rainfall data were collected at Hippo Track prior to the wildfire: two days since 0.2 mm, three days since 1 mm and five days since a cumulative 8.5 mm. The combination of the drought index and recent rainfall data by the McArthur Mk 5 Forest Fire Danger Meter to give a drought factor of 7 indicates that 70% of the fuel was theoretically available for consumption.

An integrated measure of fire weather conditions is provided by the fire danger index which is calculated using the McArthur Mk 5 Forest Fire Danger Meter. This index is directly related to the chance of a fire starting, and the fire's rate of spread, intensity and difficulty of suppression, and has been widely used in Australia for fire danger forecasting and as a guide to fire behaviour (Luke and McArthur 1978). For the Bemm River wildfire, calculations of the index are shown in Table 7. These calculations are based on the McArthur equations described by Noble *et al.* (1980) which allow the input of wind speed data greater than the maximum figure of 70 km/h found on the McArthur meter. The fire danger index peaked at 82 when the temperature was 28°C, relative humidity 27% and average wind speed 95 km/h. Values of fire danger index greater than 50 are classified as "extreme".

Table 7. Fire danger index for 14 October 1988, based on temperature, relative humidity and wind speed data at Orbost.

TIME (hour)	TEMP. (°C)	RELATIVE HUMIDITY (%)	AVERAGE WIND SPEED (km/h)	FIRE DANGER INDEX
1000	27	32	20	11
1100	29.5	26	40	24
1200	28	27	95	82
1400	24	37	75	32
1530	24	45	75	23

FIRE BEHAVIOUR AND DEVELOPMENT

The Bemm River wildfire started at Hippo Track (see Figure 5) at 1130 hours on Friday, 14 October 1988. The source of the wildfire was a burning *Eucalyptus sieberi*, located within the control lines of a fire which had been alight the previous day. The crew of a tanker had almost completed "blacking out" the previous fire when the wind speed increased dramatically. Despite the presence of this tanker crew, two spot fires became uncontrollable within minutes. Flames completely scorched the forest canopy within 15 m of the point of ignition. Gale force winds not only fanned the spot fires but blew numerous branches, 30 year old regrowth trees and dead old growth trees (known as stags) to the ground. The situation was life threatening and the crew was withdrawn.

Details of the subsequent fire development are shown on Figure 5, and the fire behaviour is summarised in Table 8. In the 15 minutes following ignition, the fire front travelled 100 m, which corresponds to a forward rate of spread of 0.4 km/h. Short distance spotting of up to 40 m was well established, even at this early stage. The author estimated the location of the fire front at 1330 hours (from the Bemm River Road, prior to the wildfire crossing the road) to be between 3.5 and 4.5 km from the point of ignition, which corresponds to a forward rate of spread of between 2.0 and 2.6 km/h. A large spot fire was observed at 1330 hours to be burning intensely near Patrol Track, which indicates long distance spotting of at least 3 km.

During the period 1330 to 1530 hours, the fire progressed between 7.0 and 8.0 km through Open Forest, Woodland and Heathland fuels, at a calculated rate of spread of between 3.5 and 4.0 km/h. At 1500 hours aerial reconnaissance detected spot fires burning east of Bemm River and south of River Road, which had resulted from long distance spotting. The position of the headfire was not accurately located by the reconnaissance flight because of the dense smoke and the necessity for the aircraft to fly at 9,000 ft due to severe atmospheric instability. The steeply angled convection column of the main fire at this stage was approximately 12,000 ft in height.

The fire behaviour prior to the wind change can be expressed quantitatively in terms of fire intensity*, as is shown in Table 8. The maximum average fire intensity (assuming an average value of heat yield for forest fuels of 16,000 kJ/kg (Luke and McArthur 1978) and an estimated dry weight of fuel consumed of 20 tonnes/ha) was between 31,200 and 35,600 kW/m.

Table 8. Summary of fire behaviour of the Bemm River fire on 14 October 1988, prior to the wind change. (Possible range in spread distance, and hence forward rate of spread and fire intensity, is shown in brackets).

TIME (hours)	SPREAD DISTANCE (km)	AVERAGE FORWARD RATE OF SPREAD (km/h)	AVERAGE FIRE INTENSITY (kW/m)
1130-1145	0.1	0.4	3,600
1145-1330	4.0 (3.5-4.5)	2.3 (2.0-2.6)	20,500 (17,800-23,200)
1330-1530	7.5 (7.0-8.0)	3.8 (3.5-4.0)	33,900 (31,200-35,600)
1130-1530	11.5	2.9	25,800

Table 6. Temperature and relative humidity data, Hippo Track, 14 October 1988.

TIME (hours)	TEMPERATURE (°C)	RELATIVE HUMIDITY (%)
1100	28.5	-
1115-1145 (approx)	30	-
1500	25	37
1530	23	45

The metric Byram Keetch Drought Index (Keetch and Byram 1968) at Orbost for Friday, 14 October 1988 was a relatively low 29. The following rainfall data were collected at Hippo Track prior to the wildfire: two days since 0.2 mm, three days since 1 mm and five days since a cumulative 8.5 mm. The combination of the drought index and recent rainfall data by the McArthur Mk 5 Forest Fire Danger Meter to give a drought factor of 7 indicates that 70% of the fuel was theoretically available for consumption.

