A Computerised Model for Bushfire Attack Assessment and Its Applications in Bushfire Protection Planning

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EXTENDED ABSTRACT

Bushfires are natural hazards posing severe threat to property, life and the environment. To minimize bushfire risks, many bushfire protection measures can be taken. Among these measures are land use planning, development controls and hazard reduction. The proper implementation of these measures requires that the level of bushfire attack be estimated with an appropriate approach. Although two qualitative approaches for this purpose are currently available in Australia, that is, the approaches specified in AS *3959* 1999 (SA, 1999) and NSW *Planning for Bushfire Protection 2001 (PFBFP)* (NSW RFS, 2001), they have some intrinsic shortcomings such as low assessment accuracy and limited application range.

In order to overcome the shortcomings with the existing approaches, a new quantitative assessment methodology together with a computer program implementing the methodology has been developed by the Authors. The methodology consists of two sets of equations. The first set of equations are used for modelling flame length while the second set of equations are used for modelling radiation. Depending on the types of vegetation, flame length is modelled by different empirical flame length equations. Radiation modelling is based on a generalised view factor model which takes effects of inclined flame and the attenuation into account.

The new methodology involves a large amount of computational effort. Although it is possible for a professional to conduct a manual assessment, the task would become very time consuming and error-prone. To improve the accuracy and efficiency of the methodology as well as its availability, it has been coded in Visual Basic for Application (VBA) within the MS Access database environment. As shown in Figure 1, the computerisation process consists of five major steps, that is, specifying inputs, calculating flame length, calculating radiation, determining bushfire attack level and displaying outputs.

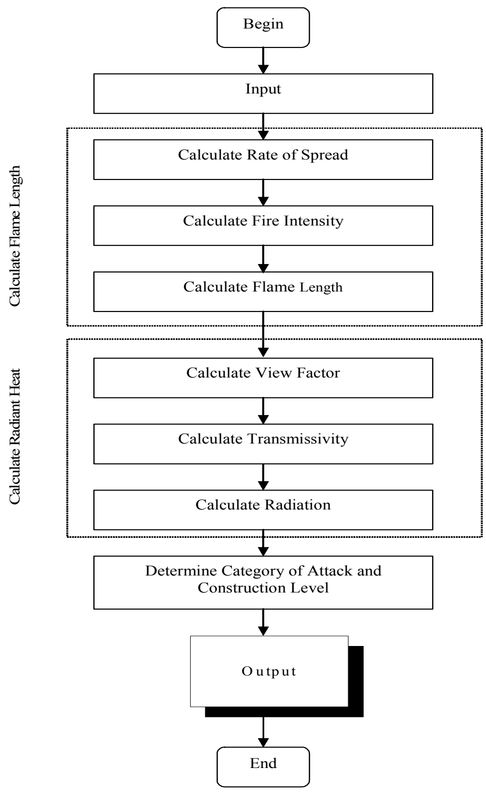

Figure 1. The Flowchart of the implementation

Compared with the existing approaches for bushfire assessment, the computerised model has following features:

1. It allows bushfire attack assessment to be conducted in a more efficient and accurate way.
2. It is more flexible and has a wider application range.
3. It reflects the latest research findings and is more scientifically advanced.

1. INTRODUCTION

Bushfires are on one hand an inevitable and essential component of the Australian landscape while on the other hand they are natural hazards which pose severe threat to property, life and the environment. To minimize bushfire risks, a variety of bushfire protection measures can be taken. Among these measures are land use planning, development controls and hazard reduction. The proper implementation of these measures requires that the level of bushfire attack be assessed with an appropriate approach. At the present time, there are two qualitative bushfire attack assessment approaches available, the table-based approaches specified in AS *3959* 1999 and NSW *Planning for Bushfire Protection 2001 (PFBFP)*. The major advantage of this table-based approach is its simplicity of use. However, there are some intrinsic shortcomings with them. Firstly, they are not applicable when assessing the bushfire attack level for a development with specific site conditions. Secondly, they do not reflect the latest advances in the field of bushfire attack modelling. Furthermore, they cannot be readily used to assess the suitability of alternative bushfire protection measures because of their qualitative nature of assessment. To overcome the above shortcomings, a new quantitative bushfire attack assessment methodology and an associated computerised model have been developed. Compared with the existing site assessment approaches, the computerised model is easy to use, more reliable, more flexible and more widely applicable. This paper explores the computerised bushfire attack assessment model and its applications for bushfire protection in detail.

