Victorian 2009 Bushfire Research Response

Final Report

October 2009

Research results from February 7th 2009 Victorian Fires Findings on:

Fire Behaviour Investigation

This work was undertaken for the Bushfire CRC as part of the Post-fire Research Taskforce
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Fire Behaviour Investigation

This report into the investigation of behaviour of the fires of 7th February 2009 is based on the best available information at the time of writing and is subject to change if new evidence or information presented during the Royal Commission hearings or other reports on fire progression and behaviour that were not available to the Bushfire CRC taskforce become available.

1. Introduction

This section of the Bushfire CRC Report on the Victorian Bushfire Research Taskforce summarises field data collected by the Fire Behaviour Investigation Team during a five week period following the 7th February Victorian bushfires. These data primarily consist of information based on *in situ* observations of scorched leaf freeze angle that, in conjunction with other information about the time and location of the bushfires not collected in this research, may be used to reconstruct the passage of the fires. Data reported here does not of itself provide information about the direction of spread or speed of the bushfires, but provides visual cues for the likely behaviour and spread of the bushfires that must be confirmed by other means that may include video and/or still imagery, and interviews with firefighting personnel and residents who witnessed the passage of the fires.

The data are presented along with ancillary information in order to provide context for both the data and the events of 7th February. This ancillary information includes information about the nature of fire behaviour and methods for predicting it, antecedent weather and fuel conditions leading up to 7th February, and discussion of other significant bushfire events that have occurred in south-eastern Australia.

2. Background information

2.1 Fundamentals of bushfire behaviour

Bushfire behaviour is everything a bushfire does. It covers the way a bushfire ignites, develops and grows, its rate of spread, the characteristics of the flame front and all other phenomena associated with the moving fire front. Most of the research effort in bushfire behaviour has focused on prediction of forward rate of spread, the dimension of the flames and the likelihood of firebrands being thrown ahead of the fire to start new fires (i.e. spotfires). To date, it has not been possible to apply traditional physical theory to the prediction of fire spread. The problem involves a chaotic chemical reaction (combustion) moving through a fuel bed that varies spatially in three dimensions, across a variable topography and interacting with a turbulent atmosphere (principally the wind) that varies widely both in space and time. Prediction of bushfire behaviour at any specific point in space or time usually has a wide margin of error because it is difficult to know the fuel that will be consumed, the direction and speed of the wind that will affect the combustion process at that point, and the interactions of all the processes involved in determining the behaviour of a bushfire.

Notwithstanding this, as a bushfire builds up from ignition, it does reach a quasi-steady rate of spread that can be correlated to some mean value or characteristics of the fuel and the mean wind speed measured at a standard location. The error in prediction is reduced by selecting a suitable period of time (often 30 minutes or more) to encompass the inherent variation in wind and fuel. Key factors that influence fire spread are the fuel characteristics, the moisture content of the dead fuel, the slope of the ground, the wind speed and its orientation to the fire. Mostly, predictions are made for the fastest moving part of the fire called the head fire which spreads generally in the direction of the wind.

2.2 Fuel

Fuel is a generic term for anything that combusts and provides energy to the fire. In a bushfire fuel is generally formed by the vegetation: leaves, bark, twigs, branches, trees, etc. Not all this fuel will be consumed in all bushfires. The availability of fuel is determined by its combustibility as well as the intensity of the fire. Higher intensity fires will consume larger and taller fuel elements than a lower intensity fire, for example.

The characteristics of the fuel that influence the spread and behaviour of a bushfire are primarily those factors that influence the speed of ignition of the fuel particle and the length of the flame. These include:

- fineness of the fuel particle (the finer the particle the faster it will ignite);
- height of the fuel bed (the higher the fuel bed the longer the flames);
- compactness of the fuel bed which determines whether the fire first burns across the top of the fuel bed and then down into lower layers or whether the fuel is mostly consumed at the same time. There is an optimum compaction that yields the maximum rate of spread:
  - if the fuel is too compact the fire will spread slowly; or,
  - if the fuel is too widely spaced the flames from one fuel particle cannot easily heat and ignite the next fuel particle;
- amount of water held by the dead fuel, determined by the antecedent weather conditions;
- fraction of live to dead material (green material generally has a moisture level greater than 120 percent ODW and must be dried out by fire before it will burn. Green material can act as both a damper to fire spread or it can contribute to the length of flame particularly if it is fine and elevated above the surface fuel; after prolonged drought the live moisture content can reduce to 80% and require less heat for ignition);
- total amount of fuel consumed; and,
- continuity of the fuel bed.

These factors are difficult to describe numerically in detail across the landscape. To overcome this, fuel may be grouped into specific types with similar characteristics (e.g. grassland, scrubland (heath) and forest fuel) and a number of conventions have been adopted. It is generally accepted that the fuel contributing most to the flame front, and thereby contributes to the heat flux that ignites new fuel is the fine fuel <6mm diameter. Fuel larger than this diameter either does not ignite or burns well behind the leading edge of the fire and does not contribute to the flame front.

Although these groupings and conventions may be seen as an over-simplification of the structure of fuels it has allowed the amount of fine fuel (i.e. fine fuel load) to be a predictor variable for fire spread and has appeared to work reasonably well provided it was used only for prediction in a specific fuel type (McArthur 1967, Sneeuwjagt and Peet 1985 but see also McCaw *et al*. 2008). In the case of grasslands, experimental studies have shown that the height of the grass sward has a greater effect on fire behavior than does the fuel load (Cheney and Sullivan 2008). For the purpose of fire behavior prediction the CSIRO Grassland Fire Spread Model recognizes three separate fuel states (natural, grazed and eaten-out) that represent different conditions of grass fuel height and continuity.

Fuel that remains unburnt or partially burnt after the passage of a bushfire can provide an indication of the likely behaviour and intensity of fire front as it passed, although it is not possible to determine whether fuel that was burnt was consumed during the passage of the front or afterwards.

2.3 Weather

Important weather variables that influence the spread and behaviour of a bushfire are those that determine the moisture content of the dead fuel (dictating the combustibility and amount of fuel available) and those that provide the dynamic force to drive the fire forward. These are:

2.3.1 Rainfall

The amount and duration of rain not only determines the immediate moisture content of the fine fuel but also, over a longer period, determines the amount and type of available fuel. Several indices of drought have been developed to predict the amount of forest fuel available for combustion. The level of drought determines the seasonal severity of fire season and the potential for conflagration fires in either forest or grasslands. Fires can burn severely in dry forest early in the season before grass has fully cured and is capable of carrying a moving fire (e.g. Linton fire Victoria, December 1998).

A conflagration grassfire can occur after a short drought period of 6–8 weeks following senescence in which all grasses become fully cured, usually after a wet spring provided abundant grass growth (McArthur 1966). Under these conditions the tall wet forests and montane forests are usually too moist to support a severe fire.

After a period of prolonged drought, all surface fuels in forests may become available to be burnt, including those in tall wet forests and forests in montane areas. Natural barriers such as wet soaks, swamps, riparian areas and shallow lakes, that may be effective in stopping a bushfire in a normal fire season, dry out and become less effective in stopping a bushfire. Fires can then become extremely difficult to suppress even under mild weather conditions. During these seasons grasslands are usually heavily grazed and eaten-out and grassfires will spread relatively slowly and be relatively easy to suppress.

2.3.2 Air temperature and relative humidity

These weather variables determine the moisture content of the dead fuel through the uptake of water vapour from the atmosphere and moisture from soils. Air temperature and relative humidity generally follow a diurnal cycle, with air temperature increasing throughout the day, peaking in mid-afternoon and then decreasing. Relative humidity mirrors air temperature, decreasing through the day, typically reaching a minimum in mid-afternoon and then increasing during the night. Uptake of moisture in fuels lags behind the change in temperature and relative humidity meaning that fuels may be most moist at night and driest in the late afternoon. See Section 2.6 for more information on fuel moisture content.

2.3.3 Wind

The wind speed is the dynamic force that drives a bushfire forward. Wind can change in strength and direction extremely rapidly due to turbulence in the atmospheric boundary layer. Both forest and grass fires will respond almost immediately to changes in wind.

Other weather variables that affect fire behaviour include solar radiation, atmospheric stability and upper wind strength. The interaction between the convection of the fire and the wind field above the fire can influence the surface wind in and around the combustion zone. This interaction is poorly understood and future advances in fire behaviour understanding will probably come through research that links the convection of the fire to the circulation in the lower atmosphere.

2.4 Drought Index

There are two systems for assessing seasonal dryness that are used in Australia. These are the Keetch-Byram drought index (KBDI) (Keetch and Byram 1968) and the Mount soil dryness index (SDI) (Mount 1972). Both systems employ a bookkeeping method for tracking soil moisture loss and recharge and use simplified evapo-transpiration relationships based on daily maximum temperature to estimate moisture loss and daily rainfall corrected for interception by forest canopies for recharge.

The KBDI has a scale of 0-200 mm (0 = soil at field capacity, 200 = soil at wilting point moisture). Correlation of the index with forest fire behaviour was made by A G McArthur in South Eastern NSW in 1965 (McArthur 1966). McArthur observed that severe forest fires in mountain country occurred when the drought index exceeded 100 mm when all the fine fuel and much of the course fuel on the forest floor dried out sufficiently to burn regardless of its position in the terrain. McArthur also found that when the KBDI did not reduce to zero for two or three months over the winter period, severe forest fires could be expected at an index value less than a hundred the following spring and summer. The KBDI was introduced into operational practice in Australia in 1966. The Mount SDI is used in Tasmania and Western Australia where it has been calibrated against soil and woody fuel moisture content and correlated with the extent of fuel removal and difficulty of fire suppression (Burrows 1987).

2.5 Drought Factor

The McArthur forest fire danger rating system (McArthur 1967) uses a short-term index of fuel dryness, called the drought factor, to reflect the effect of recent rainfall on the amount of fuel that is available for burning. This index has a scale of 1 to 10 where a drought factor of 10 is reached when the Keetch-Byram drought index exceeds 100 and there has been no recent rain. This means that all the fine fuel within the fuel bed is available for burning. The drought factor is not increased above 10 even though the Keetch-Byram drought index may rise higher. Although large logs continue to dry out as the severity of drought increases (and dams dry out and eventually trees die) the total amount of combustible fine fuel on the ground does not increase as it is already available.

Rainfall events can reduce the drought factor without substantially reducing the Keetch-Byram drought index. Generalised drying curves for litter beds reduce the impact of rainfall events with time after the rain.

2.6 Diurnal Change of Fine Fuel Moisture

The moisture held in the fine fuel (litter, twigs and bark less than 6 mm thickness) is determined by the water vapour in the atmosphere and is correlated with ambient temperature and relative humidity. The amount of moisture that can be held in a fuel particle in the field ranges from a minimum of about 3% to around 35% when the fibres of the fuel particle become saturated and free moisture forms between the fuel particles. At a fuel moisture level around 20% combustion cannot be sustained and fires in grass or eucalypt litter will die out. This moisture level can be increased through the actions of wind.

As noted previously, air temperature and relative humidity exhibit a diurnal variation as the land surface is heated by the sun. Air temperature typically reaches a maximum in mid to late afternoon and a minimum around 0600 hours in the morning, although this pattern can be modified significantly by the prevailing wind direction and local terrain influences. Diurnal change in relative humidity mirrors the change in temperature. The pattern of change of fuel moisture in eucalypt litter and other fine fuel is similar to that of humidity but lags by two or three hours. This change in moisture means that the fire danger also exhibits a diurnal fluctuation and although the drought indices maybe high the fire danger can drop to a low level at night when the fine fuels have absorbed sufficient moisture so that they cannot burn.

The importance of the high drought index is that large fuel components such as branches, logs or hollow standing trees do not respond to the diurnal change in moisture and once alight remain burning through the night and can provide numerous ignition points to ignite the entire fire perimeter when the fine fuels start to dry out during the morning.

2.7 Topography

The interaction of weather, fuel and the fire within the landscape is very complex. Terrain can have a dramatic effect on the speed and direction of the wind near the ground. Gullys and valleys can channel wind flow, establishing local wind directions and conditions. Mountain ranges will lift surface winds to higher altitudes, changing the temperature and moisture in the air. Wind speed will be accelerated on windward slopes so that ridge-top winds will be stronger than winds in free air of the same level. Separation of wind flow across hills and ridges can generate turbulence and flow contrary to prevailing synoptic winds on leeward slopes. Under strong winds it is very difficult to predict the direction and strength of winds in the valley and lee slopes of rugged terrain.

The two features of the topography that most influence fire behaviour are aspect and slope:

2.7.1 Aspect

Aspect dictates the amount of solar radiation received by surface fuels. In the southern hemisphere north facing aspects will receive more solar radiation than south facing aspects. Early in the fire season the aspect of the terrain has a strong influence on the moisture content of forest fuel. Southerly and easterly aspects will dry slower than northerly and westerly aspects. In mild fire seasons southerly aspects may remain moist and fires will burn slowly throughout the summer. However, after a period of moderate drought and by early summer fuel on all aspects may become uniformly dry so that the main influence on fire behaviour is then the orientation of the aspect to the prevailing wind.

2.7.2 Slope

The slope of the ground, when aligned with the direction of the prevailing wind, has a strong influence on fire behaviour. The rate of spread of a fire up a slope of 10 degrees will generally be double the rate of spread of the fire on level ground and up a slope of 20 degrees will generally be four times the rate of spread of the fire on level ground.

The interaction between the wind, the terrain and the convection from the fire is complex but generally under low wind speeds, the direction of fire spread is largely dominated by the slope of the terrain and fires can spread rapidly upslope in the opposite direction to the prevailing wind. Under high wind speeds the direction of spread is dominated by the wind direction. In forest fuels, the process of spotting (fire brands being carried a head of the main fire that start new fires) allows the fire to spread rapidly across the topography and overcomes the retarding effect of a negative (in the direction of the wind) slope.

2.8 Fire intensity

Fire intensity is a calculated number that represents the rate at which heat is released from a lineal segment of the fire perimeter. Expressed in kilowatts per metre of fire edge (kW/m), it is given by the equation:

$$I = H \times w \times R$$

where H is that the yield of the fuel burnt (kJ/kg), w is the amount of fuel consumed (kg/m2), and R is the rate of spread (m/s).

The intensity of the fire varies around the perimeter because the rate of spread of each section of fire perimeter varies depending on its location in relation to the prevailing wind. At the head of the fire where the rate of spread is greatest the fire intensity is greatest, and that the back of the fire where the rate of spread is least the intensity is least. Fire intensity is normally quoted for the head fire unless otherwise specified and is the maximum for the whole perimeter.

The intensity of a grass fire may range from 10 kW/m for a slow-moving backing fire in light fuels to around 60,000 kW/m at the head of a very fast wildfire. The intensity of a forest fire can range from 50 kW/m to a maximum of around 100,000 kW/m for a fire burning under extreme fire danger conditions in heavy fuels.

The calculated fire intensity figure is useful for comparing fires in the same fuel type. However, because fire behaviour and a rate of spread depends on the structure of fuel as well as the available fuel load, fires in fuels that are structurally very different will have very different fire behaviour for the same calculated fire intensity. Nevertheless, fire intensity is useful to illustrate the changes in fire behaviour such as flame height and length and for providing estimates of capacity for suppression by different techniques in the same forest type.

3. Fire weather conditions of 7th February 2009 – Overview

This report presents an overview of the fire weather conditions leading up to and including the 7th February 2009 and is based on data sourced from the Bureau of Meteorology. For a more comprehensive analysis of climate and weather relevant to the fires readers are referred to the report to the Royal Commission prepared by the Bureau of Meteorology (2009).

3.1 Rainfall

There is a strong association between drought and the occurrence of major bushfires in central and eastern Victoria. Monthly rainfall observations for the period March 2008 to February 2009 at Toorourrong Reservoir (elevation 219 m above sea level (ASL)) (Fig.FB-1) and Wallaby Creek (488 m ASL) (Fig. FB-2) are used to illustrate rainfall patterns at low and medium elevation sites within the Kilmore East fire complex as an example of general rainfall patterns across fire-affected areas of central Victoria. Both sites have a long and reliable observation record with continuous records since 1885 at Wallaby Creek and since 1893 at Toorourrong Reservoir.

Rainfall was below normal at both these sites during 2008:

- annual rainfall in 2008 at Toorourrong Reservoir was 663 mm compared with long term median rainfall of 814 mm. Rainfall was below normal during autumn and early spring but above normal in November and December with monthly totals of 104 mm and 96 mm respectively. Only 1 mm was recorded during January 2009 compared with the long term median rainfall for January of 55 mm .
- annual rainfall in 2008 at Wallaby Creek was 940 mm compared with long term median rainfall of 1223 mm. Rainfall was below normal during autumn and early spring but above normal in November and December with monthly totals of 146 mm and 117 mm respectively. Only 2.8 mm was recorded during January 2009 much less than the long term median rainfall for January of 60 mm .

The cumulative effect of successive years of below normal rainfall in the decade prior to 2009 is likely to have significantly affected groundwater levels, soil moisture and the dryness of large dead woody fuels such as stumps and fallen logs. For the decade January 1999 to December 2008 cumulative annual rainfall was 885 mm below normal at Toorourrong Reservoir and 1877 mm below normal at Wallaby Creek. This trend of cumulative rainfall deficit is exhibited across most of Victoria with the 12 year period from February 1997 to January 2009 being very much below average or lowest on record (Bureau of Meteorology 2009)

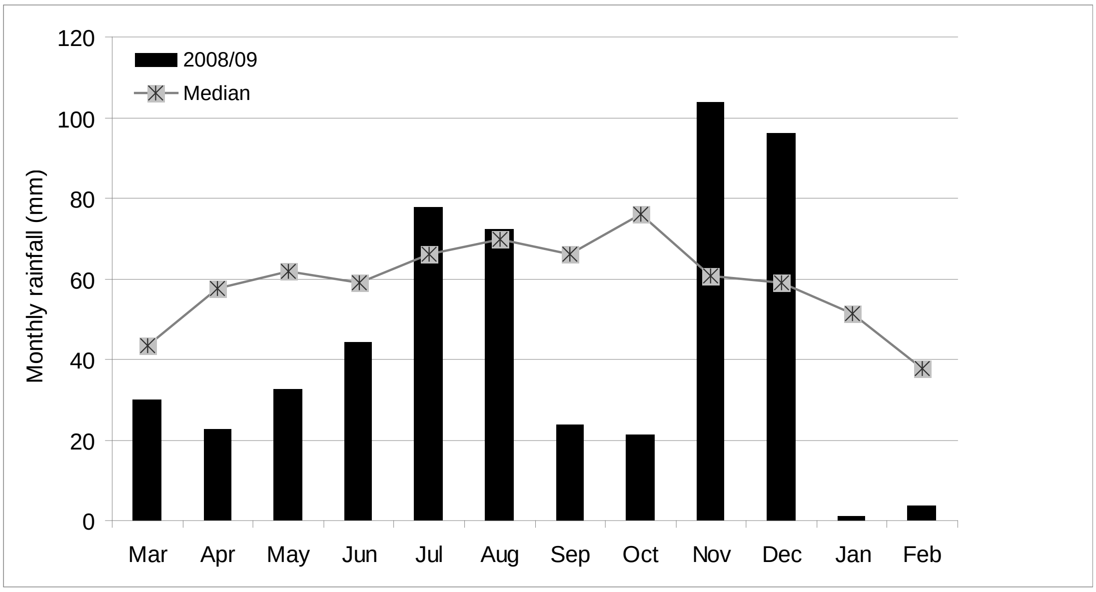


Figure FB-1. Observed rainfall (mm) at Toorourrong Reservoir for the period March 2008 to February 2009 compared with long-term monthly median rainfall (1893 to 2009).