An integrated measure of fire weather conditions is provided by the fire danger index which is calculated using the McArthur Mk 5 Forest Fire Danger Meter. This index is directly related to the chance of a fire starting, and the fire's rate of spread, intensity and difficulty of suppression, and has been widely used in Australia for fire danger forecasting and as a guide to fire behaviour (Luke and McArthur 1978). For the Bemm River wildfire, calculations of the index are shown in Table 7. These calculations are based on the McArthur equations described by Noble *et al.* (1980) which allow the input of wind speed data greater than the maximum figure of 70 km/h found on the McArthur meter. The fire danger index peaked at 82 when the temperature was 28°C, relative humidity 27% and average wind speed 95 km/h. Values of fire danger index greater than 50 are classified as "extreme".

Table 7. Fire danger index for 14 October 1988, based on temperature, relative humidity and wind speed data at Orbost.

TIME (hour)	TEMP. (°C)	RELATIVE HUMIDITY (%)	AVERAGE WIND SPEED (km/h)	FIRE DANGER INDEX
1000	27	32	20	11
1100	29.5	26	40	24
1200	28	27	95	82
1400	24	37	75	32
1530	24	45	75	23

FIRE BEHAVIOUR AND DEVELOPMENT

The Bemm River wildfire started at Hippo Track (see Figure 5) at 1130 hours on Friday, 14 October 1988. The source of the wildfire was a burning *Eucalyptus sieberi*, located within the control lines of a fire which had been alight the previous day. The crew of a tanker had almost completed "blacking out" the previous fire when the wind speed increased dramatically. Despite the presence of this tanker crew, two spot fires became uncontrollable within minutes. Flames completely scorched the forest canopy within 15 m of the point of ignition. Gale force winds not only fanned the spot fires but blew numerous branches, 30 year old regrowth trees and dead old growth trees (known as stags) to the ground. The situation was life threatening and the crew was withdrawn.

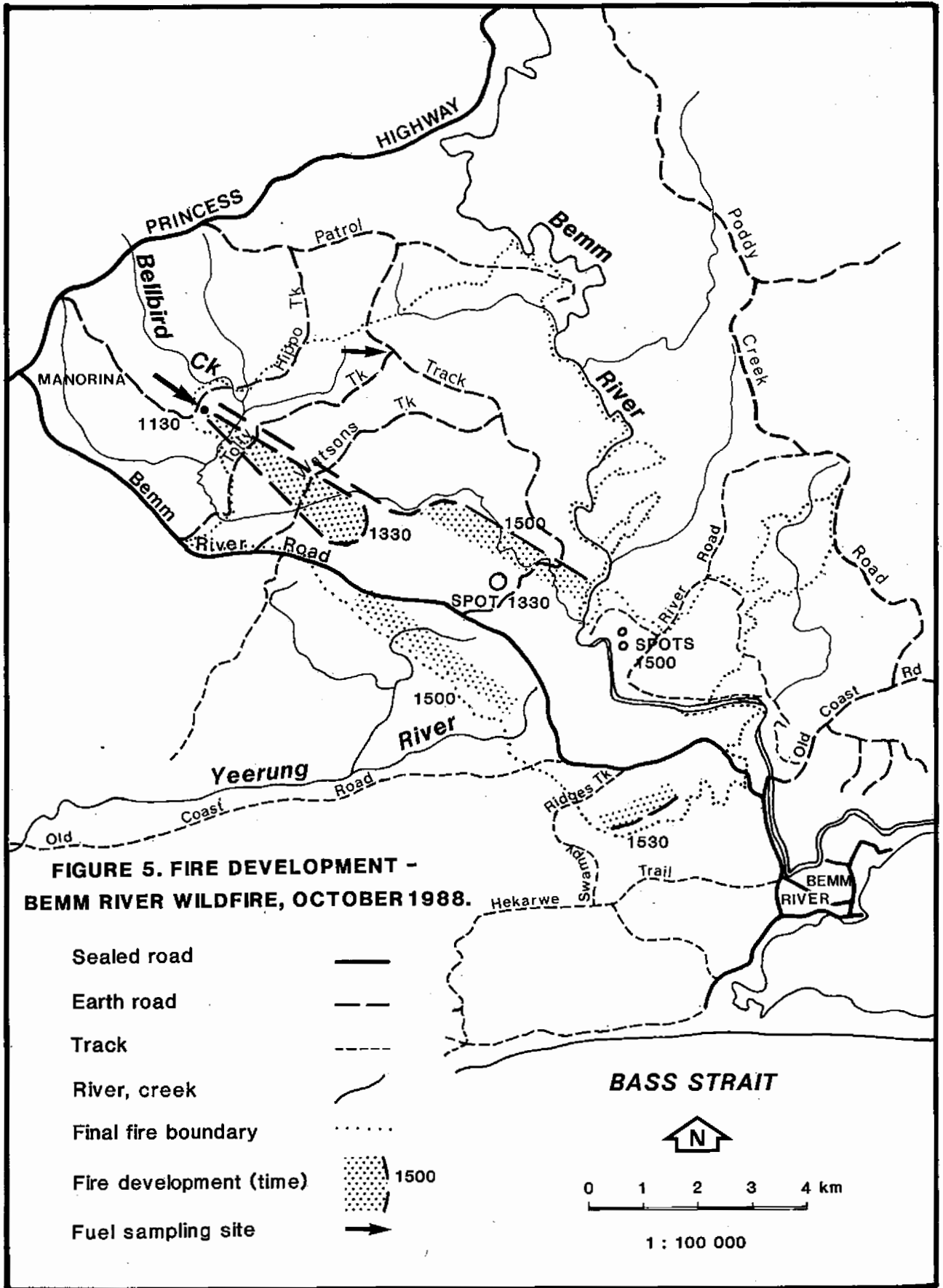
Details of the subsequent fire development are shown on Figure 5, and the fire behaviour is summarised in Table 8. In the 15 minutes following ignition, the fire front travelled 100 m, which corresponds to a forward rate of spread of 0.4 km/h. Short distance spotting of up to 40 m was well established, even at this early stage. The author estimated the location of the fire front at 1330 hours (from the Bemm River Road, prior to the wildfire crossing the road) to be between 3.5 and 4.5 km from the point of ignition, which corresponds to a forward rate of spread of between 2.0 and 2.6 km/h. A large spot fire was observed at 1330 hours to be burning intensely near Patrol Track, which indicates long distance spotting of at least 3 km.