2. ASSESSMENT MODEL

It is well known that the loss of homes from bushfires is mainly due to three attack modes: ember attack, radiant heat attack and flame contact. The bushfire attack assessment model which the computerised model implemented has taken these three attack modes into account to some different degrees. The mathematical model comprises two sub-models, a fire behaviour model and a radiation model. The bushfire behaviour model consists of a set of empirical bushfire behaviour equations derived from field fire experiments which include rate of spread equations, fire intensity equations and flame length equations. The objectives of the bushfire behaviour sub-model are two fold. One is to estimate flame length which will be used for flame contact check and another is to provide one of the major inputs required by the radiation sub model. The radiation sub-model is constituted of the equations for calculating radiation, view factor and transmissivity. To facilitate the understanding the computerisation process of the bushfire assessment model and equations of the sub-models are described in the following sections.

2.1 Bushfire Behaviour Sub Model

2.1.1 Rate of Spread Equation

Depending on vegetation classification, the rate of fire spread is modelled by one of the following empirical equations:

For Forest & Woodland (Noble et al., 1980)

$$R=0.0012 * FDI * w * \exp(0.069 * slope)$$

Where

R=rate of spread (km/h)
FDI=Fire Danger Index
w=surface fuel load (t/ha)
slope=slope of the land with vegetation (degrees)

For Shrub & Heath (Catchpole et al., 1998)

$$R=0.023 * V^{1.21} * VH^{0.54} * \exp(0.069 * slope)$$

Where

VH=average height of vegetation (m)
V =average wind speed at 10m above ground (km/hr), defaulted as 45 km/h

For Grassland (Noble et al., 1980)

$$R = 0.13 * FDI * \exp(0.069 * slope)$$

For Grassland (Noble et al., 1980)

$$R = 0.13 * FDI * \exp(0.069 * slope)$$

2.1.2 Fire Intensity Equation (Byram, 1959)

The fire intensity shall be determined by:

$$I = H * W * R/36$$

Where

I =fire intensity (kW/m)
H =heat of combustion, 18,600 kJ/kg
W = overall fuel loads (t/ha)

2.1.3 Flame Length Equation

Like rate of fire spread, there are a number of flame length equations currently available. Depending on the type of vegetation, a different flame length equation should be used. The following equations are recommended for the specified vegetation types.

For Forest & Woodland (RFS PBP, 2001)

$$L_f = (13R+0.24W)/2$$

Where

L_f = flame length (m)

R=rate of spread (km/h)
W= overall fuel loads (t/ha)

For Shrub & Heath (Alexander, 1982)

$L_f = 0.0775*I^{0.46}$

Where

I =fire intensity (kW/m)

For Grassland (Nelson, 1980 in Ellis, 2000)

$L_f = 1.192(I/1000)^{0.5}$

Table 1 Vegetation Classifications and Fuel Load

Vegetation	**Fuel Type**	**w (t/ha)**	**W (t/ha)**	**VH (m)**
Forests	Forests	25	35	-
Woodlands	Woodlands	15	25	-
Closed Shrub	Shrub & heath	25	25	3
Open Shrub	Shrub & heath	15	15	1.5
Mallee/ Mulga	Shrub & Heath	8	8	3
Rainforest	Forest	10	12	-

Source: Public Comment Draft AS 3959 (SA, 2005)

The fuel loads and heights of various types of vegetation required by the bushfire behaviour sub-model should be properly determined. When no data about these parameters are readily available, the data in Table 1 are recommended for use.

2.2 Radiation Model

The radiation modelling has been well researched in the field of fire safety engineering. The most widely used model for radiation calculation is the view factor model. When considering the effects of atmospheric attenuation, the view factor model can be mathematically expressed by:

$$R_d = \tau \phi \varepsilon \sigma T^4$$

Where

R_d = radiant heat flux (kW/m^2)
τ = atmospheric transmissivity
ε= flame emissivity, defaulted as 0.95
σ=5.67 x 10^{-11} kW/m^2 K^4
T=flame temperature (K), defaulted as 1200 K

