AS 3959 CONSTRUCTION OF BUILDINGS IN BUSHFIRE-PRONE AREAS – DRAFT FOR PUBLIC COMMENT (DR 05060) REVIEW OF CALCULATION METHODS AND ASSUMPTIONS

Report No. 20735-002.3

Prepared by

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EXECUTIVE SUMMARY

Warrington Fire Research Australia (WFRA) has conducted a review of the calculation methods and the associated assumptions made in AS 3959 Construction of buildings in bushfire-prone areas – Draft for public comment (DR 05060).

Detailed data from surveys undertaken after major bushfires in Australia has generally not been published except in the form of broad conclusions without the underlying supporting data. Therefore the analysis of Australian fires was limited to the fires of Warrimoo, Valley Heights and Yellow Rock, Lower Blue Mountains NSW, 2001-2002 for which some data was available. The analysis of these fires indicated that the methods presented in AS 3959 over predicted radiant heat flux levels by a factor of at least 3 ignoring the effects of assuming potentially conservative FDI values.

The calculation method detailed in DR 05060 for radiant heat transfer is considered to be based on established scientific/engineering principles, but a number of conservative assumptions and empirical correlations are used to derive input data such as flame height, orientation, flame temperature, and width of radiating surface etc which contribute to the over prediction of radiant heat fluxes.

Whilst safety factors of up to 3 are used for some engineering designs they are not usually applied to extreme events such as bushfires where the frequency of occurrence is relatively low. It is important that the level of conservatism is understood when considering a revision to AS 3959 which in effect establishes a community benchmark. The additional cost associated with mitigation measures prescribed in AS 3959 then needs to be balanced against a reduction in potential losses.

Some of the issues identified in the report are summarised below:

Fire Danger Index

The calculated FDI's for the bushfires considered in this report were substantially less than the State/Regional values recommended in Table 2.4 of AS 3959 (Draft). This inconsistency may be due to localised transient variations or the nominated values may overestimate the values in many cases.

The FDI data is not generally available in a suitable format over a 10 year period and this should be taken into account in the Standard. For the next four years it may be appropriate to include an option to adopt a higher percentile value over a shorter time period (say 6 years) however the data collection is variable from one site to another. The basis for calculating individual FDI's and the default FDI's provided in the Standard should be consistent and be nominated by the relevant regulatory authorities since minimum community standards are being defined based on this decision.

Fuel Loads and Flame Length

The contribution of fuel load to separation distance was also found to be significant as it determines flame length and ultimately the height of the effective radiating panel in radiant heat flux calculations. Fuel load accumulation studies demonstrated varied fuel loads with what is required by AS3959 (Draft), confirming that fuel load and accumulation rates are site specific in nature. Therefore, consideration should be given to more locality orientated specified fuel loads for vegetation types. It should also include a means and guidance in performing site specific fuel load assessment as part of the overall assessment in AS3959 (Draft); instead of only being provided by Fire Authorities.

Radiant Heat Flux Assessments

The analysis of the Warrimoo, Valley Heights and Yellow Rock, Lower Blue Mountains, NSW, 2001-2002' fires Ref [13] was used as a case study to assess the appropriateness of the parameters used in AS3959 (Draft). The analysis of these fires indicated that the methods presented in AS 3959 over predict radiant heat fluxes. The case study of the Blue Mountains 01/02 fires, indicated that radiant heat fluxes were over predicted by a factor in excess of three, ignoring the effects of assuming potentially conservative values for the FDI.

Reasons for this include:

- Predicted flame heights may not be appropriate for input into a view factor model.
- Instantaneous flame front widths were probably substantially less than 100m.
- Average flame temperature would have been less than 1,200 K.

The large over prediction can be reduced by adopting smaller values for flame temperature. This is based on the results of Table 5-7 where a reduction in flame temperature from 1,200 K to 900 K would tend to provide results more consistent with the observations in the case studies.

Use of a vertical flame in lieu of a tilted flame, optimised to impose the maximum level of radiant heat flux may is also considered more appropriate in some instances.

The size of the flame zone may also be unrealistically large. It is therefore recommended that the validity of the assumed horizontal flame projection currently in the draft standard be reviewed.

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1 OBJECTIVE

This paper is an investigation into the calculation methods and assumptions used to determine the separation distances adopted in AS 3959 Construction of buildings in bushfire-prone areas – Draft for public comment (AS 3959 Draft), which are based on radiation levels, with additional criteria to account for flame length.

The primary objective is to investigate the suitability of the fire danger indices that are recommended and the calculation methods presented in AS 3959 (Draft).

The study will also consider the appropriateness of the fuel load, flame temperature and flame width recommended in AS 3959 (Draft).

2 INPUT PARAMETERS FOR DETERMINING CATEGORY OF BUSHFIRE ATTACK

There are two methods specified in AS 3959 (Draft) for determining the category of bushfire attack: the simplified process and the detailed process.

2.1 SIMPLIFIED PROCESS

The simplified process can only be used for upslope and down slopes of up to 20º; if the slope is a down slope of greater than 20º the detailed process must be used.

The simplified process involves determining the following parameters, then looking up Tables 2.5.1 to 2.5.4:

- Vegetation type
- Effective slope (º)
- FDI
- Separation distance (m)

The outcome is the level of construction required, from low to flame zone.

2.2 DETAILED PROCESS

The detailed process is used when a more specific result is needed or when the simplified process is not applicable, i.e. down slope of greater than 20º. It involves performing calculations to determine flame length and radiant heat flux. This report only considers forest and woodland fires.

The following input parameters are required to calculate flame length:

- Vegetation type and fuel load
- Effective slope (º)
- FDI

The following input parameters are required to calculate radiant heat flux:

- Separation distance (m)
- Vegetation type
- Effective slope (º)
- FDI
- Ambient temperature (approximated as 308 K)
- Flame temperature (approximated as 1,200 K)
- Relative humidity (approximated as 25 %)
- Emissivity (approximated as 0.95)
- Slope between vegetation and structure (º)
- Elevation of radiation receiver measured from ground level (m)
- Flame width (approximated as 100 m)
- Stefan-Boltzmann constant (5.67×10^{-11} kW/(m^2.K^4))

The tables for the simplified process were derived using the generalised solution of the detailed process.

The detailed method sometimes termed the view factor method defines a radiating source of nominated width, height (based on flame height), flame temperature, emissivity and flame tilt angle. The incident radiant heat flux is then calculated based on a view factor (configuration factor) and the calculated source radiation. Since physical constants are adopted to calculate the source radiation and the view factors are based on mathematical derivations it follows that the method will yield accurate results if the input data is accurate.