During the period 1330 to 1530 hours, the fire progressed between 7.0 and 8.0 km through Open Forest, Woodland and Heathland fuels, at a calculated rate of spread of between 3.5 and 4.0 km/h. At 1500 hours aerial reconnaissance detected spot fires burning east of Bemm River and south of River Road, which had resulted from long distance spotting. The position of the headfire was not accurately located by the reconnaissance flight because of the dense smoke and the necessity for the aircraft to fly at 9,000 ft due to severe atmospheric instability. The steeply angled convection column of the main fire at this stage was approximately 12,000 ft in height.

The fire behaviour prior to the wind change can be expressed quantitatively in terms of fire intensity*, as is shown in Table 8. The maximum average fire intensity (assuming an average value of heat yield for forest fuels of 16,000 kJ/kg (Luke and McArthur 1978) and an estimated dry weight of fuel consumed of 20 tonnes/ha) was between 31,200 and 35,600 kW/m.

Table 8. Summary of fire behaviour of the Bemm River fire on 14 October 1988, prior to the wind change. (Possible range in spread distance, and hence forward rate of spread and fire intensity, is shown in brackets).

TIME (hours)	SPREAD DISTANCE (km)	AVERAGE FORWARD RATE OF SPREAD (km/h)	AVERAGE FIRE INTENSITY (kW/m)
1130-1145	0.1	0.4	3,600
1145-1330	4.0 (3.5-4.5)	2.3 (2.0-2.6)	20,500 (17,800-23,200)
1330-1530	7.5 (7.0-8.0)	3.8 (3.5-4.0)	33,900 (31,200-35,600)
1130-1530	11.5	2.9	25,800



Following the south west wind change, the north eastern flank became the headfire which burnt intensely on a wide front until weather conditions moderated late in the afternoon. The Bemm River and adjacent Warm Temperate Rainforest vegetation provided a natural boundary to the development of the fire. However, three separate fire areas developed on the eastern side of Bemm River as a result of spot fires which had ignited both before and after the wind change. The final fire area was 5,670 ha with a perimeter of 80 km.

The intense fire behaviour of the Bemm River wildfire resulted in complete crown scorch of most of the forest burnt by the main run of the fire. Interpretation of scorch classes from large scale colour aerial photographs flown four months after the fire is shown on Figure 6 with a corresponding area statement in Table 9. The scorch classes are defined on the basis of complete crown scorch**. While about half of the total fire area was classified as scorch class 1, only insignificant areas of forest were completely defoliated by this fire.

Table 9. Area statement of crown scorch classes.

CROWN SCORCH CLASS	AREA (ha)	% OF TOTAL
Scorch class 1	3,185	56%
Scorch class 2	556	10%
Scorch class 3	1,318	23%
Unburnt	276	5%
Heathland	335	6%
TOTAL	5,670	100%

An informal inspection of tree damage conducted 15 months after the wildfire found that leader shoots had been lost from some of the 20 to 30 year old regrowth stems, but that there was only limited evidence of butt scarring, as indicated by the absence of bark splitting.

* Fire intensity was devised by Byram (1959) as a measure of fire behaviour. It is the rate of energy release per unit length of fire front and is defined by the equation:

$$I = Hwr$$

Where I denotes the fire intensity (kW/m), H denotes the heat yield of fuel (kJ/kg), W denotes the dry weight of fine fuel consumed (kg/m²) and r denotes the forward rate of spread (m/s).