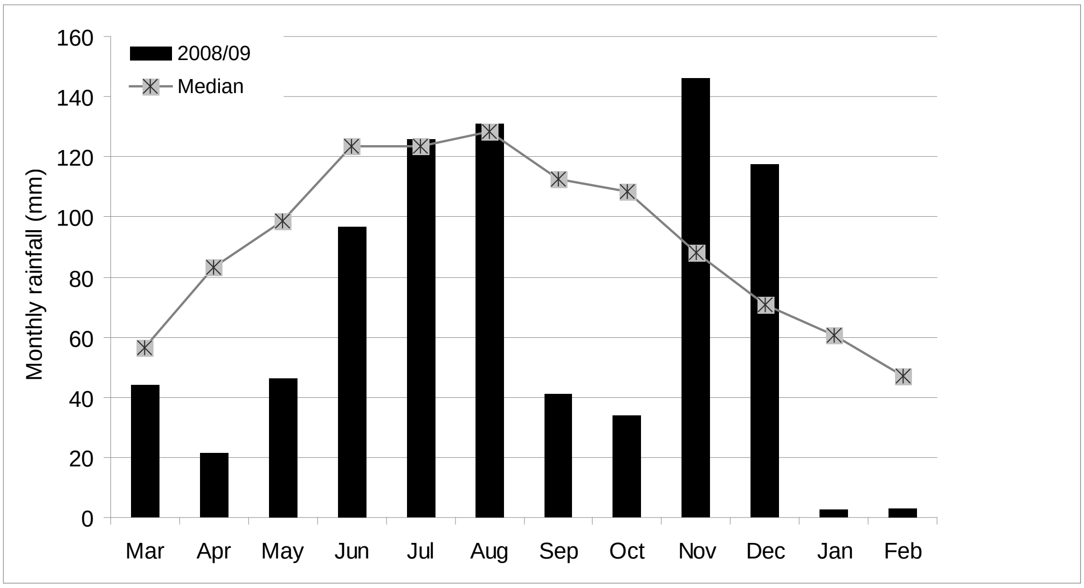


Figure FB-2. Observed rainfall (mm) at Wallaby Creek for the period March 2008 to February 2009 compared with monthly median rainfall (1885 to 2009).

3.2 Drought and fuel dryness

Gridded data at 10 km resolution provided by the Bureau of Meteorology showed that on 7 February 2009 the area north and east of Melbourne had KBDI values greater than 100 with a localized area in the Yarra Valley at values between 125 and 150 (Fig. FB-3). These values are at least 50 points above the normal level expected at this time of year.

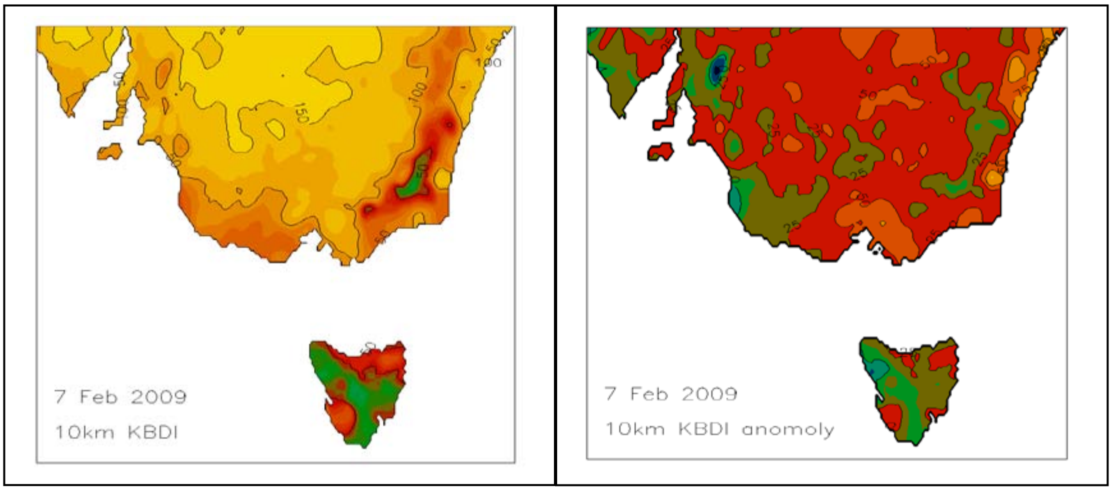


Figure FB-3. Keetch Byram Drought Index for south-eastern Australia on 7 February 2009 showing calculated actual value (left) and daily anomaly (right). Contours show values for actual and anomaly (Source: BoM 2009). Data are calculated from gridded fields of rainfall and maximum temperature. Contours show values for actual and anomaly values. For actual KBDI, green shading indicates low values (<50) and yellow shading indicate high values (>150). For KBDI anomaly green shading indicates small anomaly (<25) and orange shading indicates large anomaly (>50).

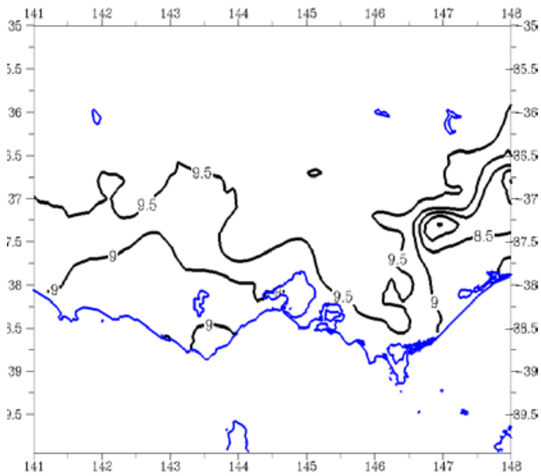


Figure FB-4. Drought Factor for south-eastern Australia on 7 February 2009 (Source: BoM 2009).

Most of Victoria had a DF of 9.5 or greater on 7 February 2009 except for parts of the Otways and the Alpine area (Fig. FB-4). This indicates a high level of potential fuel availability in open eucalypt forests.

3.3 Grass curing

Grass curing maps prepared from NOAA satellite imagery (Fig. FB-5) showed that by 7th February grasslands and pastures in the north and west of the state were approaching full curing (>95%). Curing ranged from 65% to >95% in the Upper Plenty Valley, Yarra Valley, eastern parts of the Goulburn Valley and Gippsland. The level of grass curing in early February in pastures at the base of the Hume Range escarpment is illustrated in Fig. FB-6. Curing was less advanced at higher elevation sites in central Victoria which had remained moister and cooler during January, and in moist sites along rivers and gullies (Fig. FB-7).

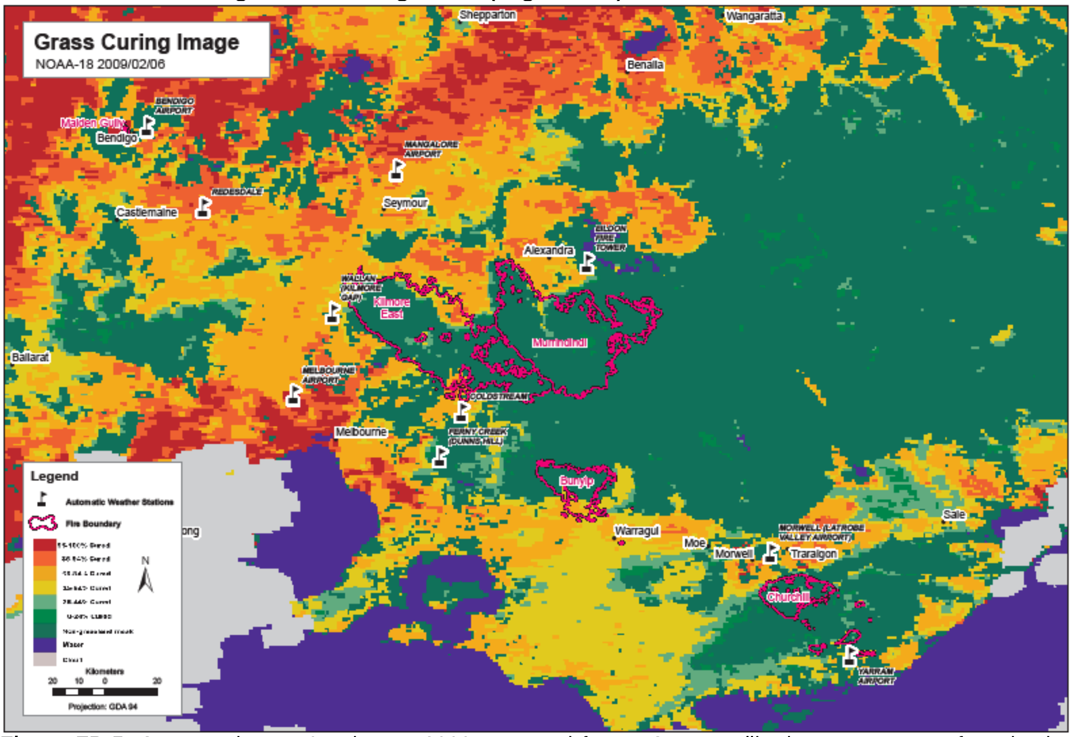


Figure FB-5. Grass curing on 6 February 2009 assessed from NOAA satellite imagery. Areas of predominantly forest vegetation cover are covered by a non-grassland mask.


Figure FB-6. View north east towards the escarpment of the Hume Range adjacent to the southern edge of the Kilmore East fire showing unburnt fully cured pasture at low elevation. Photo taken 15 February 2009.

Figure FB-7. Pasture at Kinglake West within the Kilmore East fire showing evidence of incomplete curing (curing estimated to be ~40-60%) sufficient to limit fire spread on 7 February. The direction of fire spread was from the right to left side of the photo (SW to NE) and partial and incomplete combustion can be seen in the paddock to the right. Photo taken 15 February 2009.

4. Weather on 7 February 2009

4.1 Upper atmospheric conditions

Temperatures throughout Victoria were very high, exceeding 45°C in many places (Bureau of Meteorology 2009). Much of the reason for this was a deep pool of very hot air over the southeastern part of Australia that had been generated over the previous few days. A consequence was that during the day over central Victoria once temperatures reached about 41-42°C, dry convective thermals would mix freely from the surface to above 5 km. This surface-based layer in which free convective mixing can occur is known as the *mixed layer*.

The vertical profile of temperature and humidity through the atmosphere observed by the Melbourne Airport radiosonde at 0000 UTC (1100 EDST) on 7 February 2009 is shown in Fig. FB-8. This shows the temperature (right hand red line) and dewpoint temperature (left-hand red line) as a function of pressure (ordinate, brown labels) with a height scale shown in black. The temperature axis is “skewed” to compensate for the normal decrease of temperature with height in the atmosphere. Dashed green lines running from lower right to upper left are the “dry adiabats”, and are the temperature that a parcel lifted from the surface would be if it were lifted to that height. Thus the closer the slope of the environmental temperature profile (the right hand red line) is to that of the dry adiabat; the easier it is for air parcels to mix in the vertical.

The environmental temperature profile at Melbourne Airport at 1100 EDST on 7th February 2009 shows a shallow slightly cooler and moister layer below about 1 km (point A), but between A and B (at about 3.5km) there is essentially a well mixed layer, and with little increase in stability above that level. Once the temperature exceeded 41°C, which occurred a little after 1130 EDST at Melbourne Airport, the surface air could mix to at least B on the profile (gray line), and by the time the maximum temperature was reached (above 45°C, point C), air parcels could mix without inhibition from the surface to above 5km (point D).

The winds observed at the same time are plotted on the right hand side of Figure FB-8. In these plots the units of speed are knots (1 knot = 1.85 km/hr), with a short barb representing 5 knots, a full barb representing 10 knots, and a flag (a filled triangle) representing 50 knots. While the shallow cool layer persisted, the winds below 1 km were northerly, but above that level they backed to northwesterly, with speeds through the layer between 1 and 5km of 35-45 knots. Once the shallow slightly cooler layer eroded, these winds would mix down to the ground as gusts. Thus after 1130 EDST the wind direction at Melbourne Airport began to back from northerly to northwesterly, as this momentum was mixed to the surface (Fig. FB-9). This same backing of the wind during the day, and up to the time of the abrupt wind change, was observed at most AWS through central Victoria.

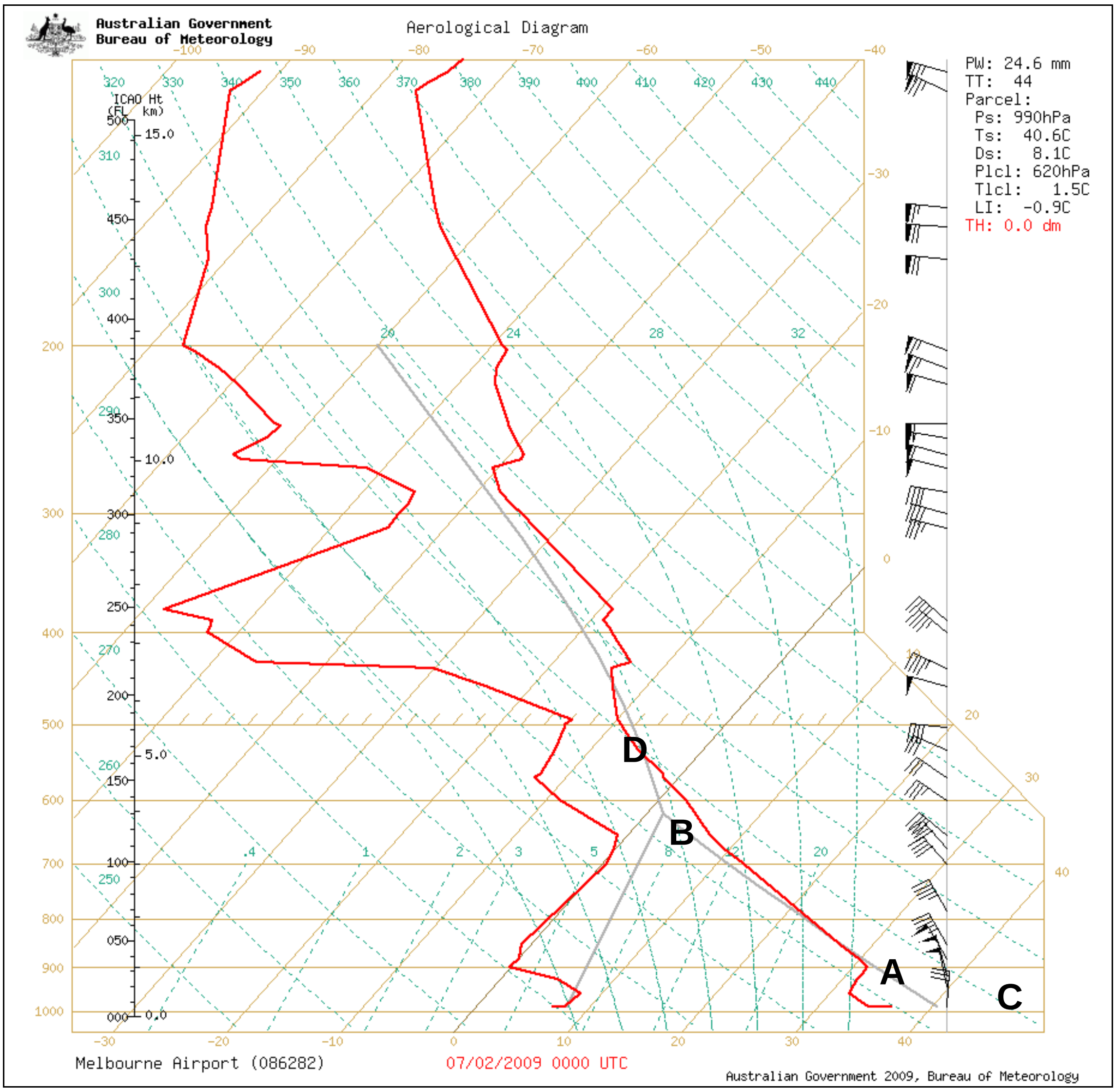


Figure FB-8. Melbourne Airport radiosonde observations of vertical temperature, humidity, and wind speed and direction at 1100 EDST 7 February 2009. (Source: BoM 2009)

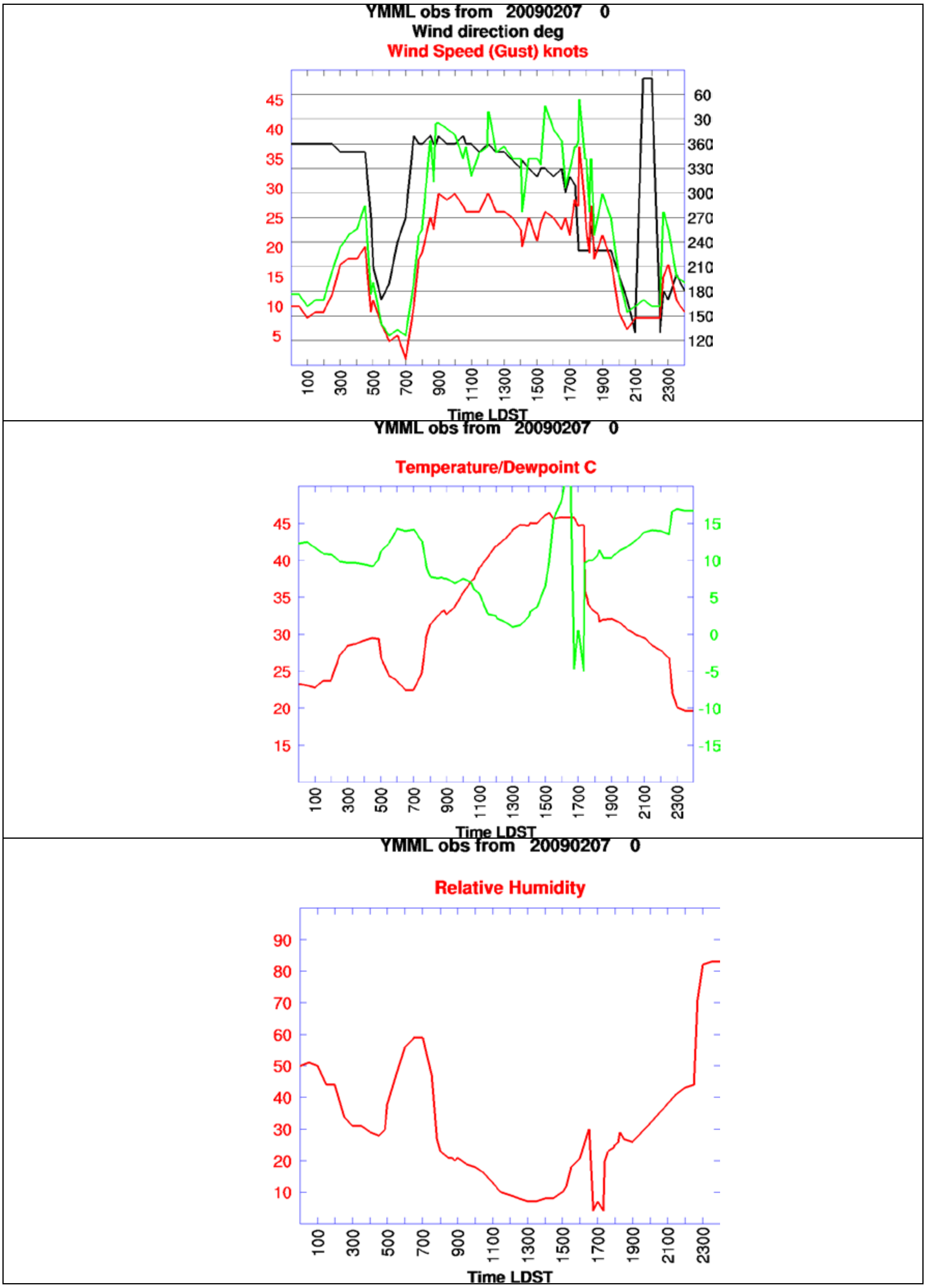


Figure FB-9. Time-series plots of observations from Melbourne Airport AWS, from 0000 EDST 7 February to 0000 EDST 8 February 2009. Upper panel wind direction (degrees, black), wind speed (knots, red), and gust speed (knots, green). Middle panel temperature (°C, red) and dewpoint (°C, green). Lower panel relative humidity, percent. Note that humidity observations are erroneous from around 1500 to 1645. (Source: BoM 2009)

4.2 Surface weather observations

Observations from 11 Bureau of Meteorology automatic weather stations (AWS) relevant to the fires are presented in Figure **FB-**10. See Figure **FB-**5 for a map of the AWS locations.