However with the current state of knowledge a number of approximations have to be made such as an assumed average flame temperature, flame width, emissivity, and the validity of the empirical relationships used to derive flame height and associated input data.

The remainder of this report will review the input data and use experimental data and use observations after bushfires as a benchmark to judge the appropriateness of the assumed input values.

3 ANALAYIS OF FIRE DANGER INDEX

3.1 GENERAL

One of the input parameters required to determine the category of bushfire attack is the Fire Danger Index (FDI). The effect of FDI has been investigated by obtaining the relevant data from the Bureau of Meteorology for weather stations located in close proximity to a selection of major bushfires which have occurred in Australia and then calculating separation distances based on this data.

The McArthur Fire Danger Index (FDI) was developed to establish a relationship between fuel and fire behaviour, incorporating atmospheric conditions as well.

3.2 AUSTRALIAN CASE STUDIES – BLUE MOUNTAINS 01/02, DANDENONG RANGES 97 AND ASH WEDNESDAY 83.

3.2.1 Selection of Weather Stations

The FDI study was primarily based on the following three bushfires: Blue Mountains (24/12/01-7/1/02), Dandenong Ranges (21-22/1/97) and Ash Wednesday (16/2/83). Weather data used to calculate FDI's, i.e. air temperature, relative humidity and wind speed, were obtained from the weather stations listed in Table 3-1 and which are in close proximity to each of the aforementioned bushfires.

Table 3-1 – List of weather stations for which data was obtained.

Date of bushfire	General location	Weather Stations
24/12/01-7/1/02	Blue Mountains, NSW	67113 Penrith Lakes AWS 67105 Richmond RAAF
21-22/1/97	Dandenong Ranges, Vic	86372 Dunns Hill 86104 Scoresby Research Institute
16/2/83	Ash Wednesday Bushfires, SA	23801 Lenswood Research Centre[1] 23733 Mount Barker[2]

Notes:
1. The only data available for weather station 23801 Lenswood Research Centre was recorded daily at 9am. This is not considered sufficient; therefore, FDI's were not calculated
2. Relative humidity data was not available for weather station 23733 Mount Barker. Therefore, FDI's for this weather station were not calculated.

The type of data available was variable: for one weather station, FDI's (at ~30 min intervals) were provided; while for others, the data comprised readings taken at 9am only. The type of data obtained is summarised in Table 3-2.

Table 3-2 – Available data for each of the weather stations.

Weather Station	Type of data available
67113 Penrith Lakes AWS	FDI (~30 min intervals) and 3-hourly data
67105 Richmond RAAF	3-hourly data
86372 Dunns Hill	3-hourly data
86104 Scoresby Research Institute	3-hourly data
23801 Lenswood Research Centre	9am data only

3.2.2 Calculation of Fire Danger Indices

AS 3959 (Draft) provides State/Regional values for FDI, which may be used in specific bushfire behaviour models to determine separation distances for particular types of constructions. Alternatively, the FDI may be calculated in accordance with AS 3959 (Draft) B1.3, i.e. the 95th percentile for the site for all days with a value greater than 12, for a minimum period of 10 years. It is stipulated that if data is not available for a period of 10 years, the State/Regional values must be used.

The method used for calculating FDI's is described below. The period of time for which the data was available is included in Table 3-3. All data was provided by the Bureau of Meteorology.

The following data was available: air temperature, relative humidity and wind speed, and the FDI's calculated using Equation 1:

$$FDI = 2e^{(-0.45+0.987\log(DF+0.001)-0.0345RH+0.0338T+0.0234WS)} \quad (1)$$

where:

FDI = Fire Danger Index
DF = Drought Factor (A number from 0 to 10, which gives an indication of the proportion of fine fuels available for the forward spread of a fire.)
RH = Relative Humidity (%)
T = Air Temperature (°C)
WS = Wind Speed (10 m above ground level) (km/h)

Drought Factor was available only for weather station 67113 Penrith Lakes AWS. For all other weather stations, it was assumed to be equal to 10. Justification of the use of a drought factor of 10 is based on the drought factor obtained for weather station 67113, which ranged from 9.2 to 9.9 during the first week and was 10 on each day of the second week of the Blue Mountains fires. The FDI's were calculated for each of the data. Any FDI's that were less than 12 (to 2 decimal places) were discarded. The 95th percentile was then calculated using the remaining values.

The calculated FDI's are summarised in Table 3-3, along with the values recommended in Table 2.4 of AS 3959 (Draft)[1].

Table 3-3 – 95th percentile FDI values for each weather station based on directly obtained FDI's, 3-hourly data and 9am data.

Date of bushfire	Name and general location	Weather Stations (including period for which data was obtained)	95th percentile FDI			Max. FDI on the day of the fire	FDI from AS 3959 (Draft) Table 2.4
			½-hourly	3-hourly	9am		
24/12/01 -7/1/02	Blue Mountains Bushfires, NSW	67113 Penrith Lakes AWS (15/9/95-10/1/02 (~6 years))	45	41	21	73 (at 3pm)	100
		67105 Richmond RAAF (22/10/93-10/1/02 (~8 years))	N/A	40	22	65 (at 3pm)	
21-22/1/97	Dandenong Ranges Bushfires, Vic	86372 Dunns Hill (1/12/90-25/1/97 (~6 years))	N/A	37	33	58 (at 12pm)	120
		86104 Scoresby Research Institute (21/1/87-25/1/97 (~10 years))	N/A	34	30	39 (at 12pm)	
16/2/83	Ash Wednesday Bushfires, SA	23801 Lenswood Research Centre (16/2/73-19/2/83 (~10 years))	N/A	N/A	N/A	N/A	120
		23733 Mount Barker[1]	N/A	N/A	N/A	N/A	

All FDI's were calculated using data obtained from the Bureau of Meteorology. The quality of the FDI's is variable, depending on the frequency at which the data was recorded, i.e. ½-hourly, 3-hourly or at 9am only.

Diurnal weather changes should be taken into consideration when selecting the critical weather period for which the FDI, used in fire behaviour models, is calculated. In a study by Plucinski [12] on the relative humidity and dead fuel moisture content in open woodland, it was noted that minimums for both factors occur between 12:00 and 18:00 in the afternoon. These factors are function of the fire behaviour and therefore it is considered that this period also corresponds to periods of high bushfire hazard conditions.

1 The only data available for Weather Station 23801 Lenswood Research Centre was recorded daily at 9am. This is not considered sufficient for calculation of FDI's; therefore, this data has been omitted.

Table 3-4 –FDI values for each weather station based on directly obtained FDI's, using data collected between 1200 and 1800.