The key for calculating radiation with the view factor model is to determine the value of the view factor. For the inclined flame shown in Figure 2, the view factor of a building element with an elevation of h at a distance of d can be determined by (Tan, 2004):

$$\phi = \frac{1}{\pi}\{ \frac{X_1}{\sqrt{1+X_1^2}} \tan^{-1}[\frac{Y_1}{\sqrt{1+X_1^2}}] + \frac{Y_1}{\sqrt{1+Y_1^2}} \tan^{-1}[\frac{X_1}{\sqrt{1+Y_1^2}}] + \frac{X_2}{\sqrt{1+X_2^2}} \tan^{-1}[\frac{Y_2}{\sqrt{1+X_2^2}}] + \frac{Y_2}{\sqrt{1+Y_2^2}} \tan^{-1}[\frac{X_2}{\sqrt{1+Y_2^2}}]\}$$

X_1=(Lf sinα-0.5Lfcosαtanθ -d tanθ – h)/(d – 0.5Lfcosα)
X_2= [h+(d-0.5Lf cosα)tanθ]/(d–0.5Lfcosα)
Y_1=(0.5Wf)/ (d –0.5Lf cosα)
Y_2 = (0.5Wf)/ (d –0.5Lf cosα)

Where

L_f = flame length (m),
W_f = flame width (m), defaulted as 100m
h=elevation of receiver (m), defaulted as the level opposite to flame centre
α= flame angle (degree)
θ=slope between vegetation and structure (degree)
d =separation distance (m)

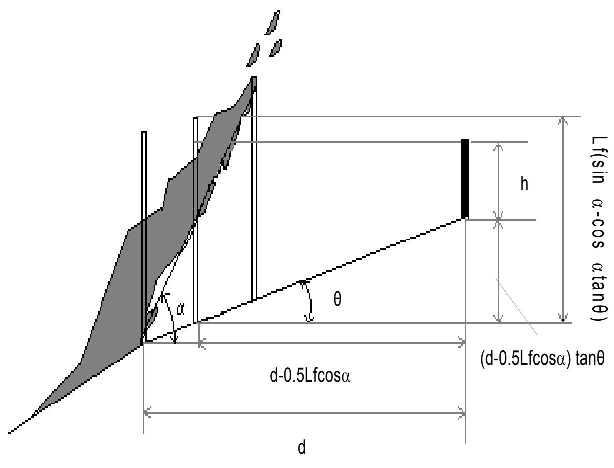

Figure 2. Diagram for Deriving View Factor

The atmospheric transmissivity τ is calculated by the following empirical formula (Fuss and Hamins, 2002):

$$\tau = a_0+a_1L+a_2L^2+a_3L^3+a_4L^4$$

Where

L=path length, determined by d -0.5$L_f$cosα

$a_n = C_{1n} + C_{2n}Ta + C_{3n}T + C_{4n}RH$

Ta=ambient temperature, defaulted as 308 K

T=flame temperature

RH= relative humidity, approximated as 0.25

C_{1n}, C_{2n}, C_{3n} and C_{4n} =Constants in Table 2

Table 2 Constants to calculate coefficient a_n

n	C_{1n}	C_{2n}	C_{3n}	C_{4n}
0	1.486	-2.003×10^{-3}	4.68×10^{-5}	-6.052×10^{-2}
1	1.225×10^{-2}	-5.900×10^{-5}	1.66×10^{-6}	-1.759×10^{-3}
2	-1.489×10^{-4}	6.893×10^{-7}	-1.922×10^{-8}	2.092×10^{-5}
3	8.381×10^{-7}	-3.283×10^{-9}	1.051×10^{-10}	-1.166×10^{-7}
4	-1.685×10^{-9}	7.637×10^{-12}	-2.085×10^{-13}	2.350×10^{-10}

3. IMPLEMENTATION

The process of carrying out a bushfire attack assessment using the proposed assessment model involves a large amount of computational effort. Although it is possible for a professional to conduct a manual assessment, the task would become very time consuming and potentially error-prone. For a lay-person, it would be extremely difficult. In order to improve the accuracy and efficiency of bushfire attack assessment as well as its availability, a computer program implementing the bushfire attack assessment model has been developed with the VBA built in MS Access. The flowchart of the implementation is shown in Figure 1.

The computerised bushfire attack assessment process consists of five major steps (see Figure 1) specifying inputs, calculating flame length, calculating radiation heat flux, determining bushfire attack level and displaying outputs. Details on each of the five steps are explained below.