** Scorch class 1 : complete crown scorch of 50-100% of crowns
 Scorch class 2 : complete crown scorch of less than 50% of crowns
 Scorch class 3 : minimal complete crown scorch (includes lower crown scorch)
 Heathland : heathland burnt by the wildfire
 Unburnt : unburnt area within the fire boundary

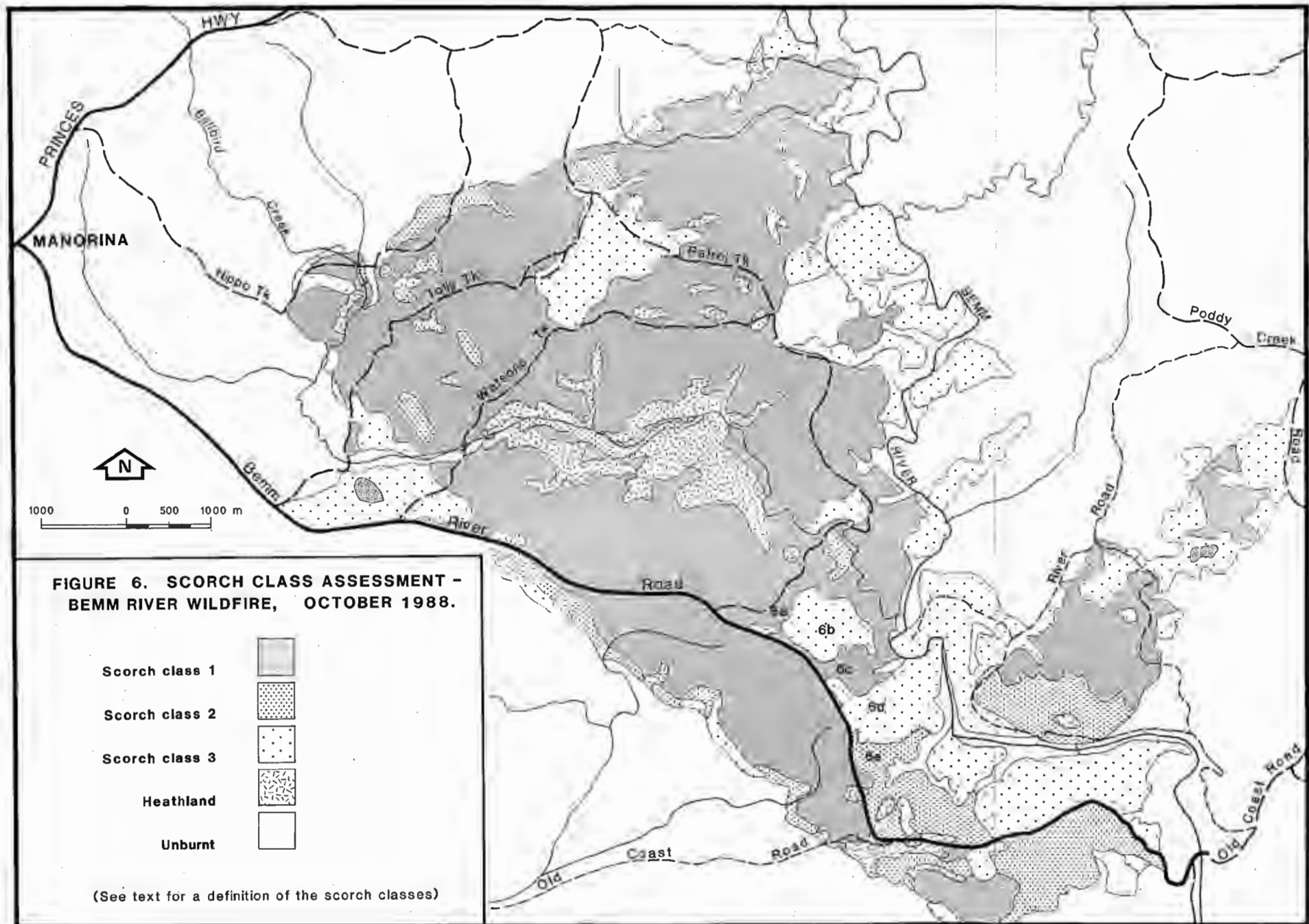
The observed average rate of spread over each of two intervals of two hours prior to the wind change is compared in Table 10 with rates of spread predicted by the McArthur Mk 5 Forest Fire Danger Meter. The predictions are based on the fire danger indices tabulated in Table 7, on a fuel quantity of 20 tonnes/ha and on zero slope*. The predicted rate of spread of 2.0 km/h during the first time period when the fire danger index peaked at 82 compares favourably with the observed rate of spread of between 2.0 to 2.6 km/h. However, despite a substantial decrease in fire danger index to 32 during the second time period and hence a decrease in the predicted rate of spread to 0.8 km/h, the fire increased its rate of spread to between 3.5 and 4.0 km/h.

Table 10. Comparison of predicted and observed rates of spread using weather conditions at 1200 and 1400 hours.