Date of bushfire	Name and general location	Weather Stations (including period for which data was obtained)	12:00 to 18:00 Percentile			Max. FDI on the day of the fire	FDI from AS 3959 (Draft) Table 2.4
			95th	98th	Max[1]		
24/12/01 -7/1/02	Blue Mountains Bushfires, NSW	67113 Penrith Lakes AWS	43	54	82	73 (at 3pm)	100
		67105 Richmond RAAF	53	63	91	65 (at 3pm)	
21-22/1/97	Dandenong Ranges Bushfires, Vic	86372 Dunns Hill	45	49	58	58 (at 12pm)	120
		86104 Scoresby Research Institute	39	39	39	39 (at 12pm)	
16/2/83	Ash Wednesday Bushfires, SA	23801 Lenswood Research Centre	N/A	N/A	N/A	N/A	120
		23733 Mount Barker[1]	N/A	N/A	N/A	N/A	

Note 1 Max reading during the sample period

3.2.3 *Discussion of Fire Danger Indices*

Although the draft AS 3959 requires 10 years of data to derive FDI's the experience of sourcing the data has shown that only approximately 6 years of data is available at most sites and the frequency of recording is such that the data may not be sufficient to capture peak or close to peak FDI's. In addition the 95th percentile value is substantially below the FDI's in the default table and those experienced during major bushfires.

The method for determining the FDI, to be used as the basis for the fire behaviour models, does not adequately reflect data available, nor is the data acceptance criterion. As it was considered that higher bushfire hazard conditions were associated with temperature, relative humidity and moisture content in the surface fuel load [11], FDI's should also be limited to the times when this is likely. This was considered in [11] to be in the afternoon between 1200 and 1800.

If the 95th FDI percentile is adopted for this higher bushfire hazard period, the value obtained is half or less of the State/Territory values assigned in AS3959 (Draft). Furthermore, these assigned FDI's were significantly greater than the days of major bushfire events and the maximum FDI values calculated during the period of weather data recording at subject weather stations. Therefore, for the selected sites, separation distances which are calculated using the recommended FDI's are likely to be conservative unless higher localised FDI's occurred during the fire

This assessment has demonstrated a level of conservatism in assigned FDI values compared to data from the weather stations, even when the percentile of FDI used is increased to the 98th percentile. Since FDI's have a significant influence on the calculated incident heat flux and hence safety levels it is recommended that the values should be set by the appropriate regulatory authorities since they will define minimum community standards.

4 ANALYSIS OF FUEL LOADS

4.1 GENERAL

AS3959 (Draft) requires the surface and overall fuel load to determine rate of spread and in the calculation of flame length. Appendix B of AS3959 (Draft) states that these values are to be sought from Table B2 or other data sets provided by the relevant fire authority that is relevant to the site.

The following is an extract from Table B2 of AS3959 (Draft):

Table 4-1 – Fuel loads to be used in assessment, proposed in AS3959 (Draft).

Vegetation Class	Surface Fuel Load (t/ha)	Overall Fuel Load (t/ha)
Forests	25	35
Woodlands	15	25
Closed Shrub	25	25
Open Shrub Mallee/Mulga	15 8	15 8
Rainforest	10	12
Tussock Moorlands	17	17

The fuel loads are used to calculate the rate of spread (R) which is given by:

$$R = (0.0012 \times FDI \times \text{Surface Fuel Load}) \times e^{(0.069 \times \text{slope})} \text{ (km/h)} \quad (2)$$

where: slope is expressed in degrees

For Forest and Woodland fuel types, with the Rate of Spread and Overall Fuel Load the flame length (L_f) is given by:

$$L_f = 1/2\ (13R+0.24 \times \text{Overall Fuel Load}) \text{ (m)} \quad (3)$$

Tolhurst [19] noted that course fuels (greater than 6mm in diameter) do not contribute to the rate of spread of a bushfire and therefore flame length. Instead, course fuels contribute to the residence time of a fire and therefore the duration that the bushfire is sustained. As this is the case, it is considered that the parameter of the 'overall fuel load' is not appropriate. The introduction of the 'overall fuel load' parameter is also inconsistent with the models originally created by Noble et. al. [11] from McArthur's work.

Therefore, the use of overall fuel load in the flame length calculation, for a Forest or Woodland vegetation, over predicts the flame length by approximately 1.1.

4.2 SITE SPECIFIC FUEL LOAD

As stated, above, AS3959 (Draft) allows the use of other data sets provided by the relevant fire authority. It does not however allow other parties to perform a site specific fuel load assessment so to formulate site specific separation distances and construction requirements.

Without a detailed assessment of the pattern of fuel load accumulation an appropriate level can not be established that is suitable to be used in the assessment.

Gould and Sullivan [7] states that the accumulation of litter fuels differs from place to place but follows the general form of:

$$w_{tt} = w_{ss}\,(1 - e^{-kt}) \quad (4)$$

where w_{tt} is the fuel load (t/ha) accumulated after time t (years); w_{ss} is the steady state quantity of accumulated litter fuels (t/ha) and k is the decay constant.

Such parameters have been studied at various sites around Australia and a summary is provided in [7]. In studies summarised the following steady state accumulated litter fuel quantities are extracted in Table 4-2, depending on location and vegetation type. Therefore these values represent a maximum fuel load in each system.

Table 4-2 - Steady state accumulated fuel loads in several locations.

Vegetation Type	Location	Steady State Accumulated Fuel Load (t/ha)
Old Forest Mix dry sclerophyll	NSW - Blue Mountains	13.7 23.8 with understorey.
E. sieberi	NSW – South East	11.7 – 12.6
	VIC – East Gippsland	5.0 – 10.0
E. diversicolor	WA - Southwest	8.1 – 15.6
E. marginata	WA - Southwest	29.4 – 41.0
Pinus radiata	ACT – Pine Plantation	17.0

In considering the studied steady state fuel loads, the recommended 25t/ha in AS3959 (Draft) is considerably higher than those found in sites in the eastern states, though under estimates for a site in southwest Western Australia. These values also assume that fuel reduction of the site has not occurred for a long period which is unlikely for many sites in NSW and Victoria.

In a *E. seeberi* forest in Victoria, AS3959 (Draft) requires the use of 25t/ha for the surface fuel load, however this is between 2.5 and 5 times the values quoted above, assuming the area had not undergone some burning, natural or prescribed burning. Assuming even ground and a FDI of 120, the AS3959 (Draft) calculated flame length is 28m rather than 9m, i.e. more than 3 times over prediction of the flame height.

Because of the large differences observed and potential for gross over or under assessment, though it may be impossible for each area to have a similar study to be undertaken, it may be considered appropriate to provide local or state values for particular vegetation type, as provided for FDI's.