3.1 Inputs

The inputs required by the computerised model have been partitioned into two groups, that is, direct inputs and indirect inputs. The direct inputs include:

- Vegetation class;
- Effective slope: slope of the land covered by vegetation;
- Separation distance between fire front and building;
- Flame angle: angle between flame and horizontal plane;
- Elevation of receiver: height of building element above the ground level;
- Site slope: slope between vegetation and building.

The first three direct inputs are mandatory while the remainder are optional. When the optional inputs are not given, the program will use default values or calculate the values by using the built-in algorithms. The program will automatically check for likely input errors such as wrong data type or required data not being input.

In addition to the above direct inputs, the following indirect inputs are also required:

- Flame temperature;
- Flame emissivity;
- Flame width;
- Surface fuel load;
- Overall fuel load;
- Vegetation height;
- Fire Danger Index;
- Wind speed;
- Ambient temperature;
- Relative humidity;
- Heat of combustion;
- Radiation upper and lower limits for each level of bushfire attack.

The values of the indirect inputs have been preset in the program. In most circumstances, the assessment conducted by using the pre-set values is considered to be appropriate and conservative. However, if there is adequate evidence that can justify different values for a specific site, these values should be used in order to obtain a more realistic assessment result. For instance, the default for FDI in the computerised model is 80. This value is appropriate for Western NSW. However, a FDI of 100 appears more appropriate for Greater Sydney, the Hunter region and Illawarra/South Coast. In addition, the default values for fuel loads are the maximum fuel loads for unmanaged vegetation. When vegetation is managed by prescribed hazard reduction burning or other means, then it would be more appropriate to specify lower fuel loads that more accurately reflect the reality. By properly changing the program settings, a more realistic and accurate assessment can be conducted.

3.2 Calculate Flame Length

The steps involved in calculating flame length include:

- Selecting appropriate rate of spread equation for a given vegetation type;
- Calculating fire intensity;
- Choosing the appropriate flame length equation for the specified vegetation type.

The equation for calculating rate of spread and flame length vary depending on the fuel type classification. Vegetation has been classified into three fuel types including Forests and Woodlands, Heath and Shrub and Grasslands for modelling rate of spread and flame length. With respect to fire intensity, its calculation is independent of fuel types. No matter what vegetation type is specified, the same fire intensity equation (i.e. Byram equation) will be used.

3.3 Calculate Radiation

The major steps involved in calculating radiation are:

- determining flame angle and view factor;
- calculating atmospheric transmissivity;
- Calculating the radiant heat flux.

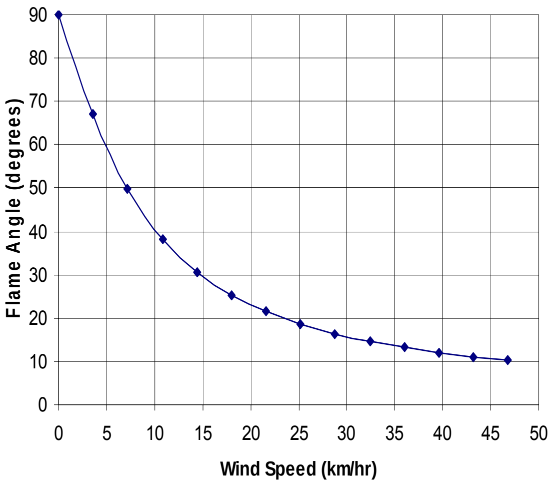

Figure 3. Flame Angle and Wind Speed

The determination of view factor requires the inputs of flame length, flame width, elevation of building element, flame angle and separation distance. All inputs except flame angle can be either directly or indirectly determined from the site specific conditions or by using the bushfire behaviour model for a given application. Theoretically flame angle is mainly a function of wind speed. Figure 3 shows how flame angle may vary with wind speed. As illustrated by the graph, flame angle varies from 90 degrees to 10 degrees when wind speed changes from 0 km/hr to 47 km/hr. Due to the highly variable nature of wind, the angle a flame may take during the period of bushfire attack is highly uncertain. To minimize the risk resulting from the variable flame angle, the flame angle which gives the maximum view is recommended for use.