TIME (hours)	AVERAGE WIND SPEED (km/h)	FIRE DANGER INDEX (ORBOST)	PREDICTED RATE OF SPREAD (km/h)	OBSERVED RATE OF SPREAD (km/h)
1200	95	82	2.0	2.0-2.6
1400	75	32	0.8	3.5-4.0

Suppression action against the head fire and north eastern flank was effectively impossible during the main run of the fire. However, effective suppression action was implemented prior to the south west wind change on the south western flank of the fire. Two D6 class bulldozers commenced a direct flank attack on the fire edge south east of the Bemm River Road at about 1500 hours, "checking" the flank later in the afternoon. Subsequent suppression action involved direct attack with bulldozers which "checked" the southern, western and much of the northern edge during the later afternoon and night of the first day. However, the total wildfire was not declared "checked" until 0900 hours on the fourth day. Strong wind conditions persisted into the second and third days of the wildfire which increased suppression difficulty on the fire areas east of Bemm River. "Control" was declared at 0900 hours on the fifth day of the fire.

* The effects of slope can be virtually disregarded when considering large fire behaviour under forest conditions (Luke and McArthur 1978).



DISCUSSION

"Very high intensity" fires are defined as having fire intensities greater than 7,000 kW/m (Cheney 1981), and severe forest fires can have intensities as high as 60,000 kW/m (Luke and McArthur 1978) or, based on the Ash Wednesday fires, even higher (Cheney 1983). The Bemm River wildfire, with an estimated average intensity in the range 31,200 to 35,600 kW/m over a two hour period, was clearly an extremely severe wildfire.

The wildfire completely defoliated only small areas of forest, despite the high intensity and rates of spread. This means that a crown fire was not maintained during the main run of the wildfire. Cheney (1981) states that crown fires can develop in most forest types, particularly those with rough barked eucalypts, at intensities of 7,000 kW/m or less. The present wildfire, with a much higher intensity, appears to be unusual in this regard and may be similar to the Daylesford wildfire of the 16 January 1962 (McArthur 1968) and the devastating southern Tasmanian wildfires of the 7 February 1967 (Luke and McArthur 1978). The Daylesford wildfire burnt under "very high" and the southern Tasmanian wildfires burnt under "extreme" fire danger conditions, yet crown fire development was limited in both cases. High wind speed was a feature of both wildfires, averaging 45 km/h at the Daylesford wildfire and 55 km/h with gusts to 110 km/h at Hobart. Luke and McArthur (1978) suggest that at high wind speeds the flame angle becomes very acute and flames are prevented from remaining in the crowns.

The 10% moisture content of exposed surface and elevated eucalypt litter at mid afternoon on the first day of the Bemm River wildfire is moderate in comparison to a level of 7% or less which is considered dangerous (Luke and McArthur 1978). The profile moisture content of litter bed fuels, measured on the day prior to the wildfire, varied widely but was generally well above 20%, the level above which fuels are considered not to sustain combustion (Luke and McArthur 1978). Despite this, the rate of spread was very high, which suggests that fire behaviour was independent of a substantial part of the fuel profile. The profile fuels were consumed, but would have generated considerably less heat radiation (Vines 1981) than if the whole fuel complex had been dry. This implied reduction in "effective" fuel load is consistent with the lack of stem damage and the finding by Knight (1981) that heat absorbed by stems during a fire is correlated with fuel load rather than rate of spread. The only fuels which appear to have had a significant bearing on fire behaviour or fire damage are those which were elevated or on the litter bed surface.

The apparent underprediction of rate of spread by the McArthur Mk 5 Forest Fire Danger Meter for the second two hour period of the main run of the fire raises the question of possible errors in the inputs to the equation. For example, the fuel load may have been 5 tonnes/ha higher than that measured and the moisture content of the fine fuels may have been lower than that predicted by the McArthur Meter using the Orbost temperature and relative humidity data because of a lag in moisture content uptake (Luke and McArthur 1978) and the time delay in the rise in relative humidity at the fire area compared to Orbost. However, the wind speed had definitely decreased and, even if it had not, accounting for each of the above possible sources of error in combination still leaves an underprediction of a factor of about one half.

The aerated arrangement of the fuel type may have contributed to this discrepancy between the observed and predicted rate of spread, but this possibility is inconsistent with the comparable prediction of the initial two hour period. Luke and McArthur (1978) state that under severe burning conditions all fire behaviour characteristics tend to accelerate with time, with the rate of spread increasing in a series of steps, due largely to the progressive involvement of different fuel components, development of a convection column and initiation of the spotting process. The 1962 Daylesford wildfire exhibited similar acceleration to the Bemm River fire over a three hour period, with the average rate of spread of 3.2 km/h three times higher than that predicted by the McArthur Meter. McArthur (1967) attributes this to the dramatic effect of concentrated spotting from a stringybark eucalypt fuel type. A similar effect may have equally applied to the Bemm River wildfire but there was a reduced number of ignitions ahead of this wildfire prior to the wind change compared to the Daylesford wildfire. Unfortunately, the lack of a complete pattern of spot fire ignition and development prevents a conclusive statement. A further possibility is that a combination of high wind speed, spotting and the aerated fuel type may have resulted in a "large fire effect" and hence the observed increase in rate of spread of the fire front.