Figure FB-10 a and b (Bendigo Airport and Redesdale) are the closest AWS to the Maiden Gully fire.

Figure FB-10 c (Dunns Hill) is the closest AWS to the Bunyip fire, although Morwell is also relevant here.

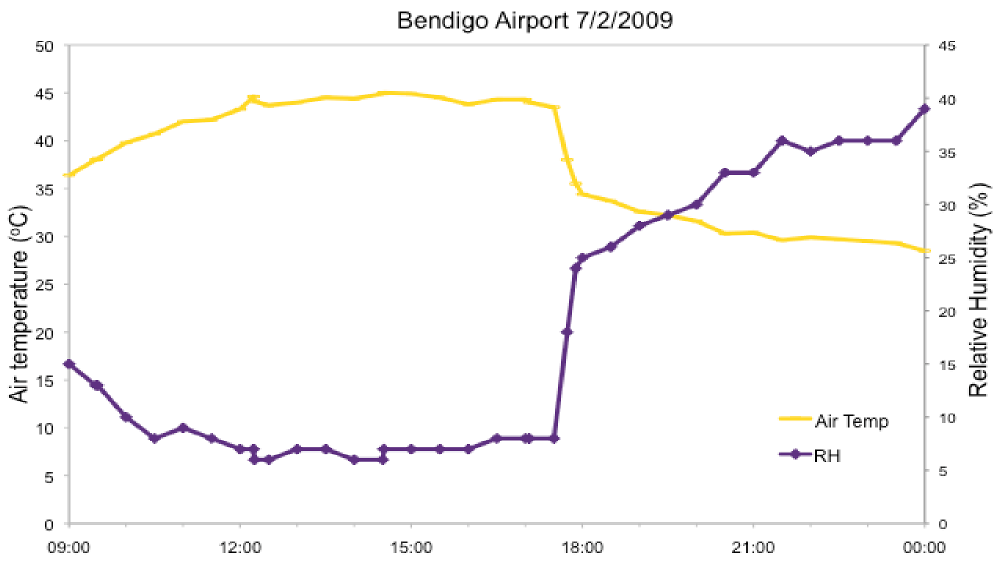
Figure FB-10 d and e (Morwell and Yarram) are the closest AWS to the Churchill fire.

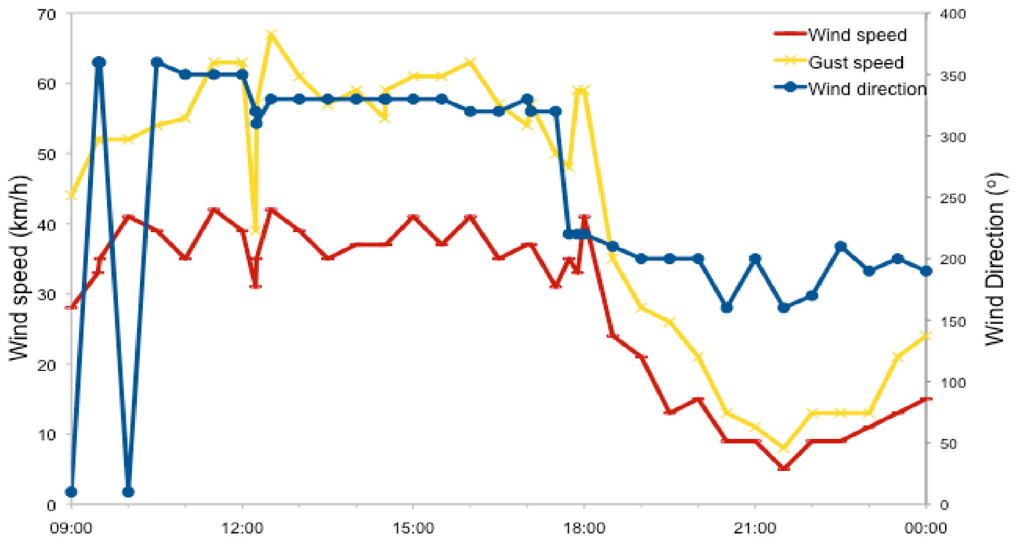
Figure FB-10 f and g (Kilmore Gap and Mangalore) are the closest AWS to the Kilmore East fire.

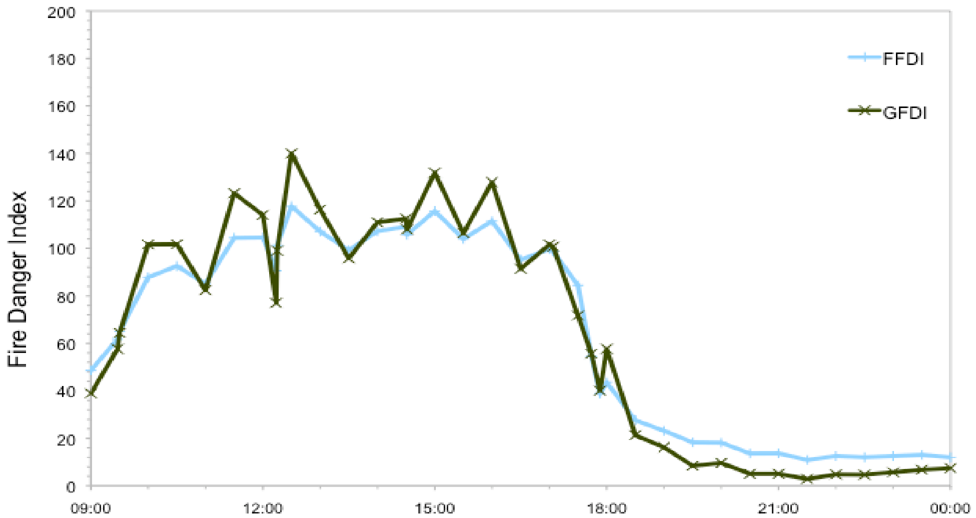
Figure FB-10 h and i (Eildon Fire Tower and Coldstream) are the closest AWS to the Yea-Murrundindi fire (although Figure 10 g may also be appropriate later in the life of the fire).

Close study of the wind direction of each AWS reveals the time of arrival of the wind change at each station. Often the wind change was associated with an increase in the strength of the wind but in some cases there was a dramatic drop in the wind speed soon after the change.

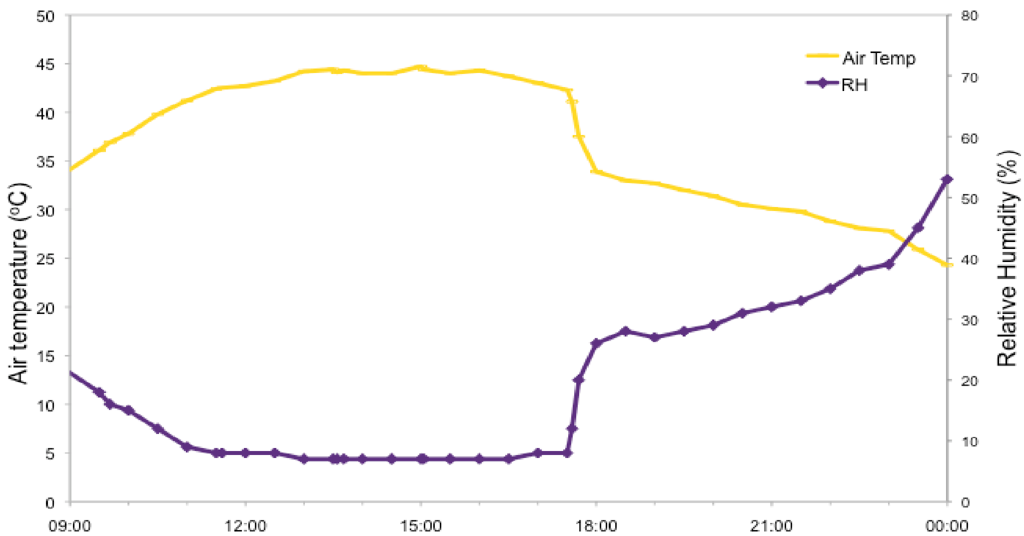
Forest Fire Danger Index (FFDI) and Grassland Fire Danger Index (GFDI) (Noble *et al.* 1980) are also presented for each AWS. Generally speaking, both fire danger indices increase from mid- to late-morning and decrease by early evening. Peaks in FDI correspond to peaks in wind speed and thus follow the peak and trough gust structure of the wind. GFDI are lower than FFDI at some sites due to grass curing being less than 100%.







Redesdale 7/2/2009



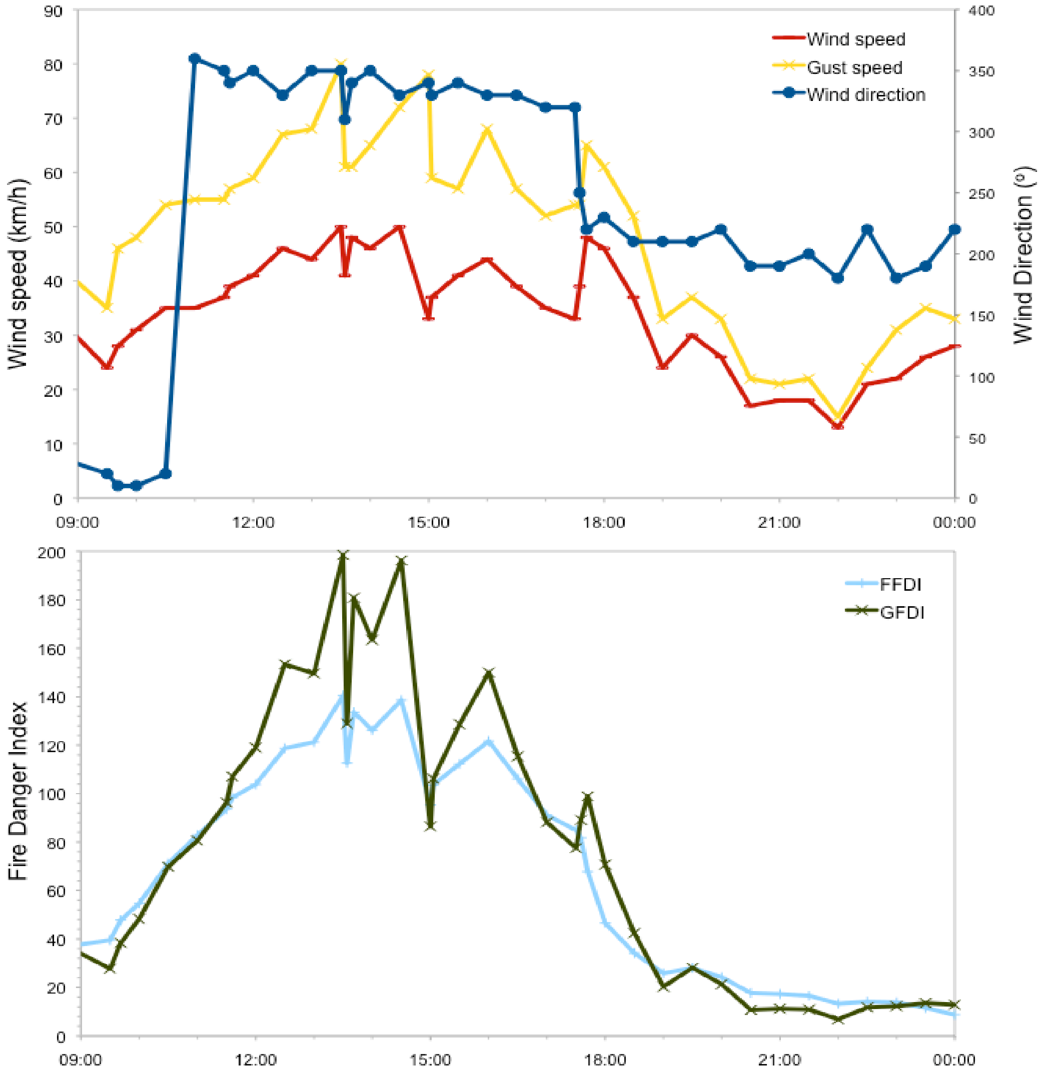


Figure FB-10b. Maiden Gully Fire: Redesdale AWS data for 7 February 2009 from 0900 hours to midnight: Air temperature and Relative Humidity (RH) (top), mean wind speed, maximum gust wind speed and wind direction (middle), and Forest Fire Danger Index (FFDI) and Grassland Fire Danger Index (GFDI) (bottom). The wind shifted to SW at about 17:35 hours and was associated with a rapid decrease in air temperature and corresponding increase in RH. Winds remained strong and gusty. (Source: BoM)

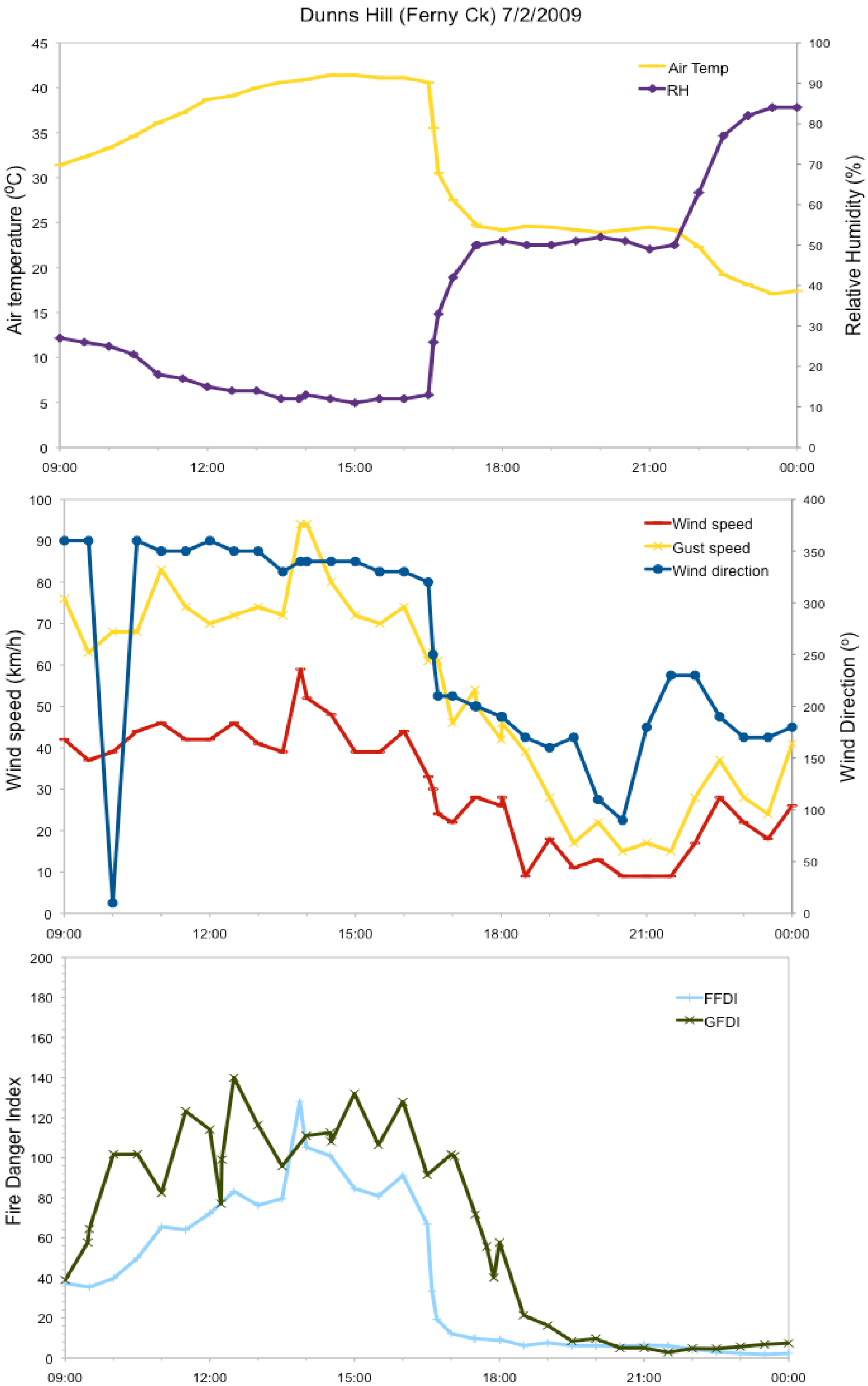


Figure FB-10c. Bunyip Fire: Dunns Hill AWS data for February 7, 2009 from 0900 hours to midnight: Air temperature and Relative Humidity (RH) (top), mean wind speed, maximum gust wind speed and wind direction (middle), and Forest Fire Danger Index (FFDI) and Grassland Fire Danger Index (GFDI) (bottom). The wind shifted to SW at about 16:36 hours and was associated with a rapid decrease in air temperature and corresponding increase in RH. Winds remained strong and gusty briefly following the change and then declined until 20:30 before increasing again. (Source: BoM)

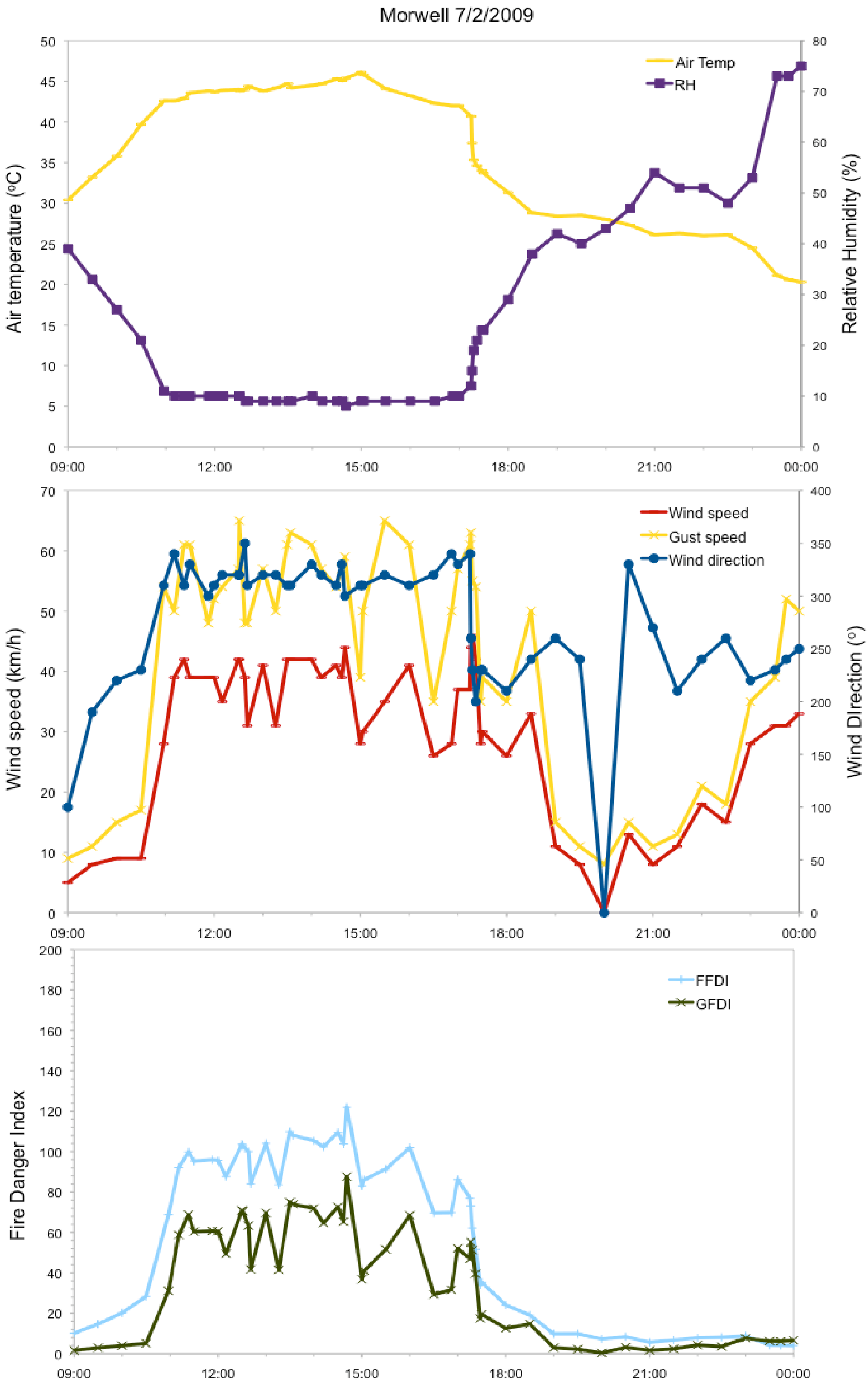


Figure FB-10d. Churchill Fire: Morwell AWS data for February 7, 2009 from 0900 hours to midnight: Air temperature and Relative Humidity (RH) (top), mean wind speed, maximum gust wind speed and wind direction (middle), and Forest Fire Danger Index (FFDI) and Grassland Fire Danger Index (GFDI) (bottom). The wind shifted to SW at about 1716 hours and was associated with a rapid decrease in air temperature and corresponding increase in RH. Winds remained strong and gusty for an hour or so before becoming light and variable in the evening. Speeds picked up again towards midnight. (Source: BoM)