The algorithm for determining the maximum view factor and the associated flame angle comprises the following steps:

(1) Assign initial values by letting the initial flame angle $\alpha_0 = \theta$, initial view factor $\phi_0 = \phi(\alpha_0)$, flame angle increment $\Delta\alpha$ =Constant such as 10^o and maximum flame angle error allowed E = Constant such as 1^o.
(2) Let $\alpha_1 = \alpha_0 + \Delta\alpha$ & $\phi_1=\phi(\alpha_1)$.
(3) Let $\alpha_2 = \alpha_1 + \Delta\alpha$ & calculate $\phi_2 = \phi(\alpha_2)$.
(4) Check if both $\phi_1 > \phi_o$ and $\phi_1 > \phi_2$. If yes, go to next step; otherwise let $\phi_0 = \phi_1$, $\alpha_0 = \alpha_1$, $\phi_1 = \phi_2$, $\alpha_1 = \alpha_2$ and repeat (3)-(4).
(5) Check whether $\Delta\alpha <= E$ or not. If yes, then stop the repetitive calculation process and the most recently updated view factor ϕ_1 and flame angle α_1 are the approximations of the maximum view factor and the corresponding flame angle to be found; otherwise use a smaller $\Delta\alpha$ to repeat (2) – (5) until the maximum view factor is found.

Once the maximum view factor and the associated flame angle are determined, the atmospheric transmissivity of radiation can be determined using the transmissivity equation described previously. The calculated transmissivity together with the maximum view factor will provide the required inputs by the radiation equation.

The radiant heat flux received by a building element at a given elevation level and given distance is then calculated by the radiation model described previously. The calculated radiant heat flux together with flame length modelling result will be used in next step to determine the level of bushfire attack.

3.4 Determine Level of Attack

Once flame length and radiant heat flux are determined, the level of bushfire attack can be determined according to the predefined exposure conditions for each level of bushfire attack. For NSW, the exposure conditions for various attack levels are predefined by Table 3.

Table 3 Bushfire Attack Levels and the Corresponding Performance Requirements of Building Materials Defined in PBP 2001 (NSW RFS, 2001)

Level of Attack	**Exposure Conditions**
Low	Radiation <= 14.5 kW/m^2 or > 100m from vegetation.
Medium	Radiation between 14.5 kW/m^2 and 16 kW/m^2.
High	Radiation between 16 kW/m^2 and 21 kW/m^2.
Extreme	Radiation between 21 kW/m^2 and 31 kW/m^2.
Flame Zone	Within the Flame Zone or Radiation >31 kW/m^2.

3.5. Outputs

Once the required inputs are specified, an assessment for the given inputs can be initiated by clicking command button **Calculate.** Following this, the assessment results will be displayed within the frame of **Assessment Results,** which include:

- Rate of fire spread;
- Fire intensity;
- Flame length;
- View factor;
- Radiation level;
- Category of attack;
- Level of construction.

In addition to the immediate screen outputs, a detailed assessment report can be previewed by clicking command button **Preview or** printed out by clicking command button **Report**.

4. APPLICATION EXAMPLES

The computerised model may find many applications in bushfire protection planning. This can be demonstrated by the following three examples.

Example 1 – Determining Construction Standard

The direct application of the computer program is the determination of the construction level required by AS 3959 for a site with specific conditions. This example demonstrates how to determine the construction level for a site with the following conditions:

- The type of vegetation surrounding the building site is classified as forests;
- Fire Danger Index (FDI) derived from the local weather conditions is 50;
- The slope of the site and the land covered by the vegetation is 1 degree;
- The separation distance between the building and the edge of the vegetation is 20m;
- The height of the proposed building is 4 m.

Based on the above assumptions, the direct inputs required by the program are determined as:

- Vegetation class = Forests;
- Effective slope= 1 degree;
- Separation distance =20 m;
- Flame angle = determined by the built-in algorithm;
- Elevation of receiver = 4m;
- Site slope =1 degree.

The major indirect inputs required for the assessment are set as:

- FDI=50;
- Flame width = 100m;
- Flame temperature = 1200 K;
- Flame emissivity = 0.95;
- Surface available fuel load =25 t/ha;
- Overall fuel load = 25 t/ha;
- Ambient temperature = 35 ^{o}C;
- Relative humidity =25%.

The outputs resulting from the above inputs are:

- Rate of Fire Spread = 1.61 km/h;
- Fire Intensity = 20759 kW/m;
- Transmissivity = .846;
- Flame Length= 13.45 m;
- Radiant Heat= 30.59 kW/m^2;
- Category of Attack= Extreme;
- Level of Construction = Level 3.