Underprediction of rates of spread by the McArthur Meter has been documented by Rawson *et al.* (1983), who report that for the devastating Deans Marsh-Lorne fire on Ash Wednesday, the rate of spread of 10.8 km/h before the wind change was almost three times greater than the rate predicted. Cheney (1983) concludes that the observed rates of spread for established wildfires burning under extreme conditions appear to be at least three times higher than those predicted by the McArthur Meter. The documentation of future severe wildfire behaviour should increase the knowledge of this important subject and allow the improvement of the predictive capacity of the McArthur Meter under "extreme" fire danger conditions.

Intense wildfires can cause loss of life and property, damage to eucalypts (for example see Appendix 1) and adverse affects on other forest values. The losses can be reduced by a rapid and effective suppression capability matched to an extensive access network and efficient detection system. However, the constraint facing forest fire control organizations in Australia is that direct attack on forest fires is generally effective only on wildfires of intensity less than 4,000 kW/m (Luke and McArthur 1978), which is within the lower range of intensity experienced in Australian conditions.

The Bemm River wildfire illustrates that even immediate on-site response to a wildfire can be ineffective. Additional protection from wildfire can be achieved by prescribed burning or fuel reduction burning. This is undertaken with the aim of reducing fuel hazards and is achieved (NBRU 1987) by reducing the total weight of fuels and hence the rate of spread and intensity, by reducing the height of the fuel bed hence reducing flame heights and by removing the fire brand material (stringybark or gum bark) from the trees and hence greatly reducing the potential of fires to generate spot fires ahead of the main fire.

The effectiveness of fuel reduction burning in modifying the fire behaviour of the Bemm River wildfire is shown by comparing the six burning units illustrated on the fire history map (Figure 2) with the crown scorch assessment map (Figure 6).

Available fuel and fire behaviour data for Area 1 are insufficient to enable interpretation of the scorch class assessment of the separate fire areas east of Bemm River. However, the level of fuel reduction achieved was insufficient to prevent the spread of the fires.

The main run of the wildfire prior to the wind change burnt intensely in Area 2. Fuel reduction operations conducted six months and one-and-a-half years prior to the wildfire, assessed as having covered the lower end of the 20-50% range, did not significantly alter the intense fire behaviour prior to the wind change but did reduce the extent of crown scorch to less than 50% (scorch class 2) in areas burnt after the wind change.

The main run of the wildfire crossed Area 3 while burning under extreme fire danger conditions, and resulted in complete crown scorch and some limited defoliation. The wildfire subsequently burnt in a north easterly direction after the wind change and caused measurably less damage within Area 3 than to adjacent forest. The crown scorch within Area 3 (scorch class 3) provides a clear comparison to the complete scorch affecting 50 to 100% of crowns (scorch class 1) in adjacent forest. The height of stem char was also significantly reduced within Area 3. Fire intensity under conditions of "high" fire danger was clearly reduced within the fuels that had accumulated over the seven years since fuel reduction, due probably to a sustained reduction in the amount of bark on the stringybark trees and a persistent change to the shrub fuel arrangement.

At the time of the wind change the north east flank of the wildfire was approximately 1.5 km from Area 4 and 2.5 km from Area 5. No data are available to enable the rate of spread to be calculated after the wind change, except to say that the decrease in wind speed and increase in relative humidity would have progressively decreased the rate of spread from the pre-change level. The fire which approached Areas 4 and 5 was of unknown intensity but fully scorched the crowns in adjacent forest and is likely to have been uncontrollable by direct attack. Both the six month old burn and the two-and-a-half year old burn prevented the spread of the fire within those areas.

The impact of fuel reduction burning which had achieved broad coverage on the main run of the wildfire can be seen in Area 6. The fire front approached Area 6 from the north west. Key areas of scorch are highlighted on Figure 6 with the notation 6a-6e. Area 6a was burnt intensely with full crown scorch (scorch class 1). However, a large reduction in fire intensity is apparent in Area 6b, downwind of Area 6a, with only the lower crowns scorched (scorch class 3). Intense fire behaviour redeveloped in Area 6c (scorch class 1) but Area 6d* was largely unburnt, which consequently halved the width of the fire front. The fuel reduction effect in Area 6e was apparently insufficient to prevent the redevelopment of intense fire behaviour as evidenced by the scorch class 2 classification. Overall, a one-and-a-half year old fuel reduction burn that had covered greater than 50% of the area caused a major reduction of both headfire intensity and fire front width of an extremely severe wildfire.

* Areas burnt in the Autumn 1987 fuel reduction burn and scorch class 3 areas which resulted from the wildfire are not separated by the scorch class interpretation. As a consequence, some areas not burnt by the wildfire in Area 6 are incorrectly shown as scorch class 3 rather than as unburnt.

The impact of fuel reduction burning on wildfire control has been reviewed by Billing (1981), Rawson (1983), Rawson *et al.* (1985) and Underwood *et al.* (1985), with actual case studies presented by these authors which highlight the effectiveness of burns of age six months to four years. Rawson (1983) states that the effectiveness of a fuel reduced area will depend upon the percentage of area on which fuel reduction has been achieved, the extent to which fuel has been reduced on the burnt sites, the distribution of burnt sites, and the rate at which fuel returns to the site. Rawson (1983) concludes that fuel reduction covering less than 50% of the area has little impact on wildfires burning under "very high" to "extreme" fire danger. Sneeuwjagt (1981) and Underwood *et al.* (1985) conclude that effective fuel reduction should cover 60-80% of the target area in average quality forests. Both these conclusions are supported by the data presented in this report.