4.3 AUSTRALIAN CASE STUDIES – BLUE MOUNTAINS 01/02, DANDENONG RANGES 97 AND ASH WEDNESDAY 83.

The vegetation for the three relevant bushfires was classified in accordance with AS 3959 (Draft) as medium open forest (trees 10-30 m high, foliage cover of 30-70%) (Type 5). Therefore, surface fuel load (w) and overall fuel load (W) were 25 t/ha and 35 t/ha respectively, as per AS 3959 (Draft) Table B2.

Some trees may have been taller than 30 m; however, this would result in tall open forest vegetation (Type 2), which has the same fuel loads as Type 5. In the case of the Blue Mountains fires, the slope varied depending on the site location: ~0º (level ground) for the Singles Ridge Rd and Paterson Rd sites (obtained from [13]), and ~18º for the Terrymont Rd and Cross St sites (obtained from [13]). All other slopes were assumed to be 0º, i.e. level ground.

Table 4-3 – Calculation of flame length using the calculated FDI's and those recommended in AS 3959 (Draft), and the observed flame lengths.

Weather station (and slope)	FDI			L_f(m)		
	95th percentile	On day of fire	AS 3959 (Draft)	95th percentile	On day of fire	AS 3959 (Draft)
67113 (0º)	45	73	100	13.0	18.4	23.7
67113 (18º)				34.6	53.5	71.7
67105 (0º)	40	65	100	12.0	16.9	23.7
67105 (18º)				31.2	48.1	71.7
86372	37	58	120	11.4	15.5	27.6
86104	34	39	120	10.8	11.8	27.6

A detailed bushland fuel quantity survey was conducted in the Blue Mountains by Van Loon [20] in 1977. The results of the survey are shown in Figure 4-1.

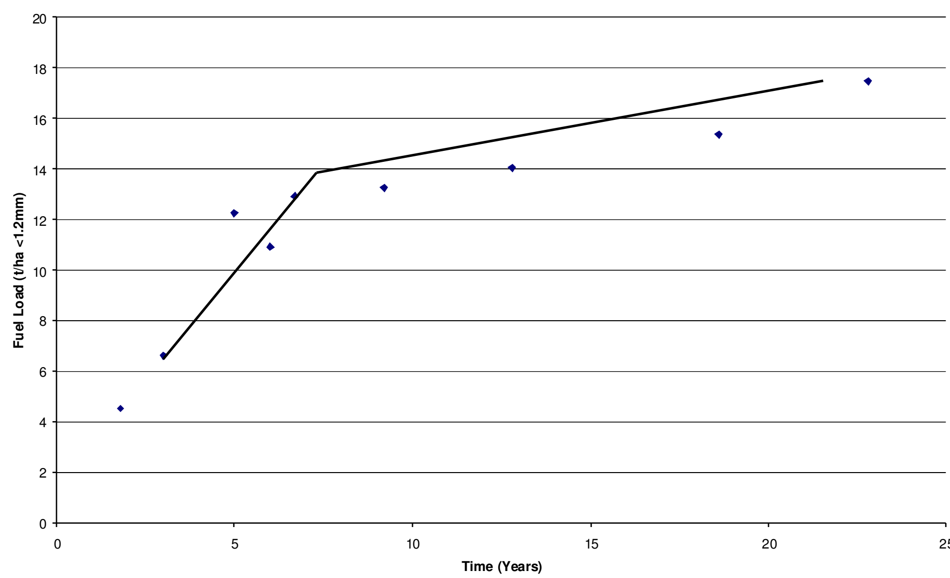

Figure 4-1 – Fuel load accumulation in the Blue Mountains.

As shown, the fuel load at the site is likely to be considerably less than the 25 t/ha specified in AS3959 (Draft) for forest vegetation type. It may be considered appropriate to specify a 20 year period between fuel reduction burns so a fuel load of 16 t/ha will be used in the case study. This is greater than the steady state fuel load accumulation of 14 t/ha specified in the general fuel load accumulation model [7] and considered appropriate when considered in conjunction with current fuel load reduction programs.

Table 4-4 – Comparison of Flame Lengths based on Fuel Load.

Weather station (and slope)	L_f (m) AS3959 Fuel Load			L_f(m) Site Specific Fuel Load based on 20 year burn		
	95th percentile	Estimate for fire	AS 3959 (Draft)	95th percentile	Estimate for fire	AS 3959 (Draft)
67113 (0º)	13.0	18.4	23.7	7.07	10.34	13.50
67113 (18º)	34.6	53.5	71.7	20.03	31.37	42.31
67105 (0º)	12.0	16.9	23.7	6.48	9.41	13.50
67105 (18º)	31.2	48.1	71.7	18.0	28.13	42.31

Table 4-5 – Ratio of over prediction indicated for AS3959 (Draft) for Calculation of Flame Length based on Fuel Load.

Weather station (and slope)	Ratio of Over Prediction		
	95th percentile	On day of fire	AS 3959 (Draft)
67113 (0º)	1.8	1.8	1.8
67113 (18º)	1.7	1.7	1.7
67105 (0º)	1.9	1.8	1.8
67105 (18º)	1.7	1.7	1.7

A comparison of the results with the different fuel loads demonstrates that with an increase in the required fuel load quantities used in AS3959 (Draft) an over prediction of between 1.7 to 1.9 is obtained. This further supports the recommendation that more site specific fuel load (state or local area variations) be provided in AS3959 (Draft).

5 CALCULATION OF SEPARATION DISTANCES AND RADIANT HEAT FLUX

5.1 COMPARISON WITH CATEGORIES OF BUSHFIRE ATTACKED PROPOSED IN AS3959 (DRAFT)

AS 3959 (Draft) categorises bushfire attack into 6 categories from Low to Flame Zone, according to the following criteria:

- Low – Separation distance ≥100 m
- Medium – Separation distance <100 m and radiant heat flux ≤ 12.5 kW/m^2
- High – Radiant heat flux >12.5 kW/m^2 but ≤ 19 kW/m^2
- Very High – Radiant heat flux >19 kW/m^2 but ≤ 29 kW/m^2
- Extreme – Radiant heat flux >29 kW/m^2 but ≤ 40 kW/m^2
- Flame Zone - Radiant heat flux >40 kW/m^2

The applicable category for a nominated distance from the fire front / vegetation was calculated in accordance with Appendix B of AS 3959 (Draft) in the following scenarios:

- the FDI's recommended in AS 3959 (Draft) Table 2.4.
- the calculated FDI's as presented in Table 3-3 using a Drought Factor of 10 (95th percentile and FDI on day of fire); and
- FDI's at the time of major bushfires

In this approach, flame angle is optimised to give the greatest radiant heat imposed by the flame front. Where FDI's were calculated for two weather stations in close proximity to one another, only the greater of the two FDI's was used to calculate separation distances. The results are presented in Table 5-1.