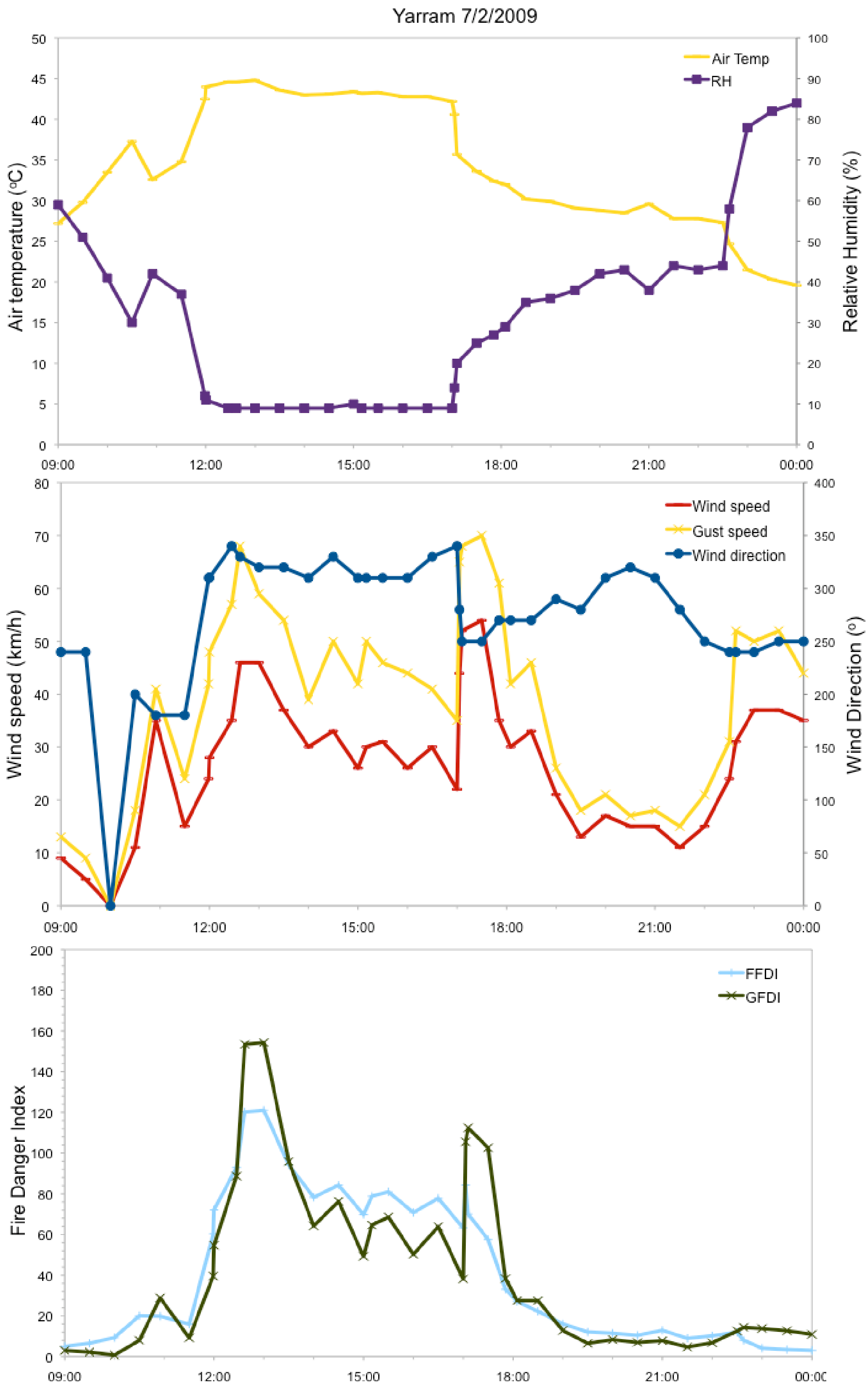


Figure FB-10e. Churchill Fire: Yarram AWS data for February 7, 2009 from 0900 hours to midnight: Air temperature and Relative Humidity (RH) (top), mean wind speed, maximum gust wind speed and wind direction (middle), and Forest Fire Danger Index (FFDI) and Grassland Fire Danger Index (GFDI) (bottom). The wind shifted to SW at about 17:03 hours and was associated with a rapid decrease in air temperature and corresponding increase in RH. Winds remained strong and gusty for 2.5 hours before swinging back to NW and moderating. (Source: BoM)

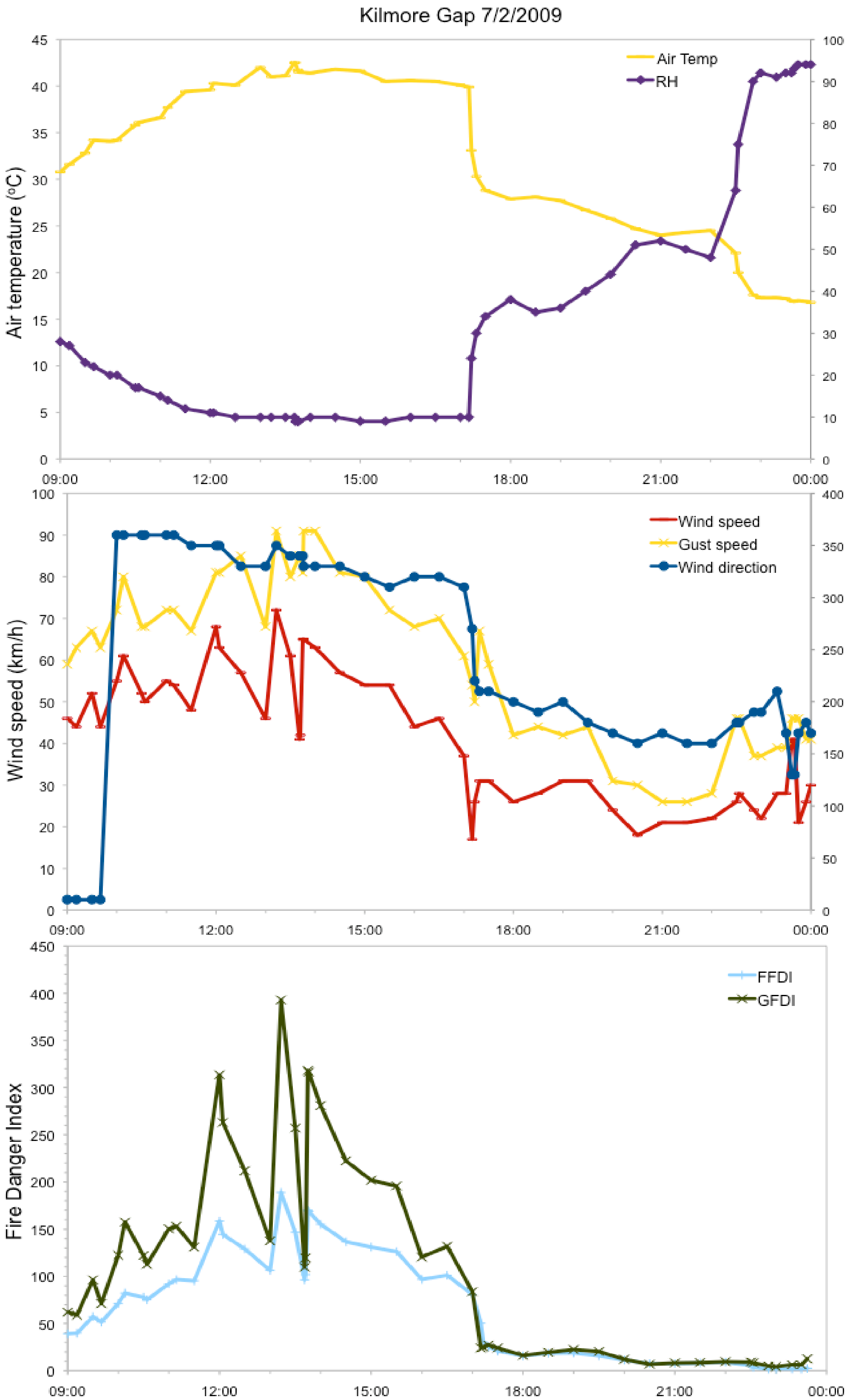


Figure FB-10f. Kilmore East Fire: Kilmore Gap AWS data for February 7, 2009 from 0900 hours to midnight: Air temperature and Relative Humidity (RH) (top), mean wind speed, maximum gust wind speed and wind direction (middle), and Forest Fire Danger Index (FFDI) and Grassland Fire Danger Index (GFDI) (bottom). The wind shifted to SW at about 17:10 hours and was associated with a rapid decrease in air temperature and corresponding increase in RH. Winds reduced in strength with the changed but remained reasonably strong (20-30 km/h) for the remainder of the evening. (Source: BoM)

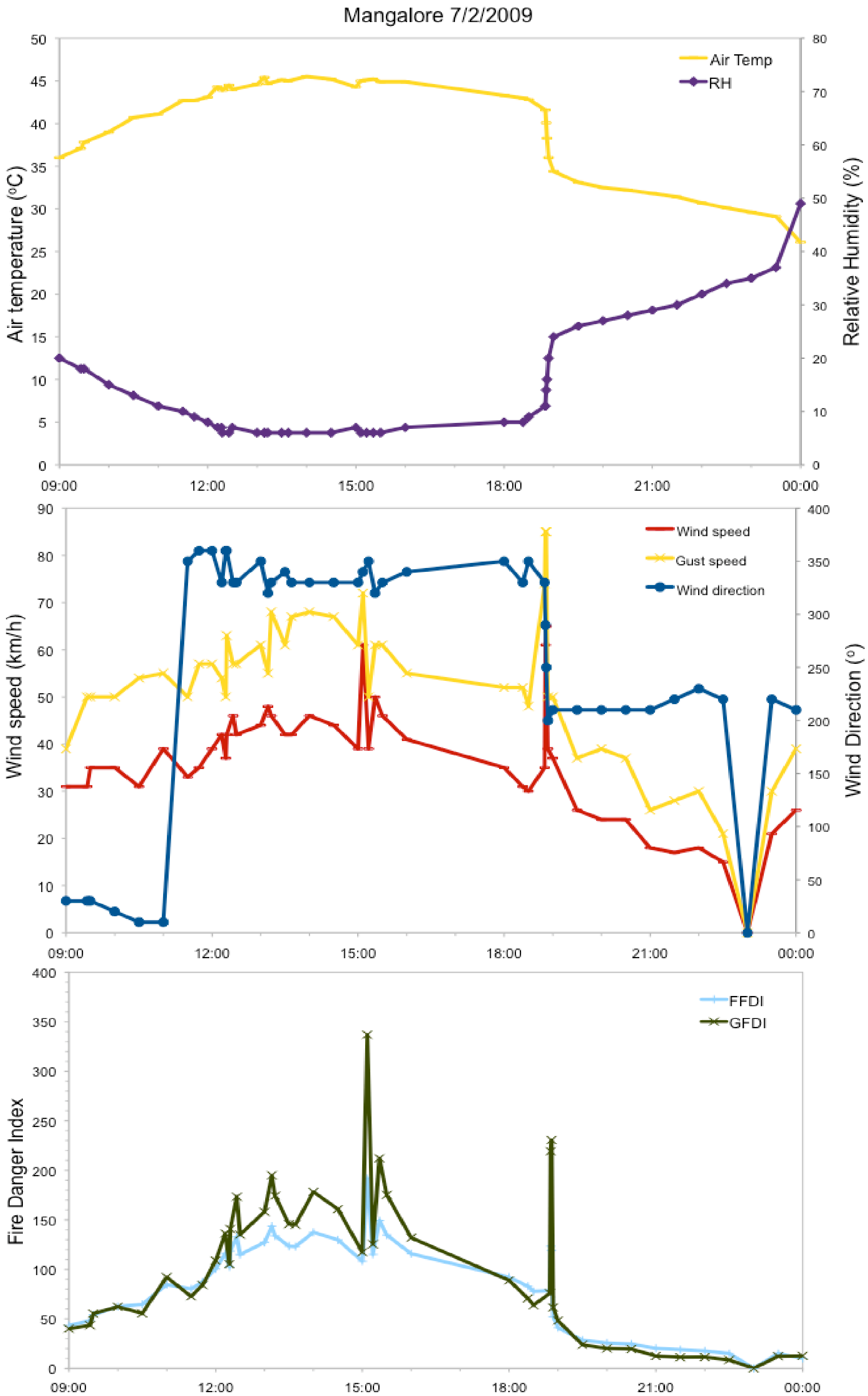


Figure FB-10g. Kilmore East Fire: Mangalore AWS data for February 7, 2009 from 0900 hours to midnight: Air temperature and Relative Humidity (RH) (top), mean wind speed, maximum gust wind speed and wind direction (middle), and Forest Fire Danger Index (FFDI) and Grassland Fire Danger Index (GFDI) (bottom). The wind shifted to SW at about 18:52 hours and was associated with a rapid decrease in air temperature and corresponding increase in RH. Winds gusted with the changed and then remained strong for much of the evening. (Source: BoM)

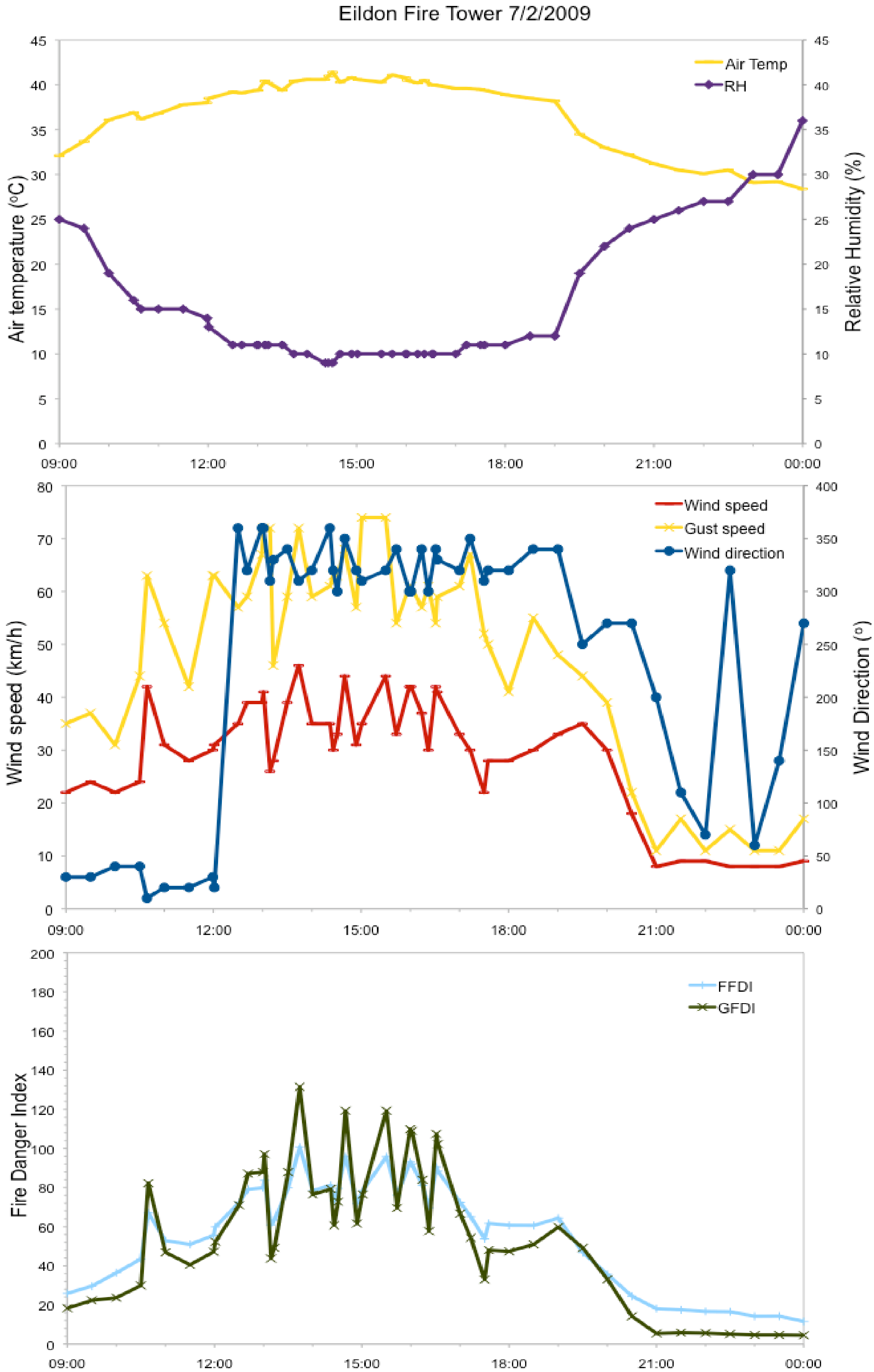


Figure FB-10h. Yea-Murrundindi Fire: Eildon Fire Tower AWS data for February 7, 2009 from 0900 hours to midnight: Air temperature and Relative Humidity (RH) (top), mean wind speed, maximum gust wind speed and wind direction (middle), and Forest Fire Danger Index (FFDI) and Grassland Fire Danger Index (GFDI) (bottom). The wind shifted to SW at about 19:30 hours and was associated with a slow decrease in air temperature and corresponding increase in RH. Winds remained strong and gusty for 1.5 hours after the change and then became light and variable for the remainder of the evening. (Source: BoM)