Example 2 – Determining Minimum Separation Distance

One of the most important measures for building protection in bushfire-prone areas is the provision of a separation between a building and bushfire hazard. The larger the separation distance is, the safer the building is. However, it may not be cost-effective if the separation distance is too large due to the exclusion of the development on the land covered by the distance. To strike a balance between cost and benefit, the separation distance required by a building complying with a given construction level should commensurate with the level of bushfire attack. At present, the separation distances prescribed in most of the Australian States are not based on a sound physical model and therefore the level of protection provided by this measure is highly questionable.

The computerised model has the capability of predicting radiation exposure level and flame contact possibility. Therefore, a minimum separation distance for a building with specific site conditions can be determined if the level of construction standard to which it is to comply and the associated performance thresholds are known.

Table 4 Levels of Construction and the corresponding Categories of Bushfire Attack

Construction Levels	Category of Attack	Performance Thresholds
1	Medium	Less than 100m from hazard and less than 12.5 kW/m^2
2	High	12.5 kW/m^2 to less than 19 kW/m^2
3	Very High	19 kW/m^2 to less than 29 kW/m^2
4	Extreme	29 kW/m^2 to less than 40 kW/m^2

Source: Public Comment Draft AS 3959 (SA, 2005)

Table 4 shows the new categories of bushfire attack proposed by the revised AS 3959 – Public Comment Daft (SA, 2005). Based on the performance thresholds of the categories of bushfire attack specified in Table 4, the minimum separation distances required by a level ground site with FDI = 100 are modelled for the vegetation classes specified in Table 1 and the results are shown in Table 5.

Table 5 Minimum separation distances for different source bushfire (FDI=100, level ground)

Vegetation class	Categories of Bushfire Attack			
	Level 4	Level 3	Level 2	Level 1
	Minimum Separation Distances			
Forests	27	35	47	62
Woodlands	17	23	33	44
Closed Shrub	14	19	27	37
Open Scrub	11	13	19	27
Mallee/Mulga	10	12	17	28
Rainforest	12	15	22	31

Example 3 – Determining Radiation vs Time Profile

The radiation level to which a building is exposed at a given distance can be directly predicted with the program. Therefore, a relation between radiation and distance can be established for the building. Because the rate of the fire spread is also modelled in the program, the relationship between radiation and distance can be transformed into the one between radiation and time.

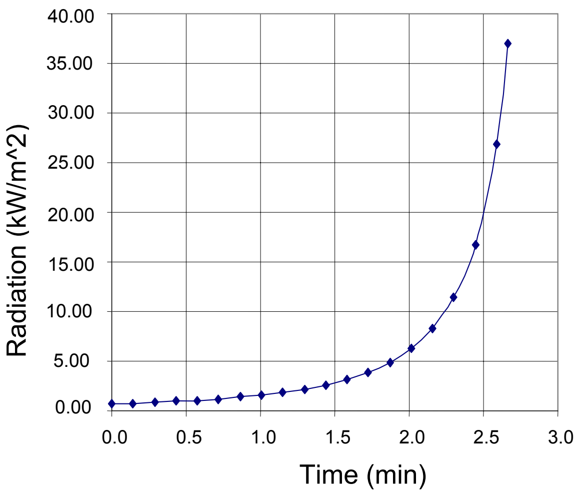

Figure 4. Radiation vs Time Profile

The establishment of the relationship between radiation and time is very important when assessing the performance of building material under radiation attack. This example shows the utility of the program in establishing the radiation vs. time profile. In this example, it is assumed that a closed shrub fire starts 200m away from a building. Under this assumption and using defaults for other inputs, the radiation vs. time profile obtained from the program is shown in Figure 4.

5. CONCLUSIONS

To conclude, a computerised bushfire attack assessment model has been developed and its application in bushfire planning was demonstrated. Compared with the existing models, it has a number of positive features including:

- The model allows bushfire attack assessment to be conducted in a more efficient and accurate way.
- The model is able to take site specific conditions into account and therefore is more flexible and has wider application range.
- The model enables a performance-based bushfire attack assessment to be carried out when alternative solutions are suggested.
- The model reflects the latest research findings and therefore is more scientifically advanced.

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