Table 5-1 – Calculated separation distances for both of the bushfires investigated for which appropriate data was available.

Bushfire location	FDI		Flame zone	Extreme	Very high	High	Medium	Low
Blue Mountains	Rec.	100	d<27	27≤ d<35	35≤ d<47	47≤ d<62	62≤ d<100	d≥100
	95th	45	d<15	15≤ d<21	21≤ d<30	30≤ d<41	41≤ d<100	
	Day of fire	73	d<21	21≤ d<28	28≤ d<39	39≤ d<52	52≤ d<100	
Dandenong Ranges	Rec.	120	d<31	31≤ d<39	39≤ d<52	52≤ d<68	68≤ d<100	
	95th	37	d<14	14≤ d<18	18≤ d<27	27≤ d<37	37≤ d<100	
	Day of fire	58	d<18	18≤ d<24	24≤ d<34	34≤ d<46	46≤ d<100	

5.2 AUSTRALIAN CASE STUDIES – BLUE MOUNTAINS 01/02

The level of radiant heat flux was calculated using FDI's of 45, 73 and 100 (refer

Table 3-3) and separation distances obtained from relevant parts of AS3959 (Draft). The calculated radiant heat fluxes were then compared to estimated levels of radiant heat flux, also obtained from [13]. The methodology used to estimate these levels of radiant heat flux, extracted from [4], is described below.

In considering these results it should be noted that precisely identifying the fuel load and vegetation class after the fire is difficult, especially when considering that items that control the spread of fire (litter less than 6mm in diameter [2]) are often completely consumed even in low intensity burns. Assessment of pictures of the aftermath to the bushfires and the Blue Mountain vegetation accumulation studies by Van Loon [20] have been used to provide a reasonable approach to determining vegetation structure and fuel load for comparative study of AS3959 (Draft) with the case studies, as discussed in Section 4.3.

Whilst the sensitivity to fuel load is relatively small, the vegetation type may have an impact of determining if flame contact would occur and therefore a firm recommendation on an appropriate size for the flame zone has not been given.

Further detailed surveys from major bushfires will enable better estimates of the size of the flame zone to be made.

5.2.1 *Estimation of observed radiant heat flux based on post fire observations at Guides' Hall, Singles Ridge Road, Winmalee*

The building was oriented North/South on generally level ground so that the rear of the hall faced west. There was bushland to the West of the building and it is from this direction that the fire front came. The building was of single brick construction with a gently sloping corrugated iron roof. The building was surrounded by a ~1.5 m wide veranda, the roof of which was supported by 90 mm x 90 mm rough sawn radiata timber posts.

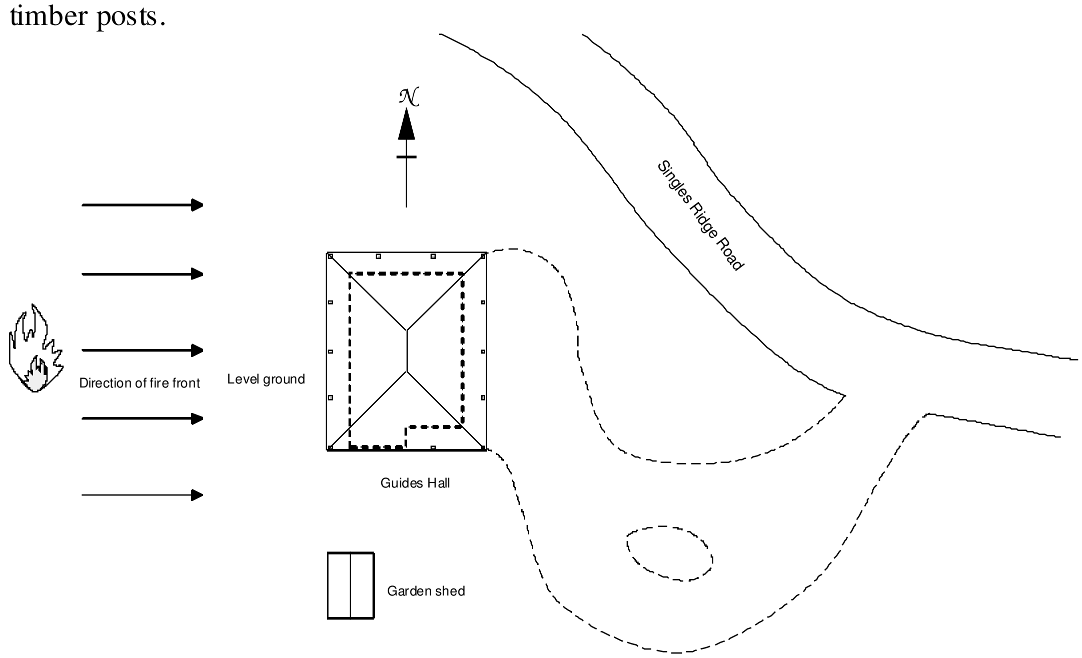

Figure 5-1- Guide's Hall building orientation off Singles Ridge Road.

1) *Damaged uPVC downpipe*

There was an uPVC downpipe located on the Southern wall of the building. Although the pipe did not show any signs of blackening, the top part had been sufficiently heated to cause softening/distortion of the pipe. There was an opening above the pipe, between the top of the brick work and the corrugated iron roof. The timber battens near this opening were badly scorched and the timber top plates were completely consumed.

This evidence suggests that damage to the pipe was caused by a localised heat source, i.e. the opening above the pipe, and that the level of radiant heat flux from the flame front was insufficient to cause blackening of the pipe.

Figure 5-2 - Melted uPVC downpipe on southern wall of the building.

During tests performed by WFRA [15], uPVC pipes of various sizes were exposed to 60 kW/m^2 for a period of 2 minutes. The background level of radiant heat flux was approximately 12.5-16 kW/m^2. The pipes were initially exposed to a radiant heat flux of 16 kW/m^2. The pipes showed signs of blackening after only about 1 minute and after 2 minutes they began to deform. The duration of exposure to the peak level of radiant heat flux of a flame front is generally in the order of 25-70 seconds [1], [2], [3] and [7]. Therefore, as the pipe didn't show any signs of blackening, the maximum peak level of radiant heat flux that could have been imposed on the pipe by the flame front is estimated at 16 kW/m^2.

Figure 5-3 – Vegetation on western side of the building where bushfire front approached.

2) *Charred timber posts.*

The exposed faces (facing the flame front) of the 5 posts on the Western side of the building were charred. Even though the posts were located only ~3.5 m from the vegetation line, as all posts were uniformly charred it is likely that non-piloted ignition occurred. Levels of radiant heat flux required for piloted and non-piloted ignition of timber are summarised in Table 5-2.