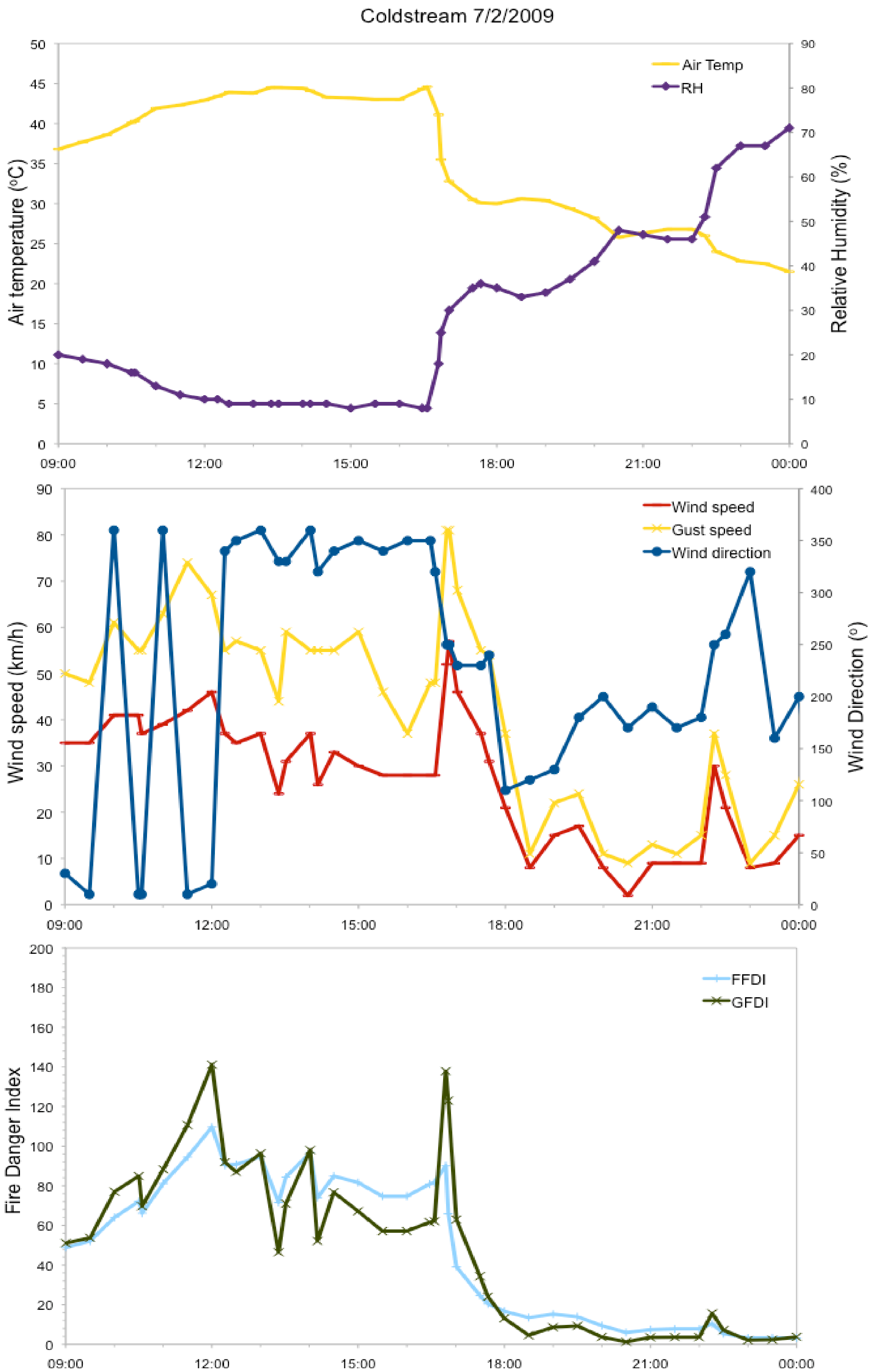


Figure FB-10i. Yea-Murrundindi Fire: Coldstream AWS data for February 7, 2009 from 0900 hours to midnight: Air temperature and Relative Humidity (RH) (top), mean wind speed, maximum gust wind speed and wind direction (middle), and Forest Fire Danger Index (FFDI) and Grassland Fire Danger Index (GFDI) (bottom). The wind shifted to SW at about 16:48 hours and was associated with a rapid decrease in air temperature and corresponding increase in RH. Winds increased with the change for about 1.5 hours and then became light and variable. (Source: BoM)

5. Fire behaviour indicators

During a five week field work program members of the Fire Behaviour Investigation Team visited fire grounds of five of the major bushfires that burnt on 7 February 2009. The objective of field work was to collect data from fire spread indicators that could, in conjunction with other information about the time and location of the bushfires, be used to reconstruct the passage of the fires. The Team gave emphasis to collecting information from sources that would change or be lost forever with the passage of time following the fires.

5.1 Methodology

5.1.1 Methodological design

The governing factors in the development of the methodology employed in the field data collection phase of this research work were primarily the short time available before key observational data was lost, limited staffing resources, and the large areas affected by the bushfires. The initial objective of field data collection was to obtain data that could be used to determine the location of the north-eastern flank of each fire prior to the arrival of the wind change.

5.1.2 Observational data

The primary indicator used to determine this change in wind direction was that of the direction of leaf and stem freeze (Cheney and Sullivan 2008). When leaves and stems are scorched by the passage of fire they freeze in the direction they were pointing at the time, providing an indication of the direction of the wind when the fire passed through. This is not necessarily the direction of the prevailing wind or the direction of spread of the fire but taken with other sources of data over a large area can be used to build up a picture of the likely direction of spread of the fire. Careful analysis is required to then differentiate whether the fuel was scorched in a heading or backing fire.

Other opportunistic data that was collected that could be used to build an understanding of direction of spread and fire behaviour included:

- pattern of char on tree stems;
- extent of crown scorch and defoliation;
- topographic slope;
- extent of fuel consumption;
- degree of grass curing.

5.1.3 Data collection

Field crews comprising 2-4 people were deployed to fires to conduct field observations of fire spread indicators. Observations and photographs were recorded in hand-written notes in field books using a pro-forma that identifies:

- photo identification (numbering from individual camera);
- date;
- time;
- location (general locality, with UTM spatial coordinate details from GPS if possible);
- bearing direction of photograph;
- name of photographer.
- topic listed by major themes:
- Origin, Surface fuel consumption, Crown damage, Unburnt fuel, Leaf freeze, Charring, Wind damage, Panorama/Landscape, Spot fire, other.

The choice of location of observation points was left up to the individual teams with the intent on collecting as broad a distribution as possible given the large fire areas. Access to much of the fire affected area was limited because roads remained closed or were unsafe to use for many weeks after the fire. Access to areas declared as crime scenes was also restricted while forensic investigations were completed. This constrained data collection in the Marysville area during February.

Where possible, fuel hazard was assessed in unburnt forest within the fire perimeter to provide an indication of the fuel load and structure. Hazard assessments were based on the Victorian Overall Fuel Hazard Guide (McCarthy *et al*. 1999) and the Project Vesta Field Guide: Fuel Assessment and Fire Behaviour Prediction in Dry Eucalypt Forest (Gould *et al*. 2007b). Some assessments were carried out on like fuels immediately outside of the fire perimeter. Due to time constraints these observations were not given priority.

A process-based model of surface and profile fuel moisture content (Matthews 2006) was employed to illustrate the likely variation in fuel moisture content over the 72-hour period 6-8 February 2009. The weather input data for this simulation was obtained from the Bureau of Meteorology AWS data.

5.1.4 Data handling

All point observations were entered into a comprehensive Microsoft Excel spreadsheet containing 37 fields with the aim of eventually exporting data into a computerised spatial information database (such as ESRI ARCMap). All data were validated following entry. Directional data were corrected for magnetic declination using a single value for each fire. These data and associated digital photographs and images were stored by the Bushfire CRC in accordance with Data/Information Metadata Standard V2.

5.2 Results

For the purpose of this report, the results of the field observations are provided in the form of maps showing observation points and inferred wind direction intersected with final perimeter extents for each fire. Observation points without inferred wind direction relate to other fire spread indicators (eg. bark char), photographs, and locations where fuels were described or assessed. Observational data are overlaid on to post-fire satellite imagery or air photography (Maiden Gully fire), ecological vegetation classification maps, digital elevation maps, and fire history maps sourced from DSE and CFA. Maps are provided as appendices to this report.

A summary of the number of total observation and number of wind direction indicator points is given in Table FB-1.

Table FB-1. Summary of observation points collected for five fires of 7 February 2009.

Fire Complex	Approx. fire area (ha)	Total no. of observation points	Sampling density (ha per point)	No. of wind direction indicator points	Direction sampling density (ha per point)
Maiden Gully	500	87	6	53	9
Bunyip	26200	144	182	108	243
Churchill	32000	218	147	164	195
Kilmore East	75744	240	316	99	765
Yea-Murrundindi	149286	104	1435	59	2530
Sum	283730	793		483	

5.2.1 Fuel Moisture Modelling (Kilmore Gap)

A processed-based model of fine fuel surface and profile fuel moisture content (Matthews 2006), parameterized using observations of fuel moisture content of dry eucalypt forest of Western Australia (Matthews *et al*. 2007), was used to provide an indication of what the likely value of the fuel moisture contents were during the period 6–8 February. Weather data from the Kilmore Gap AWS was used as the basis for this simulation for illustrative purposes.

Figure FB-11 shows that on 6 February the minimum surface moisture content (SMC) reached about 6.2% at 1500 hrs. Over the evening this increased but only to a maximum of 13.2% at 2100 hrs. From then until 0500 on 7th February the SMC declined slightly to about 11.9%. Following sunrise, the SMC (and profile moisture content (PMC) decreased rapidly during the morning to reach 4.6% by midday. Over the next 4 hours, the SMC decreased further to around 4% before increasing rapidly with the arrival of the wind change at 1700 hrs. The SMC and PMC for the following day reached a minimum of only 13% and 14.5% respectively.

This simulation suggests that due to the very hot and dry conditions, the moisture content of the fine fuels (both surface litter and the whole depth to mineral soil) was extremely dry, resulting in high combustibility and increased available fuels. The very low overnight moisture contents of the night of February 6 meant that, with the onset of hot dry conditions on the morning of 7 February, there was not much moisture in the fuel available for desorption and SMC and PMC values became very low.

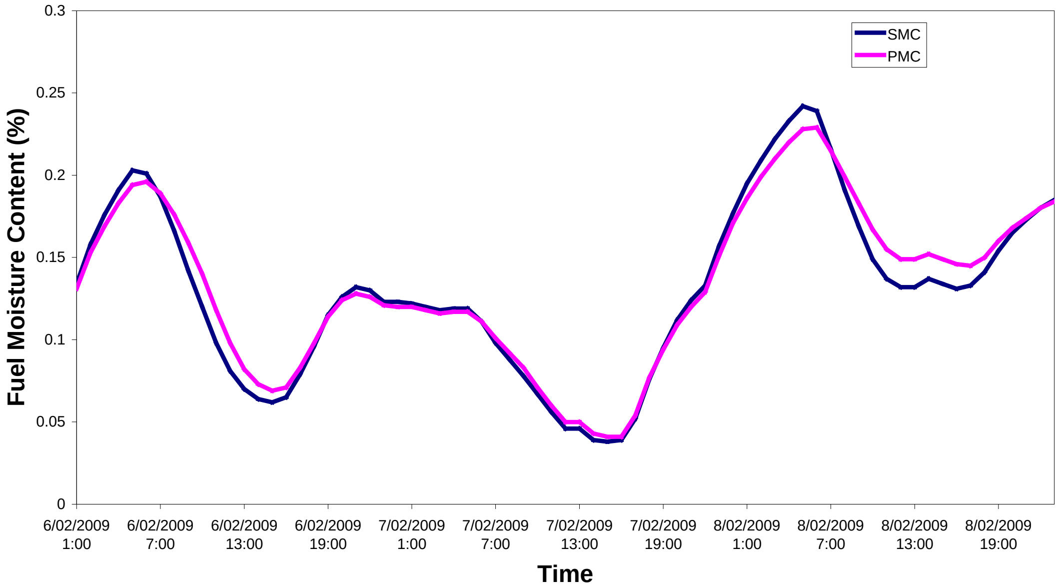


Figure FB-11. Simulation results from a process-based model of surface and profile fuel moisture content using the meteorological data from the Kilmore Gap AWS. Low moisture contents of the evening of 6 February meant that moisture contents for the morning of 7 February already started very low and reached a minimum of about 4% for most of the afternoon.

5.3 Maiden Gully

The fire perimeter is shown in Figure FB-12 overlaid onto aerial photography with vectors of inferred wind direction during the passage of the fire. See Appendix FB-1-1 for a larger scale map of this image.

5.3.1 Vegetation

The main vegetation type burnt by the fire was ironbark woodland up to 25 m tall with a shrubby understorey, and localized areas of riverine grassy woodland and forest up to 25 m tall. See Appendix FB-1-2 for a map of the Maiden Gully Ecological Vegetation Classes (EVC) overlayed with the locations of observations and inferred wind directions during the fire.

5.3.2 Fuels

Surface and elevated fuels were generally of low to moderate fuel hazard rating according to the Victorian Overall Fuel Hazard Guide (McCarthy *et al*. 1999) with occasional areas having high surface and elevated shrub fuel hazards (Fig. FB-13); examples of such areas included parts of watercourses with dense ti-tree to 3 m, and rehabilitation planting of pampas grass on mine tailings.

5.3.3 Fire spread indicators

Indicators shown in Figure FB-12 are consistent with fire spreading under north-westerly winds from the point of origin, at least to the stage where the fire crossed the road between West Bendigo and Long Gully; on the eastern side of this road indicators are mostly consistent with winds from a south-westerly direction. The section of the north-east flank of the fire that burnt through the locality of California Gully was associated with indicators of spread under south-westerly winds, as were a number of smaller burnt areas around Eaglehawk and Long Gully which could have been ignited by spotting following the south-westerly change.

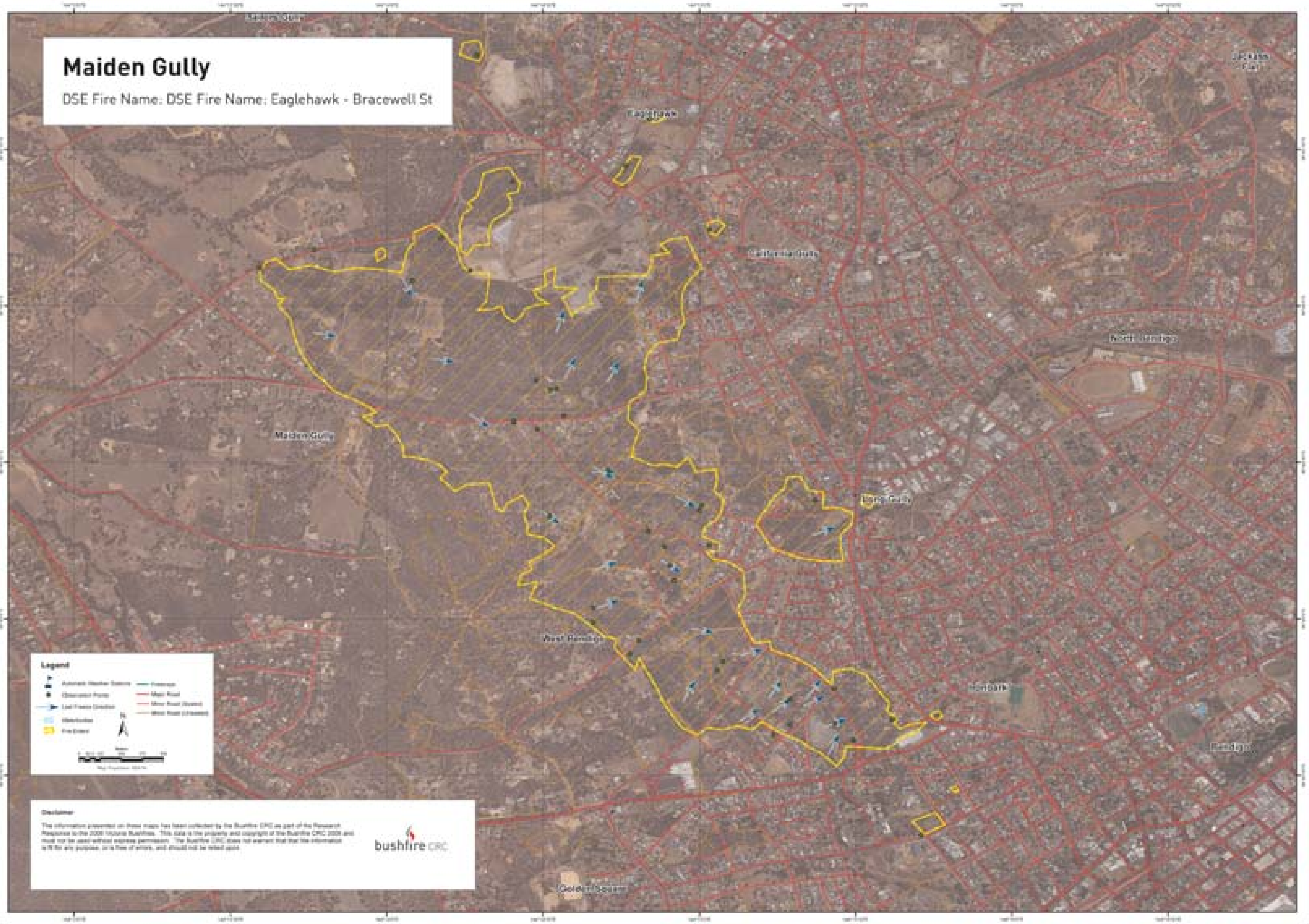


Figure FB-12. Air photograph of the Maiden Gully fire showing location of leaf freeze observations and inferred wind direction at these locations.

Figure FB-13. Maiden Gully fuels exhibited low to moderate fuel hazard for surface fuels. In some areas the elevated fuel hazard was high, particularly where ti-tree was present.

5.4 Bunyip

The fire was reported in the Bunyip State Park on 4 February at 17:00 hrs. The origin was east of the Bunyip Ridge Track next to a track in a riparian zone of heavy tea-tree fuels last burnt in 1939. The fire was not contained on initial attack and continued to burn north up the valley to the immediate west of Bunyip Ridge Track. Over the next 2 days the fire extent increased to approximately 170 ha. At some time early on the morning of February 7th the fire broke containment lines constructed during the preceding days and travelled in a generally SE direction along timbered ranges for about 7 km and into adjoining farmland.

The fire perimeter is shown in Figure FB-14 overlaid onto aerial photography with vectors of inferred wind direction during the passage of the fire. See Appendix FB-2-1 for a larger scale map of this image.

5.4.1 Vegetation

Under the generally north-westerly wind influence the fire burned initially in heathy woodland and foothill forests of mealy stringybark, silvertop ash and messmate (Appendix FB-2-2). Forests had a dense understorey of predominantly hakea and banksia. Riparian vegetation included swampy heathlands and dense stands of prickly tea-tree. Wet schlerophyll forest including mountain ash was present at higher elevations and southerly aspects. The majority of forest burnt following the south-westerly wind change was wet schlerophyll.

Farmland was mainly pastured with a mix of dry dairy, grazing and meadow hay in a wide range of curing conditions depending on species and management practices. Windbreaks, roadside reserves and riparian areas along the Labertouche Creek dominated by mealy stringybark were common in the farming landscape. Much of this remnant bushland had been fully crown scorched or in some places defoliated by crown fire, even remnants located within otherwise unburnt paddocks.

5.4.2 Fuels

Much of the area within the fire perimeter, including farmland is recorded as having last burnt in the 1939 bushfires. More recently burnt areas included a substantial section (10 km x 2 km) between the powerline easement and the southern edge of the fire perimeter burnt by wildfire in 2004, and a 700 ha area about 7 km north-north-east of Labertouche that was prescribed burnt in 2005 (Appendix FB-2-3). There were very few areas of unburnt vegetation to provide a benchmark for fuel condition prior to the fire, and no hazard scoring assessment was carried out for the Bunyip fire.

5.4.3 Fire spread indicators

Access into parts of the fire burnt under the north-westerly wind influence was difficult and only a few observation points with reliable spread direction indicators were collected in this area (Fig. FB-14). Topography appears to have strongly influence on fire behaviour following the wind change (See Appendix FB-3-4).