Raison *et al.* (1983) state that there is no published information to suggest that any significant benefit in terms of wildfire control under difficult conditions occurs from prescribed burns more than three years old. Fuel accumulation data are presented by these authors that shows that in some Australian forest types litter accumulates to "dangerous" weights (12 tonnes/ha) in three to six years. The authors conclude that hazard reduction resulting from prescribed burning in the fuel types which rapidly reaccumulate will be very short lived. Data presented in this report strongly suggests that part of the protection afforded by fuel reduction is derived from the modification of the shrub layer and the bark on the stringybark trees, as well as the reduction of litter fuels. Fuel reduction which achieves broad coverage has demonstrated dramatic protection under "very high" fire danger conditions experienced during the Bemm River wildfire in fuels burnt one-and-a-half years previously. Similar protection was achieved under "high" fire danger conditions in fuels burnt six months and two-and-a-half years previously and a measurable effect was apparent in fuels burnt seven years previously. Even if the protection offered by a particular burn is not fully effective after three or four years, burns with good coverage provide substantially increased protection when compared with the alternative "no burn" strategy. The burning of adjacent units in a planned rotational fuel reduction program adds further to that protection.

Achieving the protection afforded by effective fuel reduction in coastal fuel types can, however, be difficult, as evidenced by the low coverage which had been obtained by aerial ignition operations in Area 2 of Figure 2 in 1987 and 1988 and Area 6 in 1985 and the excessive scorch which resulted from the ground ignition of Area 3 in 1981. Spring weather patterns which move rapidly and often result in a rapid increase in wind strength followed by a change in wind direction add further to operational difficulties. The combination of wind, slope and moisture content of the different strata of litter are the key factors which affect fire behaviour with lighting pattern also being significant at the indices of fire danger at which fuel reduction burning is conducted. Regrowth fire behaviour research can assist in improving this area of incomplete knowledge.

CONCLUSION

The Bemm River wildfire was an extremely severe wildfire with fire behaviour primarily influenced by gale force wind speeds and a highly flammable, aerated shrub fuel complex. In particular, the fire behaviour demonstrated that the fuel arrangement can be much more significant than the litter fuel load in determining fire hazard.

The prediction of rate of spread by the McArthur Mk 5 Forest Fire Danger Meter of an established wildfire burning under "very high" to "extreme" fire danger conditions can underestimate actual rate of spread by a factor of at least three. The meter appears not to take into account some unquantified effects which are associated with the behaviour of large and well developed fires.

Fuel reduction burning in the coastal forests of East Gippsland, with coverage of greater than 50%, provides excellent protection against wildfire spread for at least one-and-a-half years, and to a progressively decreasing extent, for longer periods of up to seven years.

As part of an integrated fire prevention and suppression program, fuel reduction is a key element in the protection of human life, private property and the forest itself.

ACKNOWLEDGEMENTS

I wish to acknowledge and thank the DCE Orbost and Bairnsdale Regional staff members who provided comments on aspects of fire weather, fire behaviour and fire suppression relevant to this report.

I gratefully acknowledge the critical comments and detailed suggestions on report format and content from Andrew Wilson, Senior Fire Research Officer, DCE and the comments of Phil Cheney, Principal Research Scientist, NBRU, CSIRO.

Grateful thanks are extended to Bairnsdale DCE Regional staff Julie Morrison, Deidre Murray and in particular Linda Youngs for word processing and Alicia McShane, Draughting Officer, for technical advice and assistance with map preparation.

Thanks also to Enrique Stucken, Research Officer, DCE Orbost for his interpretation of crown scorch classes in Figure 6 and to Melissa Ellis, Draughting Officer, DCE Orbost for draughting the original crown scorch class map.