Table 5-2 – Effect of radiant heat flux on timber.

Radiant heat flux (kW/m^2)	Exposure time (s)	Result	Source
12.5	Prolonged	Piloted ignition	Drysdale (1998) [5]
13	Prolonged	Piloted ignition	AS 1530.4-1997 [16]
25	Prolonged	Non-piloted ignition	AS 1530.4-1997 [16]
29	Prolonged	Non-piloted ignition	Drysdale (1998) [5]
45	20	Non-piloted ignition	AS 1530.4-1997 [16]
55	10	Non-piloted ignition	AS 1530.4-1997 [16]

During tests performed by WFRA [15], an 88 mm x 88 mm treated pine timber post was exposed to 60 kW/m^2 for a period of 1 minute. The background level of radiant heat flux was approximately 12.5-16 kW/m^2. Non-piloted ignition of the post occurred when the level of radiant heat flux was increased from 16 kW/m^2 to 60 kW/m^2. The post burnt for approximately 90 seconds. When the level of radiant heat flux was reduced to 12.5 kW/m^2, the post self-extinguished. The post was charred to a depth of ~2 mm on all three exposed sides. The results of the test indicate that flaming combustion of the timber post is unlikely to be sustained if the level of radiant heat flux to which it is exposed is less than 12.5 kW/m^2, which is in general agreement with those values specified in Table 5-2.

Figure 5-4 – Charring of veranda posts.

5.2.2 *Estimation of observed radiant heat fluxes based on post fire observations at House E2, 52 Terrymont Road, Winmalee*

The house was a 2 storey brick house with a tiled roof. It was oriented generally along the North/South axis and there was bushland to the West of the House. The fire front approached from the West and the land sloped away from the house in this direction. Full details can be obtained from Poon [13].

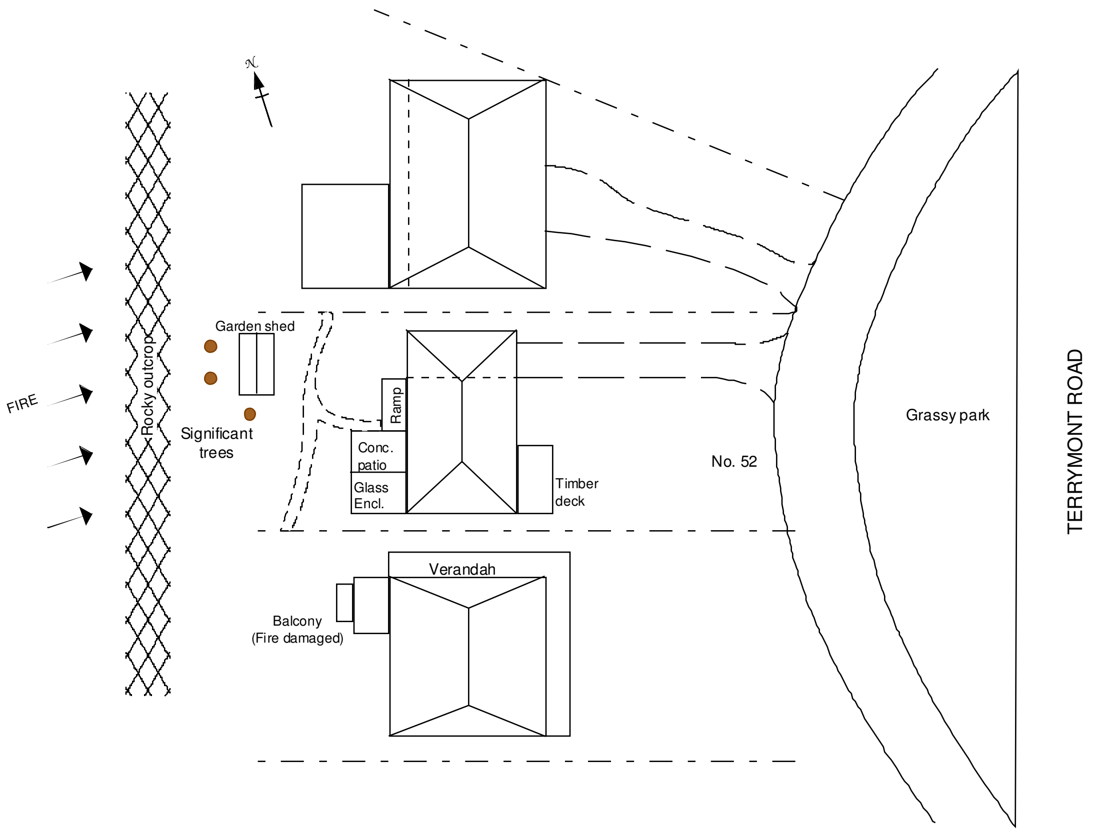

Figure 5-5 - Terrymont Road – Warrimoo.

There was a concrete patio at the rear of the house, upon which outdoor timber furniture was present. Although there is evidence of ember damage, the timber was generally unaffected by the fire and did not show any signs of scorching. Both of the adjacent houses had light timber trellis and railings at the rear of the house, located a similar distance from the fire front as the outdoor furniture. As was the case for the furniture, the trellis and railings did not show any signs of significant scorching.

Figure 5-6 - Outdoor furniture on concrete patio largely intact.

During tests performed by WFRA [15], Western Red Cedar siding was exposed to 40 kW/m^2 for a period of 1 minute. The background level of radiant heat flux was approximately 12-13 kW/m^2. After exposure to 12 kW/m2 for ~3 minutes, the siding showed signs of scorching. Non-piloted ignition of the siding occurred after it had been exposed to a radiant heat flux of 40 kW/m^2 for ~1 minute (5 minutes total exposure). The siding burnt for approximately 90 seconds. When the level of radiant heat flux was reduced to 13 kW/m^2, the siding self-extinguished.

The results of the test indicate that the timber becomes scorched after exposure to 12 kW/m^2 for 3 minutes. Furthermore, flaming combustion of the timber siding cannot be sustained if the level of radiant heat flux to which it is exposed is less than 13 kW/m^2, which is in general agreement with those values specified in Table 5-2.

The likely duration of a bushfire flame front is estimated at 60-120 seconds [2] and [6]. Evidence suggests that timber will become scorched if exposed to a radiant heat flux of 12 kW/m^2 for 3 minutes. Therefore, it is unlikely that the peak level of radiant heat imposed on the furniture, trellis and railings by the fire front could have been significantly greater than 12 kW/m^2.