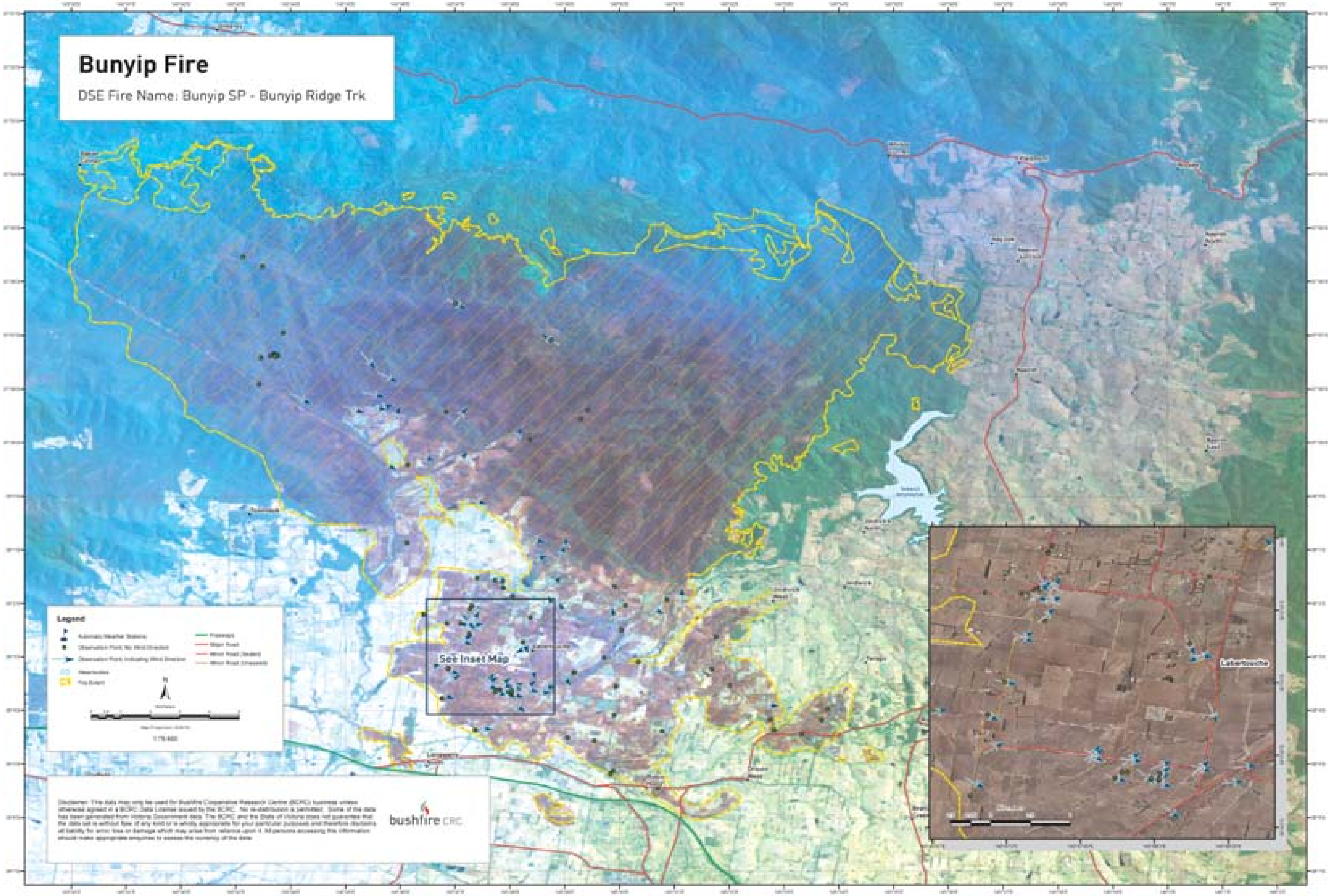


Figure FB-14. Map of burnt area of the Bunyip fire showing location of leaf freeze observations and likely directions of wind at those locations.

Aspects facing south-west burnt at very high intensity with extensive crowning and several areas where all fine fuel was consumed over continuous areas up to 10 hectares. Examples of crown fire activity associated with head fire spread across slopes of 10° were also observed. On lee slopes away from the prevailing wind the inferred direction of fire spread sometimes differed to the prevailing wind. The tendency of the fibrous bark to fully char made it to impossible to identify if the fire was a head, flank or backing fire.

Spot fires, or congregations of spots, were observed in at least over four locations on line-scan imagery at distances of 8 km and 10 km from the head fire and forest edge respectively. Burnt areas associated with these spots was as large as 100 ha.

Fire spread indicators in agricultural lands around Labertouche were highly variable and suggested head, flank and backing fire activity within very short distances. The eastern flank of the fire prior to the wind change was not readily determined in the farmland. Within the extent of burnt area in the farmland, Landsat images taken on the 17th of Feb show as much as half the area unburnt. It was difficult to determine if farmland areas were unburnt due to low curing or suppression efforts. Remnant vegetation along road reserves and planted windbreaks within the farmland was mostly fully crown scorched or defoliated and appears to have provided a conduit for fire spread through otherwise incombustible pastures.

Severe wind damage was observed along Ryson Creek which is located about 8 km NNE of Labertouche and to the north of the 2005 prescribed burn area indicated on Appendix FB-2-3. The valley of Ryson Creek is oriented towards the south-west. Wind throw was observed throughout a 3 km stretch of the creek that was accessible. Entire stands of 50 m tall trees with stem diameters of >60 cm at 1.3m above ground were uprooted or snapped-off at varying height about ground heights (Fig. FB-15). Typically trees were laid out in a south-west to north-east orientation, but in areas the pattern was irregular. Fine leaves and twigs from the tree-tops remaining unburnt on or near the ground at the time of sampling in early March 2009 indicate that wind damage occurred after the passage of fire.

The extent of crown scorch and defoliation evident in satellite imagery appeared to be considerably reduced in the area burnt in the 2004 wildfire and the 2005 prescribed burn, suggesting lower fire intensity in these areas. This observation warrants a more systematic evaluation with supplementary field assessment and analysis of high resolution air photography.

Figure FB-15. Evidence of blow-down within the burnt area of the Bunyip fire. Fine twig and leaf material remaining on the ground suggests this occurred after the passage of the fire.

5.5 Churchill

Ignition points for this fire were on the southern side of Glen Donald Road, 3 km SE of the town of Churchill. Smoke was detected at 1335 hrs with fires reportedly ignited in roadside grass, but rapidly spreading uphill into 15-year-old bluegum plantation, intensifying and crossing Jelleff's Outlet road under the influence of strong NW winds. The fire continued spreading SE pushed by the NW winds and aided by positive slopes, which took the fire into complex terrain within the Strzelecki Ranges. The SE run ended near Balook (~15 km from ignition point) probably due to the arrival of the wind change.

The fire perimeter is shown in Figure FB-16 overlaid onto aerial photography with vectors of inferred wind direction during the passage of the fire. See Appendix FB-3-1 for a larger scale map of this image.

5.5.1 Vegetation

The initial stage of the fire run was predominantly in bluegum, shining gum and pine plantation. About half of the burnt area was shining gum and radiata pine plantation aged 5-15 years (Fig. FB-17). A further third of the burnt are was mature native forest with stands of tall wet sclerophyll forest with a moist understorey. Farmlets and dryland agricultural lands were burnt during the latter part of the fire run and in various localities within the overall forested landscape.

5.5.2 Fuel

Apart from post-harvest residue burning, fire has largely been excluded from forested areas within the fire perimeter since 1939. As the forest is productive and receives reliable high rainfall there has been very considerable build up of fuel during this period. Grasses were less than 60% percent cured in many parts, particularly at the bottom of valleys and creek lines. Grass and shrub understoreys were common in plantations. Wetter forest at higher elevation tended to have a tall dense understorey.

5.5.3 Fire spread indicators

Leaf freeze indicated that the fire was probably about 2-3 kilometres wide during the initial run under north-westerly winds. The head of the fire at this time had reached an elevated ridge. The exact location of the NE flank at the time of the wind change is difficult to determine because complex terrain affected the wind direction observed at most sites. Forest on the south-east (unburnt) side of the ridge was tall wet sclerophyll forest with an understorey of tree ferns and moister shrubs. Some small spot fires in the area appeared to have burnt with a much lower intensity than the main fire.

The consistency of the wind direction over the fire ground after the wind change is difficult to determine because of terrain interaction, though it was mostly SW. The wind direction at some points close to the NE extent of the fire appears to have northerly influence, though it is unknown what time these sections burned. There was evidence of variable wind directions in some parts of the fire run from the SW (e.g. Old Callignee Road) that requires further investigation through interviews with observers.

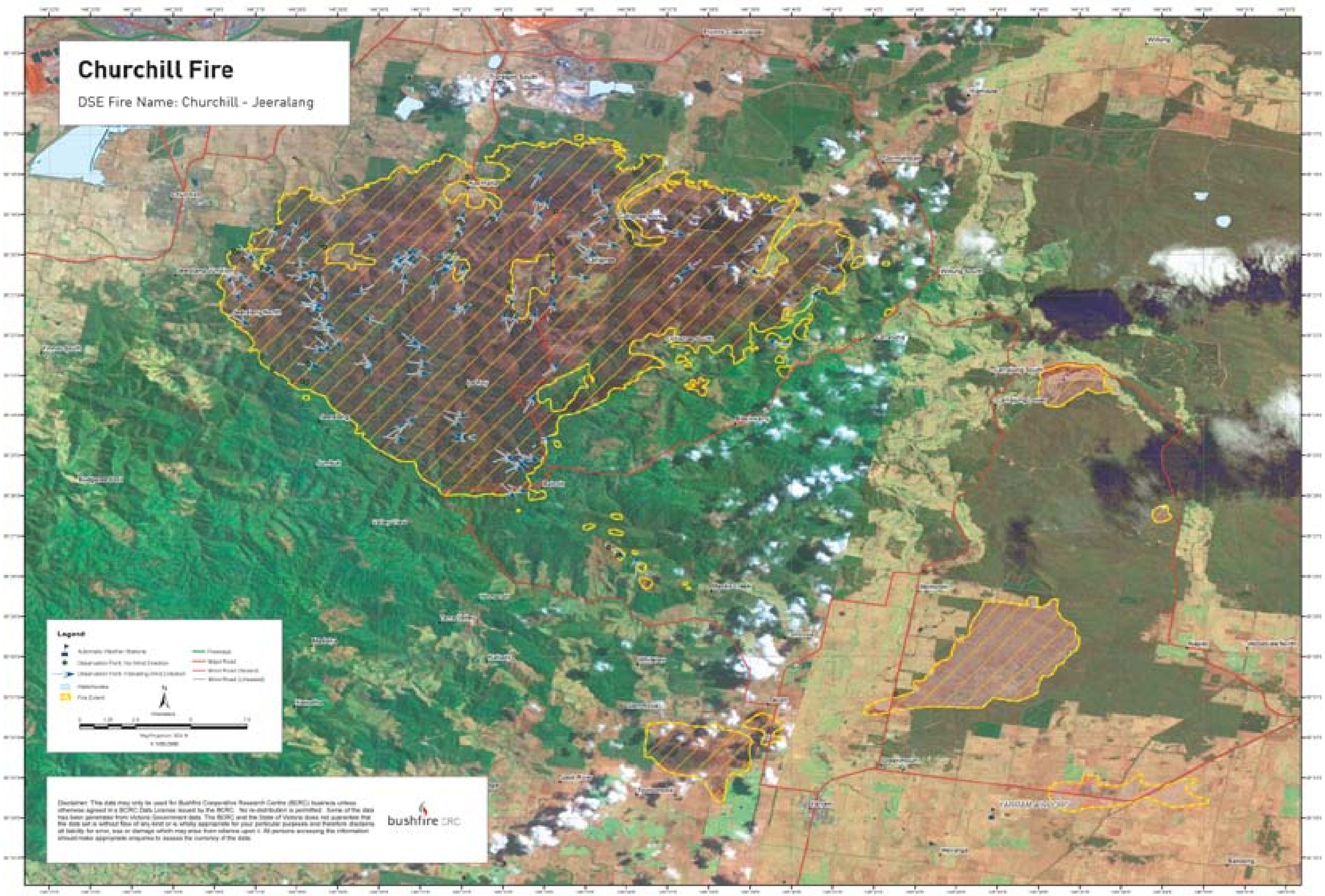


Figure FB-16. Map of burnt area of the Churchill fire showing location of leaf freeze observations and inferred wind direction at these locations.

Figure FB-17. Example of shining gum plantation within similar to that burnt in the Churchill fire. Overall fuel hazard is Very High.

Fire spread is likely to have involved substantial spotting as evidenced by the number of spot fires outside the final perimeter of the main fire. There were more of these than indicated on the official fire maps, though these tended to be much less intense than the main fire. A number of long distance spots from the initial fire run under north-westerly winds reached around 22 km from the main fire perimeter (Fig. FB-16). Two of these spots developed to about 550 and 2000 ha in area and burnt mainly following the SW wind change. Two other fires NW of Yarram were managed as part of the same incident. These were more than 10 km down wind from the south eastern limit of the Churchill fire.

Some unburnt patches remained within the main fire perimeter. These were mainly in grass fuels, and could be associated with areas with lower curing, such as valley bottoms and creek lines, as well as paddocks that had different pasture grass species and pasture treatments.

There was only one small (<1 ha) section of unburnt forest found within the most severely burnt sections of the fire (NW of intersection of Government and Rules Roads). The fuels in this patch appeared to be recently burnt, as the trunks had a lot of young epicormic budding and the surface fuels were very light.

5.6 Kilmore East

The fire perimeter is shown in Figure FB-18 overlaid onto aerial photography with vectors of inferred wind direction during the passage of the fire. See Appendix FB-4-1 for a larger scale map of this image.

The point of origin of the fire was in the Saunders Road area near Kilmore East and the general direction of fire spread was initially to the SE through pasture and radiata pine plantation. The fire crossed the Hume Highway north of Wandong, skirting the northern edge of the town and SE along the escarpment of the Hume Range (Fig. FB-6) which becomes increasingly rugged and broken east of Humevale. Following the south-westerly wind change the NE flank of the fire moved on a broad front through forested country on the Hume plateau and mixed agricultural lands extending between Kinglake West and Kinglake. The final perimeter reached just north of Flowerdale, Break O'Day and Glenburn.

5.6.1 Vegetation

The fire burned in grasslands, open dry eucalypt forest of messmate stringybark, peppermint and gum, tall wet eucalypt forest of mountain ash, messmate and manna gum, and plantations of bluegum and radiata pine. See Appendix FB-4-2 for a map of ecological vegetations classes for this region. A comprehensive account of the vegetation of the Hume Range is provided by Ashton (2000). In spite of the dry condition experience in January 2009 green grass was observed in some paddocks on the Kinglake plateau, and fire did not spread continuously across these paddocks in spite of extensive spotting.

5.6.2 Fuels

Much of the northern part of the Hume plateau was burnt in 1982 with some smaller patches burnt again in the period from 1995-2008. The area extending east from the Humevale Kinglake road and north to Glenburn included large areas of fuel dating from the 1938/39 fire season and some smaller patches burnt in the period 1995-2008. The area between Stathewen and St Andrews was burnt in the decade from 1965-1974. Fuel structure and hazard were assessed in unburned dry schleophyll forest near St Andrews (Fig. FB-18), north of Kinglake (Figs. FB-20 and FB-21), Glenburn and at the Bushfire CRC experimental site in Tallarook which is generally representative of the north extent of the burnt area near Strath Creek.

5.6.3 Fire spread indicators

Fire spread indicators revealed a number of important characteristics of the Kilmore-Kinglake fire as follows:

- the fire had a very elongated shape under the influence of north-westerly winds the fire with a length to breadth ratio of about 7:1;
- under the influence of north-westerly winds the fire passed to the south of Kinglake West and did not impact on this community until after the south-westerly wind change;
- patterns of fire spread became increasingly complex east of Humevale with fire spread indicators consistent with an head fire running under north-westerly winds and fire runs from the south or south-west associated with the wind change and localized terrain effects. This may have extended the period of time over which residents of ridge-top settlements and farms were subject

to severe fire behaviour and led to uncertainty about which direction the fire was approaching from;

- the Strathewen area appears to have been impacted by fire running on a north-westerly wind and also by a major fire front approaching from the south;
- much of the area north of the road between Pheasant Creek and Kinglake remained unburnt because of cultivated paddocks or incompletely cured pasture;
- a number of areas burnt since 1995 had reduced levels of canopy scorch or had not burnt at all, suggesting that fire intensity was reduced because of younger fuels.

Figure FB-18. Open eucalypt forest 3 km east of St Andrews adjacent to the southern boundary of the Kilmore-Kinglake fire. Surface and near-surface fuel rated as moderate, elevated fuel rated low, and bark fuel hazard rated as high. Photo taken 17 February 2009.

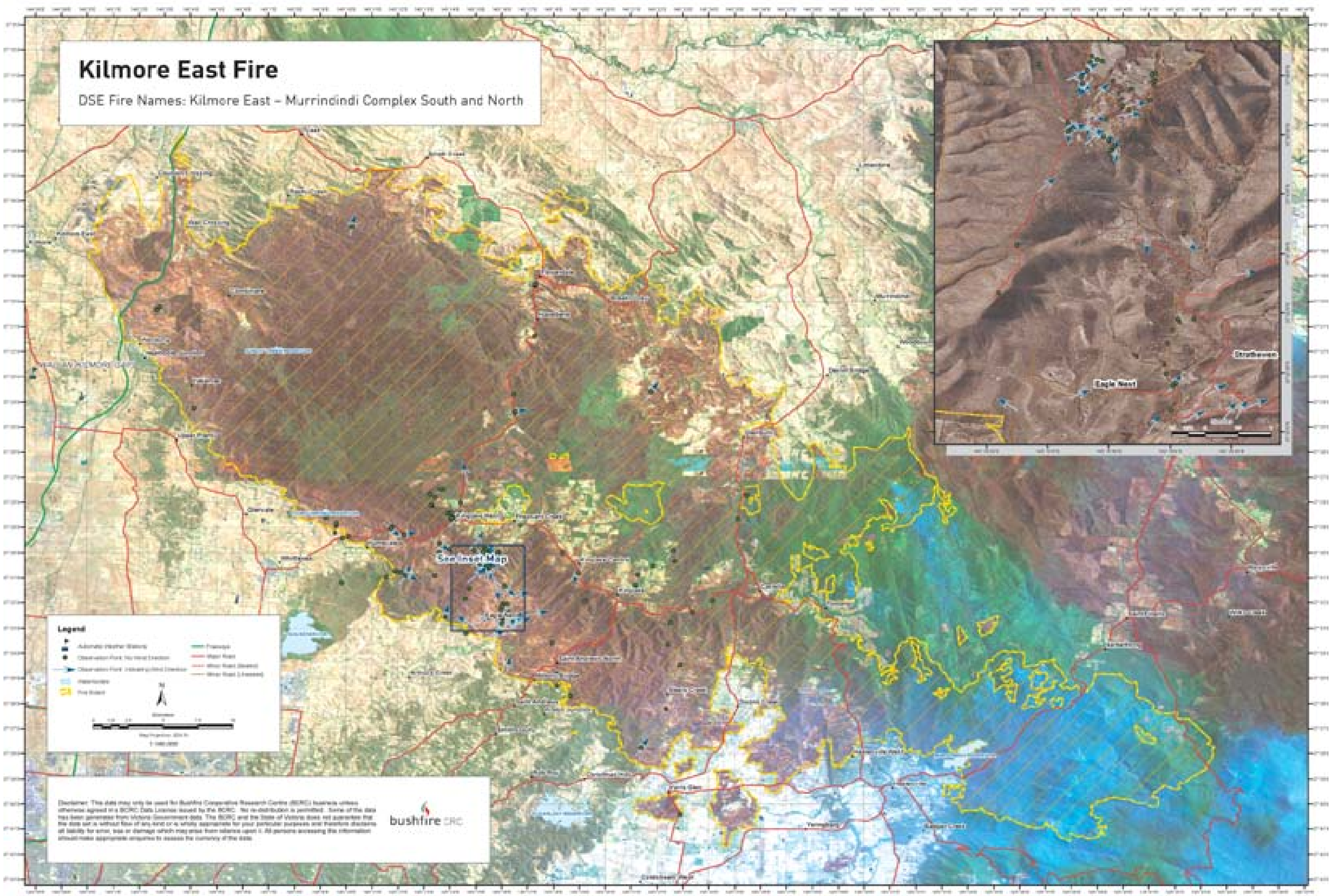


Figure FB-19. Map of burnt area of the Kilmore East fire showing location of leaf freeze observations and likely directions of wind at those locations.

Figure FB-20. Open eucalypt forest north of Kinglake with an understorey of bracken fern and a near-surface fuel layer comprised of dead bracken, bark and twigs. Elevated fuel and bark fuel hazard were rated as high. Photo taken 17 February 2009.

Figure FB-21 Surface fuel layer of eucalypt litter and fine twigs at Kinglake. Photo taken 17 February 2009. Surface fuel hazard is very high.