REFERENCES

- Billing, P. (1981). The effectiveness of fuel reduction burning. Five case histories. Fire Research Branch Report No. 10. Forests Commission, Vic. (unpubl.) 13 pp.
- Bureau of Meteorology (1984). Observing the weather. Department of Science. A.G.P.S. Canberra. 49 pp.
- Byram, G. M. (1959). Combustion of forest fuels. In: Forest fire: control and use. Ed. by K. P. Davis. McGraw Hill, New York. pp. 61-89.
- Cheney, N. P. (1981). Fire Behaviour. In: Fire and the Australian biota. Ed. by A. M. Gill, R. H. Grove and I. R. Noble. Aust. Acad. Sci. Canberra. pp. 151-176.
- Cheney, N. P. (1983). Behaviour of fire in Australian forests. Proc. Aust. Nat. Fire Prot. Assoc. 9th Aust. Nat. Conf., Sydney, 14-16 Sept. 1983., paper "A". 12 pp.
- Dexter, B. D. (1975). Fire research burning guides. Division of Forest Protection. Forests Commission, Vic. (unpubl.).
- Incoll, W. D. (1981). Effects of wildfire on survival, growth, form and defect in *Eucalyptus obliqua* and *Eucalyptus sieberi* forests. Research Branch Report No. 180. Forests Commission, Vic. (unpubl.).
- Keetch, J. J. and Byram, G. M. (1968). A drought index for forest fire control. USDA For. Serv. Res. Pap. SE-38. 32 pp.
- Knight, I. K. (1981). A simple calorimeter for measuring the intensity of rural fires. Aust. For. Res. 11 : 173-7.
- Land Conservation Council (1974). East Gippsland study area report. Govt. Printer, Melbourne. 236 pp.
- Loane, I. T. and Gould, J. S. (1985). Aerial suppression of bushfires - cost benefit study for Victoria. CSIRO Division of Forest Research, Canberra. 213 pp.
- Luke, R. H., and McArthur, A. G. (1978). Bushfires in Australia. A.G.P.S., Canberra. 359 pp.
- McArthur, A. G. (1962). Control burning in eucalypt forests. Leaflet 80. Commonwealth of Aust. Forestry and Timber Bureau, Canberra. 31 pp.
- McArthur, A. G. (1967). Fire behaviour in eucalypt forests. Leaflet 107. Commonwealth of Aust. Forestry and Timber Bureau, Canberra. 36 pp.
- McArthur, A. G. (1968). The fire resistance of Eucalypts. Proc. Ecol. Soc. Aust. 3 : 83-90.
- NBRU (1987). The effectiveness of hazard reduction burning in reducing fire intensity and assisting fire control. CSIRO Division of Forest Research, Canberra. 3pp.
- Noble, I. R., Bary, G. A. V., Gill, A.M. (1980). McArthur's fire danger meters expressed as equations. Aust. J. Ecol. 5 : 201-203.

Raison, R. J., Woods, P. V. and Khanna, P. K. (1983). Fuel dynamics in recurrently burnt eucalypt forests. Proc. IFA 10th Tri. Conf., Melbourne, 29 Aug. - 2 Sept. 1983. pp. 59-64.

Rawson, R. P. (1983). Effects of fuel reduction burning on wildfire behaviour. In : Fighting Fire with Fire. Symposium on fuel reduction burning in forests, 17-18 Sept. 1983. Monash Uni., Melbourne. pp. 203-210.

Rawson, R. P., Billing, P. R. and Duncan, S. F. (1983). The 1982-83 forest fires in Victoria. Aust. For. 46(3) : 163-172.

Rawson, R. P., Billing, P. R. and Rees, B. (1985). Effectiveness of fuel reduction burning. Fire Research Branch Report No. 25. Forests Commission, Vic. (unpubl.) 49 pp.

Sneeuwjagt, R. J. (1981). The Eden fire and its implications for fire protection. IFA Newsletter 22(3): 8-14. Institute of Foresters of Australia, Canberra.

Underwood, R. J., Sneeuwjagt, R. J. and Styles, H. G. (1985). The contribution of prescribed burning to forest fire control in Western Australia : case studies. In : Symposium on "Fire Ecology and Management in Western Australian Ecosystems", May 1985. Ed. J. R. Ford. West. Aust. Instit. Tech. pp. 153-170.

Appendix 1

The effects of wildfire on eucalypt mortality, growth and defect are discussed by Luke and McArthur (1978), Loane and Gould (1986) and Incoll (1981). The paper by Incoll (1981) titled "Effects of Wildfire on Survival, Growth, Form and Defect in *Eucalyptus obliqua* and *Eucalyptus sieberi* Forests" is particularly relevant to the Bemm River wildfire. The following is a summary of the major points from Incoll's paper.

1. Stands of *Eucalyptus obliqua* (Messmate) and *Eucalyptus sieberi* (Silvertop) are seldom killed by wildfire; they survive by production of epicormics in the crown, or over the whole stem, or by the production of coppice or lignotuberous shoots (*Eucalyptus obliqua* only).
2. The degree of damage sustained depends primarily on the amount of crown scorched and the extent of cambial death.
3. Bark thickness rather than type is the important factor in protecting the cambium of eucalypts from lethal temperatures (McArthur, 1968).
4. Very severe wildfires are capable of causing significant mortality in young regeneration.
5. Old trees appear to be more susceptible to wildfire than trees of intermediate to mature age.
6. If the leading shoot survives, tree form is usually unaffected by wildfire. When the leader is killed, it remains as a dry spike and subsequent development of a new leading shoot from the live trunk below results in the formation of a stem kink.
7. Radial stem growth of both *Eucalyptus obliqua* and *Eucalyptus sieberi* is reduced when more than half of the tree crown is scorched. When the whole crown is scorched, basal area growth in the succeeding year may be reduced by 70-80%, but after 2-4 years annual basal area growth usually returns to that of unburnt stands.
8. Wildfire damage may lead to the formation of kino plates and the entry of decay though the relationship between fire severity and the amount of internal defect is not known.
9. The season in which burning occurs can also affect the degree of damage to trees. At times of vigorous growth, such as Spring, bark generally has a higher moisture content than in other seasons. McArthur (1968) suggests this moisture reduces the rate of heat flux through the bark and thereby reduces cambial damage.