5.2.3 Estimation of observed radiant heat fluxes based on post fire observations at House B97, Paterson Road, Valley Heights

The house was oriented approximately North/South with bushland to the South of the house. The fire front came from the South West. The house was of full brick construction on a concrete slab. There was a timber deck at the rear of the house that was completely consumed during the fire.

There was a uPVC pipe running along the rear wall of the house. Although the pipe did not show any signs of blackening, a section of it appeared to have been sufficiently heated to cause it to become softened/melted. The softened section was adjacent the timber deck; the rest of the pipe was unaffected by the fire. This suggests that damage to the pipe was caused by heat from the timber deck, and that the level of radiant heat flux from the flame front was insufficient to cause blackening of the pipe. This is a similar scenario to the Guides' Hall where it was concluded that damage to the uPVC pipe was caused by a local heat source. Based on the same evidence as for the Guides' Hall, the maximum peak level of radiant heat flux that could have been imposed on the pipe by the flame front is 16 kW/m^2.

5.2.4 Estimation of observed radiant heat fluxes based on post fire observations at House I3, Cross Street, Warrimoo

The house was located on a ridge running North/South along Cross Street, with the rear of the house facing west. The house was located at the top of a rocky outcrop that sloped away from the house at approximately 25-30 degrees. The fire came from the West.

There was a basketball frame and backboard on a concrete slab at the rear of the house. Although this was badly scorched during the fire, only a small portion, in the bottom corner, was burnt through. As the backboard was not consumed, it is unlikely that the level of radiant heat flux was insufficient to cause non-piloted ignition of the backboard. The small portion that burnt through is likely to have occurred due to piloted ignition.

Figure 5-7 - Damaged basketball backboard.

During tests performed by WFRA [15], Western Red Cedar siding showed signs of scorching when exposed to 12 kW/m^2 for ~3 minutes and non-piloted ignition of the siding occurred after it had been exposed to a radiant heat flux of 40 kW/m^2 for ~1 minute (5 minutes total exposure). On this basis, and assuming a flame front duration of 30-70 seconds, it is likely that the level of radiant heat flux to which the backboard was exposed was greater than 12 kW/m^2 and less than 40 kW/m^2, which is consistent with the data provided in Table 5-2.

Figure 5-8 – Vegetation behind basketball court.

5.2.5 *Results of Blue Mountains Case Study*

Table 5-3 - Calculation of radiant heat flux for Blue Mountains fires using a tilted flame, optimised for maximum radiant heat flux.

Location		Sep. dist. (m) & slope (º)	Calculated imposed radiant heat flux using various FDI's (kW/m^2)			Estimated imposed radiant heat flux based on observations (kW/m^2)	Ratio of calculated radiant heat flux (day of fire) to observed radiant heat flux
			95th	Day of fire	Rec.		
Guides' Hall	uPVC pipe	3.5 (0º)	102*	102*	102*	q < 16	> 6.4
Guides' Hall	timber posts	5.5 (0º)	102*	102*	102*	q > 29	< 3.5
House E2 – timber furniture, timber trellis and railings		15 (18º)	102*	102*	102*	q ~ 12	~ 8.5
House B97 – uPVC pipe		10 (0º)	64	92	102*	q < 16	> 5.8
House I3 – basketball backboard		3 (18º)	102*	102*	102*	12 < q < 30	3.4-8.5

Notes: * Imposed radiant heat fluxes of 102 kW/m2 indicate potential flame contact if flames are deflected due to wind.

The results of Table 5-3 indicate that flame contact from the fire front would occur i.e. the elements of construction were engulfed in flame. There was no evidence of flame engulfment of the elements considered. The calculated radiant heat fluxes are generally 102 kW/m^2 and are approximately 3 to 9 times greater than the estimated radiant heat fluxes based on observations of actual bushfires. The value of 102 kW/m^2 is indicative of the source level of radiant heat, reduced to take into consideration atmospheric transmissivity and emissivity just before flame contact.

A sensitivity study has been undertaken by recalculating Table 5-3 using:

- A vertical flame (Table 5-4),
- site specific fuel load of 16t/ha in lieu of 25t/ha (Table 5-5),
- reduction in flame temperature from 1,200 K to 900 K with a tilted flame (Table 5-6), and
- a reduction in flame temperature from 1,200 K to 900 K with a vertical flame (Table 5-7).

Table 5-4 – Calculation of radiant heat flux for Blue Mountains fires using a vertical flame.

Location		Sep. dist. (m) & slope (º)	Calculated imposed radiant heat flux using various FDI's and assuming a vertical flame (kW/m²)			Estimated imposed radiant heat flux based on observations (kW/m²)	Ratio of calculated radiant heat flux (day of fire) to observed radiant heat flux
			95th	Day of fire	Rec.		
Guides' Hall	uPVC pipe	3.5 (0º)	88	94	96	q < 16	> 5.9
	timber posts	5.5 (0º)	76	85	89	q > 29	< 2.9
House E2 – timber furniture, timber trellis and railings		15 (18º)	65	82	86	q ~ 12	~ 6.8
House B97 – uPVC pipe		10 (0º)	52	62	74	q < 16	> 3.9
House I3 – basketball backboard		3 (18º)	99	100	100	12 < q < 30	3.3-8.3

Table 5-5 – Site Specific Fuel Loads for Blue Mountains.

Location		Sep. dist. (m) & slope (º)	Calculated imposed radiant heat flux using various FDI's and assuming a vertical flame (kW/m²)			Estimated imposed radiant heat flux based on observations (kW/m²)	Ratio of calculated radiant heat flux (day of fire) to observed radiant heat flux
			95th	Day of fire	Rec.		
Guides' Hall	uPVC pipe	3.5 (0º)	68	83	89	q < 16	> 5.6
	timber posts	5.5 (0º)	54	68	77	q > 29	< 2.7
House E2 – timber furniture, timber trellis and railings		15 (18º)	52	68	77	q ~ 12	~ 6.4
House B97 – uPVC pipe		10 (0º)	32	45	54	q < 16	> 3.4
House I3 – basketball backboard		3 (18º)	96	98	99	12 < q < 30	3.3-8.3

Notes: * Imposed radiant heat fluxes of 102 kW/m2 indicate potential flame contact if flames are deflected due to wind.

Table 5-6 – Calculation of radiant heat flux for Blue Mountains fires using a flame temperature of 900 K in lieu of 1,200 K.