5.6 Murrundindi

The fire perimeter is shown in Figure FB-22 overlaid onto aerial photography with vectors of inferred wind direction during the passage of the fire. See Appendix FB-5-1 for a larger scale map of this image.

The fire initially spread south-east from a point of origin near Murrindindi Mill. The fire was narrow, with its eastern flank somewhere between the Murrindindi River and Black Range Rd, based on leaf freeze observations (Fig. FB-22). Evidence of spotting and NE spread near Bull Creek Rd suggest this was as far as the fire progressed in this direction before the wind change. After the wind change the fire spread NE towards Marysville and the Goulburn Valley highway.

5.6.1 Vegetation

The fire burned predominantly in tall wet eucalypt forest of mountain ash and manna gum, with open dry eucalypt forest of messmate and broad leaved peppermint on drier and more exposed northern aspects, and plantations of bluegum, shining gum and radiata pine (Appendix FB-5-2). Grass remained green in many places despite the dry conditions in January 2009 (Fig. FB-24).

5.6.2 Fuels

The majority of the area within the fire perimeter had last been burnt in 1939 (Appendix FB-5-3). West of the Narbethong-Taggerty road there were a number of areas burnt in the decades 1985-94 and 1995-2004 which varied in size with the largest being about 3 km^2. Other areas burnt in the decade 1985-1994 included the area east of St Filians and south of Torbreck Station at the eastern extremity of the fire run. Around Marysville township a number of small patches (mostly <1 km^2) had been burnt in the decade 1995-2004 and since 2005. Forest fuels were dry enough to burn right to the edge of flowing creeks (e.g. Murrindindi River). Pastures were incompletely cured in some places (e.g. Maroondah Hwy south of Buxton) and did not burn.

5.6.3 Fire spread indicators

Limited road access into burnt areas meant that fire spread indicators were only examined at a few places between the point of origin near Murrindindi Mill and road linking Narbethong to Buxton (FB-22). Indicators in this area were mostly consistent with fire run under north-westerly winds but in at least one place suggested up-slope fire spread contrary to the prevailing wind during this phase of the fire run. In the area around Narbethong and St Filians indicators were variable with inferred wind directions ranging from north-westerly to south-westerly, and a strengthening trend towards south-westerly winds as the fire approached Marysville. Indicators in and around Marysville were predominantly for south-westerly winds although with some examples of fire spread direction apparently terrain dominated. Based on the location of several observation points showing inferred south-westerly wind direction and the presence of linear patterns of scorched tree crowns the width of the headfire burning under north-westerly winds appears to have been about 5 km, resulting in a length to breadth ratio of about 5:1.

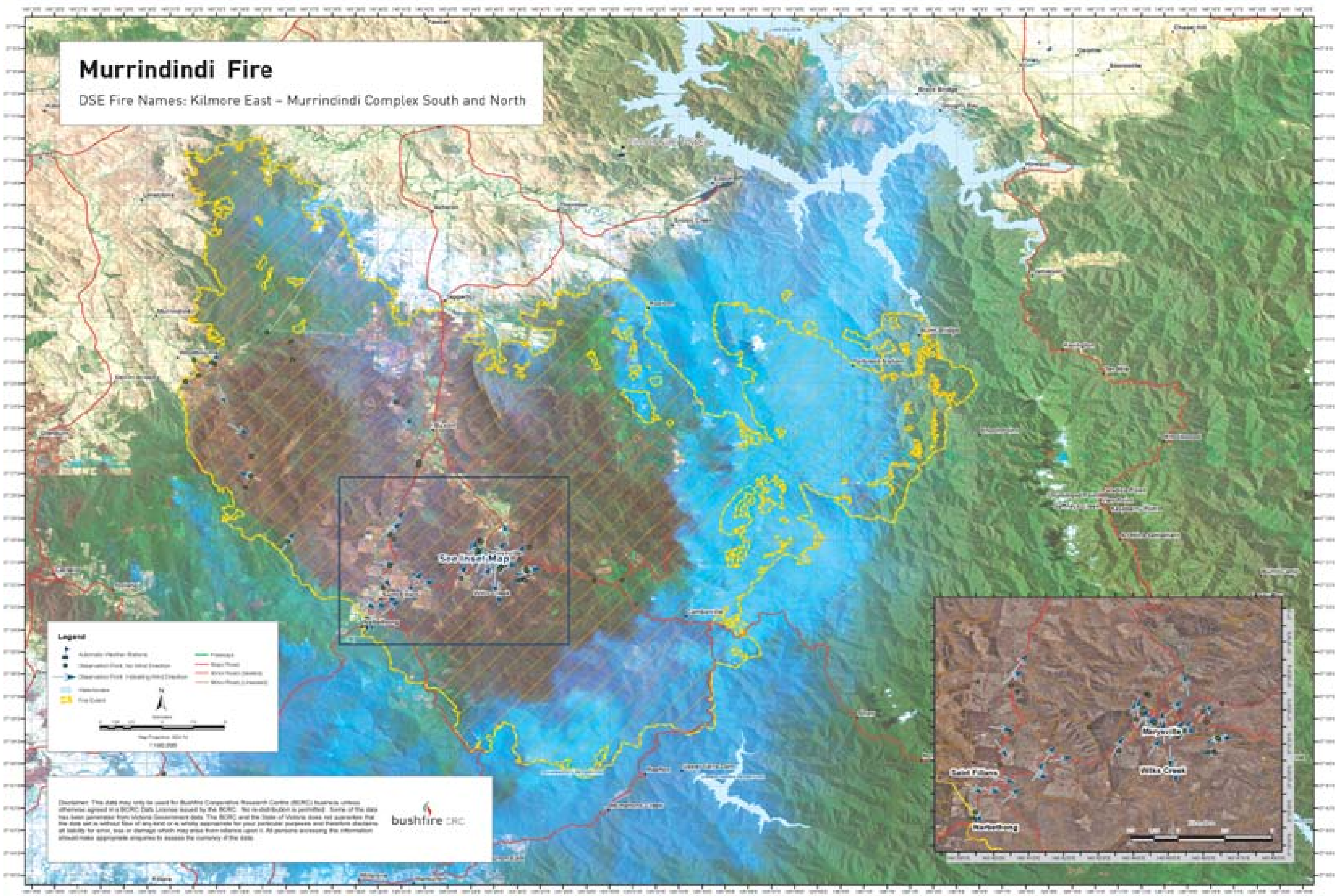


Figure FB-22. Map of burnt area of the Murrundindi fire showing location of leaf freeze observations and likely directions of wind at those locations.

Figure FB-23 Unburnt fuel near Narbethong showing high surface and elevated fuel hazard layers and very high near-surface hazard.

Figure FB-24 Unburnt tall open forest 9 km east of Marysville showing very high near-surface and high elevated fuel hazard. Grass in the foreground is estimated to be about 40% cured.

6. Discussion

6.1 Previous severe fire events

Severe bushfire events are generally associated with high temperatures, low relative humidity and strong winds in conjunction with abundant fuels that are available for combustion (i.e. long period of drought for forest fires, good spring growth and late summer drought for grass fires). In Australia, these weather conditions are generated under synoptic situations where pressure systems are located such that hot dry strong wind from the centre of the continent is directed toward the coastal regions (Cheney 1976). In south-eastern Australia, this synoptic situation occurs when a high pressure system has moved off the east coast into the Tasman Sea and a low-pressure trough approaches from the west. Hot northerly or north-westerly winds, which can be gale force depending on the intensity of the low, will dominate the weather patterns for much of the state of Victoria. As the trough and associated cool change passes, the wind will revert to a westerly or southerly direction. The frequency of such patterns occurs with the normal weather cycle, which is approximately 6 or 7 days.

Occasionally the high-pressure system in the Tasman Sea can become stationary, producing a ridge along the east coast that results in extended periods of extreme heat (heat waves) and extreme fire weather in south-eastern Australia (see Fig. 18). Days on which such weather coincides with the existence of fires (either pre-existing or new ignitions) generally results in high intensity fire behaviour. The passage of a trough and resulting cold front from the south-west will result in generally cooler, moister air reducing fire danger. However squalls and increased wind speed associated with the change, coupled with the time required for dead fine fuel to respond to higher humidity's, can cause significant short-term increases in fire intensity and result in additional suppression issues for firefighters.

In Victoria there have been a number of days in which the occurrence of these conditions has resulted in disastrous wildfire conditions: Black Friday (13 January 1939), Western Districts (12 February 1977) and Ash Wednesday (16 February 1983) (see Table FB-3). Of these, Black Friday provides the closest set of conditions for comparison with 7 February 2009.

The 1977 Western Districts fires are unique here as they were predominantly grassfires and not associated with rainfall deficit. The Canberra fires of January 2003 occurred under slightly lower temperatures than 7th February but very low relative humidities resulted in extremely dry fuels and very high intensity wildfire behaviour.

Recently, identification of columns of very dry in the upper atmosphere (i.e. dry slots) have been found to coincide with many of the worst bushfires in Australia (Mills 2005a). Under certain atmospheric conditions columns of dry, fast moving, high-altitude air can descend to the surface, causing a rapid loss of humidity at ground level and strong, gusty winds. Mills (2005b) identified dry slot occurrence with the Canberra fires which is demonstrated by the extremely low relative humidity under an air temperature that is not similarly extreme.

Table FB-3. Occurrence of selected severe fire events in Victoria and the ACT with associated fire weather conditions (Source: Sullivan 2004).

Event	Date	Max. Temp (°C)	Min R.H. (%)	Max. Mean Wind Speed (km/h)	Impact
Black Friday	13 January 1939	45.6	8	35	71 lives, 2 million ha burnt.
Western Districts	12 February 1977	36	22	50-55	3 lives, 100,000 ha burnt,
Ash Wednesday	16 February 1983	43	15	70+	72 lives, 380,000 ha burnt.
Canberra	18 January 2003	35	4	50	4 lives, 100000 ha burnt
Black Saturday	7 February2009	45.7	4	69	173 lives, 300 000 ha burnt.

6.1.2 Black Friday, 13 January 1939

The 1938/39 fire season was preceded by below to very much below normal winter and spring rainfall. A comparison of monthly rainfall at Toorourrong Reservoir and Wallaby Creek in the 12 month period leading up to the 1939 Black Friday bushfires and the 2009 Black Saturday bushfires is provided in Fig. FB-25. Other notable drought years recorded at both sites include 1945, 1967, 1982, 1997 and 2002. In contrast to the 1938/39 fire season the lead up to Black Saturday 2009 was associated well-above normal rainfall in November and December 2008. This late rainfall is likely to have delayed the onset of senescence and curing off in grassy fuels and may have contributed to some residual moisture in the deep litter layers in tall wet forest, particularly on more sheltered southerly aspects.

The first fires of the 1938/39 fire season in Victoria occurred in August and resulted in crown fire spread. Grasslands were cured early by a dry spring. In the eastern highlands of Victoria, the worst fires in many years had occurred by October of 1938. A large bushfire burned from Wandong to Wallaby Creek in December 1938 affecting much of the forest that was to burn again in February 2009 (Table FB-4).

A high-pressure system developed over the Tasman Sea in early January and remained in place for almost a fortnight (Fig. FB-26). This resulted in steadily increasing daily temperatures. The general flow of wind over south-eastern Australia was from the north-west. Fronts frequently passed over south-eastern Australia at 2-3 day intervals following heat wave events during this period. During these heat wave events, hundreds of fires spread fiercely before conditions abated following the passage of a front. Adelaide experienced 10 consecutive days over 36°C and three days over 45°C. Melbourne set a record high temperature of 44.7°C on 10 January, only for it to be surpassed 3 days later. Three other Australian capital cities experienced their extreme maximum temperatures during the January 1939 period Canberra reached 42.8°C on 11 January; Adelaide reached 47.6°C on 12 January; and Sydney reached 45.3°C on 14 January.

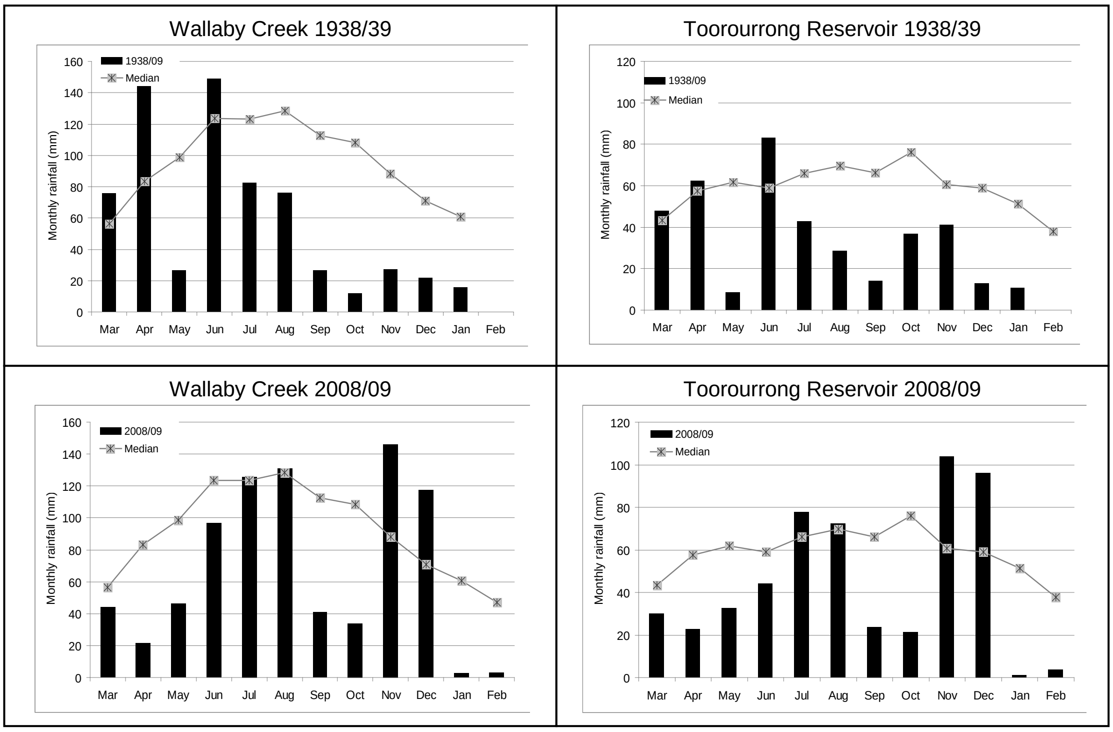


Figure FB-25. Comparison of rainfall observed March 1938-January 1939 (top row) and March 2008-February 2009 (bottom row) against long-term median rainfall against for Wallaby Creek (left column) and Toorourrong (right column). Note that rainfall for January 1939 was recorded after Black Friday 13 January, and for February 2009 after the Black Saturday 7th February bushfires.

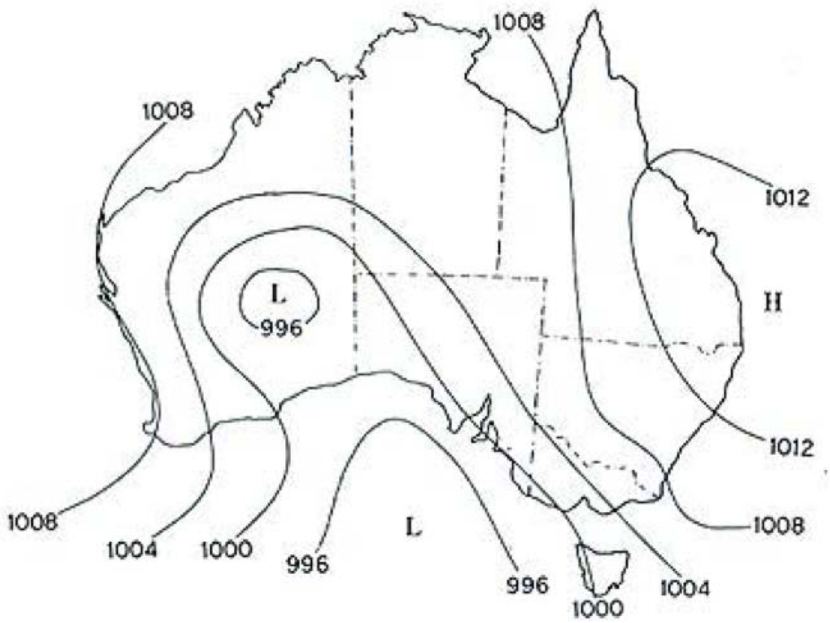


Figure FB-26. Synoptic situation at 0900 hrs EST on 13 January 1939 resulting in record temperatures and strong winds throughout south-eastern Australia. Source: Foley (1947) in Furler (1984).

Table FB-4. Annual rainfall at Toorourrong Reservoir and Wallaby Creek in years preceding major bushfires in central and eastern Victoria. Bushfire activity sourced from Foley (1947) and Ashton (2000).

Year	Annual rainfall (mm) Toorourrong Reservoir	Annual rainfall (mm) Wallaby Creek	Bushfire activity
1908	533**	915	
1914	566	738**	Widespread bushfire activity in central Victoria and Gippsland, March 1914.
1927	550*	866*	
1938	499**	766**	Bushfire burnt from Wandong to Wallaby Creek, December 1938. Black Friday bushfires, January 1939.
1945	483**	820*	
1967	473+	728+	Bushfires in Dandenong Ranges
1982	545*	761**	Bushfire burnt from Wallan to Mt Disappointment, November 1982 Ash Wednesday bushfires, February 1983.
1997	531**	739**	Bushfires in Dandenong Ranges
2002	519**	794*	Alpine bushfires, January-March 2003
2006	605	741	Great Divide bushfires, December 2006-March 2007
2008	663	940	Black Saturday, 7 February 2009

* Annual rainfall less than or equal to the 10th percentile value.
** Annual rainfall less than or equal to the 5th percentile value.
+ Lowest on record

January 13 brought further record-breaking temperatures to south-eastern Australia: Melbourne reached 45.6°C, Wangaratta reached 46.0°C. A low-pressure depression stretching from western and central Australia developed, resulting in strong, hot and gusty north-westerly winds directed over south-eastern Australia. In Melbourne, the winds started at about 0800 hrs (Fig. FB-27). By 1000 hrs, the temperature had reached 43.3°C. Black Friday's extreme fire weather reached 45.6°C, 8% relative humidity and average wind speed 30 km/h-60 km/h in places. Wind gusts up to 74 km/h were recorded in Melbourne (Foley 1947).

Bushfires killed 71 people in Victoria and 650 major buildings, including the township of Narbethong, were destroyed. From December 1938 to January 1939 between 1.5 and 2.0 million ha were burnt out in Victoria, including over 1.4 million ha of forested land. There were relatively few fires in grasslands due to a lack of fuel as a result of grazing pressure and poor pasture growth during the extended rainfall deficit.

Conditions on Black Saturday 2009 were remarkably similar to that of Black Friday: contiguous heat wave conditions, a day of hot, dry and extremely strong and gusty wind, and significant rainfall deficit for much of the state.

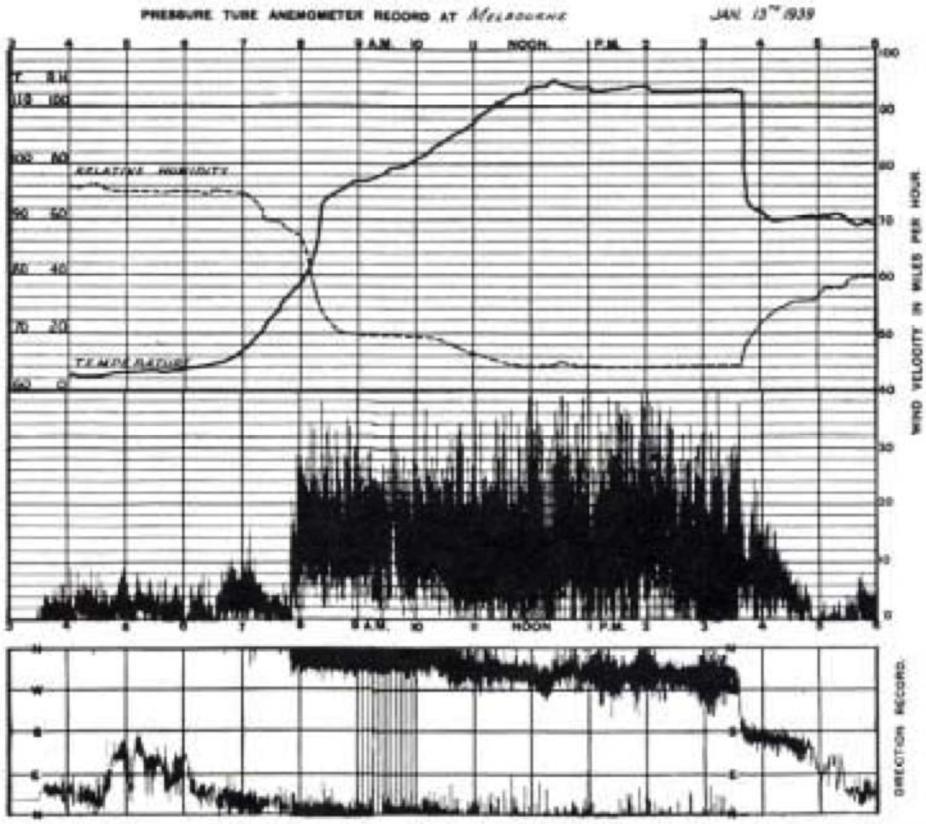


Figure FB-27. Diurnal pattern of wind speed (centre panel) and direction (lower panel), temperature and relative humidity (upper panel) at Melbourne on 13 January 1939 showing the early increase in wind speed and temperature that is maintained throughout the day. Source: Foley (1947).

6.3 Spotting

On 7th February 2009 the existence of a very deep mixed layer, combined with the existence of strong winds aloft created conditions conducive to the long distance carriage of firebrands such as burning bark. Very dry fuels and strong winds at the surface resulted in intense fire behaviour and the formation of very strong convective activity capable of lofting firebrands to significant heights within the convection column (Fig. FB-27). Strong upper winds provided the mechanism to transport firebrands downwind for distances of many kilometers.

In situations where topography was broken, such as along the southern escarpment of the Hume Range (Fig. FB-28), this capacity for significant lofting of firebrands translated into significant potential for massive short-distance (0-200 m) and medium-distance (200-1000 m) spotting. Spotting appears to have been an important mechanism of fire spread on 7th February by facilitating fire spread from one ridge top to the next in areas of broken terrain, and by carrying the fire across areas of sparse eaten-out pasture or, at higher elevation, across areas where grass was less than fully cured and might otherwise have arrested fire spread.

Figure FB-27. Massive convective plume on northern flank of the Kilmore East fire at 1525 EDST (Photo: Richard Alder).

Figure FB-28. Spotfire activity on the southern escarpment of the Hume Range north east of Whittelsea at 1627 EDST (Photo: Richard Alder)

Evidence for spotting only remains where the spotfire caused by a firebrand fails to burn out all fuel around it but it may be inferred from changes in fire intensity along a ridge top where the windward side of the slope has burnt under high intensity leading to full defoliation and the leeward side shows much less intense fire behaviour and no defoliation. The distances of travel of firebrands can only be inferred from the location of the spotfires relative to the nearest main fire edge as there is no information about their source location and thus represent only the minimum distance of travel long distance spotfires - actual distances may in fact be much greater.

Spotfire information was gathered by measuring distances in a GIS from burn perimeter information provided by DSE and CFA. This information is presented in Table FB-8 against predicted spotting distances

6.4 Fire behaviour prediction systems

The project plan prepared for the Bushfire CRC Research Taskforce posed the question of whether the fires of 7th February 2009 behaved in a manner that was consistent with existing fire behaviour models. This is an important question as it relates directly to planning for emergency response, and also to the direction of future fire behaviour research in Australia.

Proper evaluation of the performance of existing fire behaviour prediction guides requires detailed reconstruction of the path of spread of each of the major fires using weather data, fire spread direction indicators and reliable information about the position of the fire perimeter at various times during the day as each fire developed; information about the location of spotfires ahead of the main fire front is also required. The Bushfire CRC Fire Behaviour Team was not able to access time specific observations of fire location during the preparation of this report and so a detailed reconstruction of fire spread is not presented here. However, to facilitate an evaluation of existing fire behaviour guides information sourced from publicly available weather observations, maps, and eyewitness accounts of fire behaviour was used to determine the distance travelled and average rate of spread prior to the wind change on 7 February. No reliable information was available about the duration of run of the Bunyip fire and hence a rate of spread has not been determined.

Weather, fuel and fire spread observations were given a reliability score (using the categories described in Tables FB-5 and as used by Gould *et al.* (2007a)) for rating the reliability of wildfire behaviour observations (Table FB-6). Fuel, rate of spread and spotting observations were given low reliability scores, with greater reliability attributed to weather observations for the Maiden Gully, Kilmore East and Churchhill.

Table FB-5. Reliability rating for weather, fuel and fire spread observations for wildfires in open eucalypt forests.

Rating	Weather (W)	Fuel (F)	Rate of spread (R)
1.	Nearby meteorological station or direct measurements in the field.	Fuel characteristics inferred from a fuel age function developed for the particular fuel type.	Direct timing of fire spread measurements by the authors.
2.	Meteorological station within 50 km of the fire.	Fuel characteristics inferred from a visual assessment of nearby unburnt forest.	Reliable timing of fire spread by a third party.
3.	Meteorological station > 50 km of the fire, reconstruction of wind speed for fire site.	Fuel characteristics inferred from a fuel age curve for a forest type of similar structure.	Reconstruction of fire spread with numerous cross references.
4.	Spot meteorological observation near the fire.	Fuel characteristics typical of equilibrium level in a dry sclerophyll forest	Doubtful reconstruction of fire spread.
5.	Distant meteorological observations at locations very different to fire site.		Anecdotal or conflicting reports of fire spread.

Table FB-6. Reliability scores for weather, fuel and fire behaviour observations.

	Reliability score		
Fire	Weather	Fuel	Fire behaviour
Maiden Gully	2	2	5
Bunyip	5	4	5
Churchhill	3	4	5
Kilmore East	3	4	5
Murrundindi	5	4	5

Forward rates of spread (Table FB-7) and spotting distances (Table FB-8) were calculated using the McArthur FFDM (McArthur 1967) and the Project Vesta fire spread model presented as tables in the Field Guide: Fuel Assessment and Fire Behaviour Prediction in Dry Eucalypt Forest (Gould *et al.* 2007b). Average fine fuel loads and fuel hazard scores were assigned to each fire based on the experience of members of the BCRC Fire Behaviour Team. These values represent typical default values for eucalypt forests unburnt for at least 15 years where the fuel is approaching equilibrium with environmental conditions that determine fuel accretion and decomposition. Fine fuel loads for use in the McArthur FFDM are only those of the surface fuels less than 6 mm in diameter and do not include fuels such as shrub (near-surface or elevated fuels) or bark.

The Bunyip, Churchhill and Kilmore East fires were assigned the same fuel values and a fine fuel moisture content of 3%, but the Bendigo fire was assigned lower fuel values because of the very open nature of the dry forest in the area. The Murrundindi fire was assigned higher fuel values and a fine fuel moisture content of 4% because of the more widespread occurrence of taller, denser forest within the area burnt. Predicted rates of spread were not corrected for slope on the basis that the fires traversed both positive and negative slopes during their run.

The Bendigo fire spread faster by a factor of 2 to 3 times than predicted by either the FFDM or the Project Vesta model, possibly because the very open nature of the forest at Bendigo resulted in higher wind speeds under canopy than assumed by either model. The observed rate of spread of the Churchill fires was intermediate between the prediction from the FFDM and the Project Vesta model. The Kilmore East and Murrundindi fires spread 2 to 3 times faster than predicted by the FFDM, and up to 1.5 times faster than predicted by the Project Vesta model. It needs to be recognized that these simple predictions make no allowance for the contribution of spotting to the spread of the fire, which is unlikely to be a valid assumption under the extreme fire danger conditions that prevailed on 7th February.

Rates of spread observed on 7th February are within the range reported previously for eucalypt forest burning under extreme fire danger conditions on Ash Wednesday 1983 at Trentham and Deans Marsh (Rawson *et al*. 1983).

Table FB-8 gives the results of the comparison with estimated shortest-distance spotting and the models of McArthur FFDM and the Project Vesta field guide. Spotting distances predicted by the McArthur FFDM range from 3.6 km for Bendigo to 11 km for the Kilmore East fire. Spotting distances predicted by the Project Vesta field guide ranged from 0.7 km for the Bendigo fire to between 6.5 and 7.4 km for the other fires, which is the highest value currently provide for in the tables.

Based on the weather conditions presented in Table 7 predicted rates of spread in fully cured grazed pastures for the Kilmore and Bendigo fires were 17 and 12 km/h respectively.

Table FB-7. Estimated forward rates of spread under north-westerly winds prior to the wind change on 7 February 2009 compared with spread predictions from the McArthur FFDM and Project Vesta fire spread model presented as tables in the Field Guide: Fuel Assessment and Fire behaviour prediction in Dry Eucalypt Forest. Weather data have been sourced from the automatic weather station considered most relevant to the fire.

Fire	Length of run (km)	Duration of run (hr)	Mean rate of spread (km/h)	AWS data source	Air temp. (°C)	Relative humidity (%)	Wind Speed (km/h)	FFDI	FFDM fuel load (t/ha)	FFDM predicted rate of spread (km/h)	Vesta surface fuel hazard score	Vesta near-surface hazard score (height, in cm)	Vesta Fine fuel moisture content	Vesta predicted rate of spread (km/h)
Maiden Gully	4	1.25	3.2	Bendigo Airport	44	8	35	95	10	1.10	2	1 (5)	3	0.9
Bunyip	7*	unknown	unknown	Latrobe Valley	42	9	33	82	20	1.95	3.5	3 (20)	3	5.2
Churchhill	15	4.75	3.2	Latrobe Valley	42	9	33	82	20	1.95	3.5	3 (20)	3	5.2
Kilmore East	50	4.75	10.5	Kilmore Gap	41	9	56	135	20	3.25	3.5	3 (20)	3	7.5
Murrundindi	37	4.5	8.2	Eildon	40	10	35	80	25	2.40	4.0	3.5 (25)	4	5.7

* Distance from point of origin is inferred as its exact location is not known

Table FB-8. Predicted spotting distances on 7 February from the McArthur FFDM and Project Vesta tables.

Fire	Shortest point between furthest spot and main fire extent (km)	Shortest point between furthest spot and origin (km)	Distance/s between spots on NW-SE orientation (km)	Wind Speed (km/h)	FFDI	FFDM fuel load (t/ha)	FFDM predicted spotting distance (km)	Vesta surface fuel hazard score	Vesta bark hazard score	Vesta predicted spotting distance (km)
Bendigo	0.6	4.6	N/A	35	95	10	3.6	2	3	0.7
Bunyip	10.0	N/A	2.0	33	82	20	6.6	3.5	3	6.5
Churchhill	22.0	37.6	1.8, 8.1, 7.1**	33	82	20	6.6	3.5	3	6.5
Kilmore East	3.1	46.1	1.2, 1.3, 2.0,	56	135	20	11.0	3.5	4	7.0
Murrundindi	5.9+ 4.7++	47.9+ 47.5++	N/A+ N/A++	35	80	25	7.7	4.0	4	7.4

* Measured from linescan data taken at 14:30 on the 7th February. Distance from origin was not possible as its exact location is not known.
** Over a 22km line from the main fire edge were 1.8km from the main fire edge then a cluster from 1.8 to 4.8km, then a further 2 spots 8.1 and 7.1 km apart, taking the distance out to 22km.
+ For Murrindindi no spots to the SW of the origin were named as part of the complex. However two fires were mapped that failing any information on their ignition source have the potential to have been ignited from embers from the Murrindindi complex. The fire called *Upper Yarra Rd – Doctors Ck* distances are provided as possible spotting activity
++ For Murrindindi no spots to the SW of the origin were named as part of the complex. However two fires were mapped that failing any information on their ignition source have the potential to have been ignited from embers from the Murrindindi complex. The fire called *Upper Yarra Rd – Rd 3* distances are provided as possible spotting activity

6.5 Areas identified for potential further research

6.5.1 Fuel dryness

Fuel dryness has a critical effect on fire behaviour and influences fuel consumption, rate of spread and spotting potential. Dry conditions during January and early February 2009 together with periods of extreme high temperatures and low relative humidity in the weeks leading to the 7th February would have contributed to very dry fuels in most forests throughout Victoria. A number of models have been developed to predict fuel moisture content in forests, based either on physical processes (Matthews 2006) or empirical relationships established from field data (Sneeuwjagt and Peet 1985). These models tend to perform best when fuels are drying from a saturated condition, and there is minimal interruption of drying cycles by rain. This was in fact the situation in Victoria during the late spring and early summer leading up to 7th February. Insights into fuel drying trends during January and February 2009 could be provided by using fuel moisture prediction models for representative locations where reliable daily weather observations are available. Modelling would provide a basis for comparing the moisture content of various fuel components (eg. surface litter, deep profile litter, woody fuel particles of different sizes) in a range of forest types and topographic settings. Better knowledge of fuel moisture conditions in different forest types on Black Saturday 2009 would allow fire behaviour to be interpreted and placed in context of other extreme bushfire days experienced in Victoria.

6.5.2 Observations required to determine rate of spread

Reliable determination of the rate of spread of a fire depends upon knowing the position of the fire perimeter at different periods of its development. This information may be obtained from a range of sources including direct observation and reporting on the ground, aerial observation, remote sensing, and inferential observation (eg. activation of alarms, or failure of infrastructure at a known time coincident with arrival of a fire). In preparing this report, the BCRC Fire Behaviour Team did not have access to information on fire location at different times from incident logs, interviews with agency personnel, witness statements taken by the Police, or fire cause investigation reports. Data collected during other parts of the Bushfire CRC investigation particularly from interviews with landowners who witnessed the passage of the fires at their properties would prove valuable in reconstructing the path and timing of fire spread, but this has yet to be validated and cross-referenced to fire behaviour. All of these sources of information will need to be collated and cross-referenced to provide the best possible understanding of the spread of the 7th February bushfires, and to obtain reliable estimates of rate of spread at different stages of fire development. This is a necessary precursor to a proper evaluation of the performance of existing fire behaviour prediction models.

6.5.3 Spotting characteristics of smooth-barked eucalypts

Spotting was an important mechanism of fire spread on 7th February, particularly through broken topography, and is likely to have contributed significantly to the heavy loss of life and extensive property damage in the Kilmore East and Murrundindi fire complexes. Spotting was also an important mechanism of fire spread at the Churchill and Bunyip fires.

The McArthur FFDM predicts expected average spotting distance according to fire danger index and fuel quantity. Spotting information on the FFDM is derived from field observations of wildfires, and potential effects of forest type on spotting behaviour are not explicit in predictions. The Field Guide for Fuel Assessment and Fire Behaviour Prediction in Dry Eucalypt Forest provides tables to predict maximum spotting distance in dry eucalypt forests that contain stringybark trees. Spotting distance predictions from these latter tables do not take into account the contribution of ribbons of bark shed by smooth-barked species which are a potential source of firebrands with significantly longer burn-out times. These ribbons of bark can remain alight in the convection column for considerable time and result in spotting distances much greater than expected for stringybark types.

Substantial areas of forest burnt on 7th February contained smooth barked eucalypts that shed long ribbons of bark conducive to very long distance spotting. Prediction of maximum spotting distance for these forest types under the conditions of 7th February requires knowledge of the maximum height of the convective plume and the flight and burning characteristics of relevant bark types. Firebrand characteristics such as terminal velocity can be determined experimentally in a vertical wind tunnel such as the CSIRO Vertical Wind Tunnel facility in Canberra.

6.5.4 Effects of fuel age on fire behaviour and post-fire ecosystem impacts

Prescribed fire has been used extensively for fuel hazard management in the eucalypt forests of southern Australia since the 1960s. Prescribed burning to reduce fuel load and modify the behaviour of wildfire has long been promulgated as a basic fire protection strategy in eucalypt forest. The reduction of wildfire behaviour immediately following fuel removal by burning is obvious as there is no surface fuel to burn, and crown fires collapse within a few metres of the perimeter of the burnt area. As fuel re-accumulates in subsequent years the benefits of prescribed burning in reducing fire suppression difficulty occur through reduction in fire intensity and spotting.

Systematic analysis of interaction between wildfire behaviour and such factors as vegetation types, weather conditions, and fuel characteristics as modified by prescribed burning is problematic due to the unplanned and chaotic nature of wildfire events. There are always uncertainties about the fuel load on prescribed burnt areas at the time of the wildfire which result from uncertainties about the areas actually burnt during the operation, the fraction of fuel removed and the subsequent rate of fuel accumulation. Accurate measurement of rates of spread and wind speeds during the wildfire are almost unattainable on comparable sites.

Despite these limitations, well designed case studies can contribute to an understanding of the operational effectiveness of fuel reduction by prescribed burning and comparison of matched sites carrying fuel of different ages provides a tangible demonstration of the contribution of fuel load to fire intensity, and the opportunity to compare resultant effects on vegetation, soils and streams (McCaw *et al.* 2008). The bushfires of 7th February burnt in forests with times since last fire ranging from as short as one or two years through to more than 80 years, providing the opportunity for systematic evaluation of the effects of fuel age on fire behaviour and resultant ecosystem impacts. Insufficient time was available for the Bushfire CRC Fire Behaviour Team to examine these questions, but it is strongly recommended that this be done as part of ongoing post-fire research programs.

6.5.5 Fire atmospheric interactions

The events of 7th February 2009 highlight the importance of continuing to investigate the relationship between fire behaviour and weather under extreme burning conditions. Climate change scenarios indicate an increase in the average number of days of very high or extreme fire danger across broad areas of south-eastern Australia (Hennessy *et al*. 2005, Lucas *et al*. 2007). Significant research questions arising from these predictions include the effect of extreme high temperatures on short term dessication of vegetation (Groom *et al*. 2004) and on wind circulation pre and post-frontal changes. Air circulations at and behind frontal systems can interact with the topography and the fire to significantly affect fire behaviour, but these influences remain poorly documented or understood

7. Conclusion

This report summarises data collected by the Fire Behaviour Investigation Team during a five week period of field work following the 7th February Victorian bushfires. Weather data obtained the Bureau of Meteorology has also been presented to provide a context for conditions prior to and on the day of the fires. The objective of the field work was to collect data from fire spread indicators that could, in conjunction with other information about the time and location of the bushfires, be used to reconstruct the passage of the fires. Emphasis was given to collecting information from sources that would change rapidly or be lost forever with the passage of time following the fires.

Data has been organized and presented in a spatial context that will allow it to be linked to sources of information from other investigations undertaken by the Bushfire CRC taskforce, information held by CFA, DSE and other agencies, and observations made by eyewitnesses to the events. A detailed reconstruction of the spread of the fires on 7th February would need to draw upon data and information obtained from a range of sources including incident logs, interviews with agency personnel, witness statements taken by the Police, and fire cause investigation reports. These sources were not available to the Bushfire CRC Fire Behaviour Investigation Team in the time available for preparation of this report and thus no attempt has been made to provide a reconstruction of events or draw conclusions about the behaviour and spread of these fires.

Detailed reconstruction of the spread of the fires is a necessary precursor to placing the events of 7th February in a broader context of past major bushfire events, in understanding the phenomena that may have led to such extensive loss of life and damage to infrastructure, and in evaluating the performance of existing fire behaviour prediction guides under extreme weather conditions. This report has also identified a number of areas within fire perimeters burnt on 7th February that carried fuels less than 10 years old resulting from previous wildfires or prescribed burning. Systematic evaluation with supplementary field assessment and analysis of high resolution air photography or satellite imagery would contribute to a better understanding of the extent to which wildfire behaviour is modified in younger fuels under extreme fire danger conditions.

Acknowledment

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