Location		Sep. dist. (m) & slope (º)	Calculated imposed radiant heat flux using various FDI's (kW/m^2)			Estimated imposed radiant heat flux based on observations (kW/m^2)	Ratio of calculated radiant heat flux (day of fire) to observed radiant heat flux
			95th	Day of fire	Rec.		
Guides' Hall	uPVC pipe	3.5 (0º)	32*	32*	32*	q < 16	> 2.0
Guides' Hall	timber posts	5.5 (0º)	32*	32*	32*	q > 29	< 1.1
House E2 – timber furniture, timber trellis and railings		15 (18º)	32*	32*	32*	q ~ 12	~ 2.7
House B97 – uPVC pipe		10 (0º)	20	29	32*	q < 16	> 1.8
House I3 – basketball backboard		3 (18º)	32*	32*	32*	12 < q < 30	1.1-2.7

Notes: * Imposed radiant heat fluxes of 32 kW/m2 indicate potential flame contact if flames are deflected due to wind.

Table 5-7 – Calculation of radiant heat flux for Blue Mountains fires using a vertical flame and a flame temperature of 900 K in lieu of 1,200 K.

Location		Sep. dist. (m) & slope (º)	Calculated imposed radiant heat flux using various FDI's and assuming a vertical flame (kW/m^2)			Estimated imposed radiant heat flux based on observations (kW/m^2)	Ratio of calculated radiant heat flux to observed radiant heat flux	
			95th	Day of fire	Rec.		Day of fire	Rec
Guides' Hall	uPVC pipe	3.5 (0º)	27	29	30	q < 16	> 1.8	> 1.9
Guides' Hall	timber posts	5.5 (0º)	24	26	28	q > 29	< 0.9	< 0.97
House E2 – timber furniture, timber trellis and railings		15 (18º)	20	25	27	q ~ 12	~ 2.1	~ 2.25
House B97 – uPVC pipe		10 (0º)	16	19	23	q < 16	> 1.2	> 1.4
House I3 – basketball backboard		3 (18º)	31	31	31	12 < q < 30	1.0-2.6	1.0-2.6

The results of Table 5-4 indicate that use of a vertical flame instead of a tilted flame results in a reduction in imposed radiant heat flux. This is to be expected due to a reduction in view factor. Furthermore, there is no longer any flame contact.

The results of Table 5-5 indicate that a site specific fuel load does effect the overall radiant heat flux calculations. The calculated radiant heat fluxes are approximately 2 to 8 times greater than the estimated radiant heat fluxes based on observations of actual bushfires (rather than 3 to 8 times). This is due to the small separation distances that were present, which generally cause the radiant heat flux to be less dependent on flame height, particularly when an optimised flame angle is used.

The results of Table 5-6 indicate that a reduction in assumed flame temperature from 1,200 K to 900 K will cause a significant reduction in imposed radiant heat and the resulting ratio of calculated to observe radiant heat is approximately 1 to 3. This is to be expected as radiant heat flux is approximately proportional to T^4. This is the most significant of the three sensitivity studies in which a single input parameter was altered.

Whilst transient peak temperatures of 1200K and above will occur the fire front is not uniform and the peak temperatures will not occur simultaneously across the whole front [1]. Thus it is reasonable to consider a lower average value for an assumed fire front that is 100m wide.

The results of Table 5-7, in which a reduction in flame temperature is considered along with a vertical flame, are results which better reflect post fire observations with over predictions in the range of approximately 1 to 3.

6 CONCLUSIONS

Detailed data from surveys undertaken after major bushfires in Australia has generally not been published except in the form of broad conclusions without the underlying supporting data. Therefore the analysis of Australian fires was limited to the fires of Warrimoo, Valley Heights and Yellow Rock, Lower Blue Mountains, NSW, 2001-2002 for which some data was available. The analysis of these fires indicated that the methods presented in AS 3959 over predicted radiant heat flux levels by a factor of at least 3 ignoring the effects of assuming potentially conservative FDI values.

The calculation method detailed in DR 05060 for radiant heat transfer is considered to be based on established scientific/engineering principles, but a number of conservative assumptions and empirical correlations are used to derive input data such as flame height, orientation, flame temperature, and width of radiating surface etc which contribute to the over prediction of radiant heat fluxes.

Whilst safety factors of up to 3 are used for some engineering designs they are not usually applied to extreme events such as bushfires where the frequency of occurrence is relatively low. It is important that the level of conservatism is understood when considering a revision to AS 3959 which in effect establishes a community benchmark. The additional cost associated with mitigation measures prescribed in AS 3959 then needs to be balanced against a reduction in potential losses.

Some of the issues identified in the report are summarised below

Fire Danger Index

The calculated FDI's for the bushfires considered in this report were substantially less than the State/Regional values recommended in Table 2.4 of AS 3959 (Draft). This inconsistency may be due to localised transient variations or the nominated values may overestimate the values in many cases.

The FDI data is not generally available in a suitable format over a 10 year period and this should be taken into account in the Standard. For the next four years it may be appropriate to include an option to adopt a higher percentile value over a shorter time period (say 6 years) however the data collection is variable from one site to another. The basis for calculating individual FDI's and the default FDI's provided in the Standard should be consistent and be nominated by the relevant regulatory authorities since minimum community standards are being defined based on this decision.

Fuel Loads and Flame Length

The contribution of fuel load to separation distance was also found to be significant as it determines flame length and ultimately the height of the effective radiating panel in radiant heat flux calculations. Fuel load accumulation studies demonstrated varied fuel loads with what is required by AS3959 (Draft), confirming that fuel load and accumulation rates are site specific in nature. Therefore, consideration should be given to more locality orientated specified fuel loads for vegetation types. It should also include a means and guidance in performing site specific fuel load assessment as part of the overall assessment in AS3959 (Draft); instead of only being provided by Fire Authorities.

Radiant Heat Flux Assessments

The analysis of the Warrimoo, Valley Heights and Yellow Rock, Lower Blue Mountains, NSW, 2001-2002' fires Ref [13] was used as a case study to assess the appropriateness of the parameters used in AS3959 (Draft). The analysis of these fires indicated that the methods presented in AS 3959 over predict radiant heat fluxes. The case study of the Blue Mountains 01/02 bushfires indicated that radiant heat fluxes were over predicted by a factor in excess of three, ignoring the effects of assuming potentially conservative values for the FDI.

Reasons for this include:

- Predicted flame heights may not be appropriate for input into a view factor model.
- Instantaneous flame front widths were probably substantially less than 100m.
- Average flame temperature would have been less than 1,200 K.

The large over prediction can be reduced by adopting smaller values for flame temperature. This is based on the results of Table 5-7 where a reduction in flame temperature from 1,200 K to 900 K would tend to provide results more consistent with the observations in the case studies.

Use of a vertical flame in lieu of a tilted flame, optimised to impose the maximum level of radiant heat flux may is also considered more appropriate in some instances.

The size of the flame zone may also be unrealistically large. It is therefore recommended that the validity of the assumed horizontal flame projection currently in the draft standard be reviewed.

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